FATE AND EFFECTS OF PRODUCED WATER DISCHARGES IN NEARSHORE MARINE WATERS

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Fate and Effects of Produced Water Discharges In Nearshore Marine Waters

Final Report

Prepared for the American Petroleum Institute
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FOREWORD

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Special acknowledgment is extended to the petroleum industry for cooperation in providing access to the offshore platform sites which were the subjects of the present study.

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EXECUTIVE SUMMARY

New Source Performance Standards recently proposed by the U.S. Environmental Protection Agency would prohibit the discharge of produced water to the ocean from new production facilities located in 20 meters or less of water in the Gulf of Mexico. There is a limited amount of information available about the chemical and biological impacts of chronic discharges of treated produced water to shallow marine waters. Therefore, the present investigation was designed to determine (1) if sediments located near platforms that have been discharging produced water to shallow coastal waters for many years contained elevated concentrations of organic and metal contaminants and (2) if the communities of bottom-dwelling animals resident in the sediments were adversely impacted by the discharges.

There were three major objectives of the research program:

1. To compare the distribution and biological effects of chemicals from produced water and drilling fluids in sediments around an oil-water separation platform in shallow water (2-5 meters) and in deeper coastal waters (5-15 meters);
2. To determine the magnitude and areal extent of long-term (more than 5 years) accumulation in sediments of chemicals from produced water and the resulting effects on benthic communities around oil-water separation platforms in estuarine and coastal waters of Louisiana;
3. To determine the chemical composition and variability over time of produced water from oil-water separation platforms in the northern Gulf of Mexico.

The program was divided into phases:

Phase 1. Preliminary survey to evaluate candidate sites;

Phase 2. Detailed survey at two produced water discharge sites.

Four oil-water separation platforms were selected for the preliminary survey. They were all located in the Gulf of Mexico off the central coast of Louisiana (Figure i). They included an estuarine site in Terrebonne Bay at Lake Pelto Tank Battery No. 1, and three offshore sites in 8 to 15 meters of water, Eugene Island, Block 105, Eugene Island, Block 120, and Ship Shoal, Block 114. All the platforms were producing oil, rather than gas and condensate. Rates of produced water discharge from each platform were near the mean rate of discharge (1801 barrels/day) for the entire industry operation on the outer continental shelf of the Gulf of Mexico (Walk, Haydel & Associates, 1984).

Sediments were sampled at a radial array of stations located 20 to 2000 meters in all directions from each platform. These samples were analyzed for two- to five-ring aromatic hydrocarbons, four metals (barium, chromium, copper, and zinc), total organic carbon, and sediment grain size. In addition, at a subset of stations around each platform, REMOTS (Remote Ecological Monitoring of the Seafloor) sediment profile imaging was used to further characterize the physical, chemical, and biological features of the area. Produced water from each platform was collected and analyzed for the same analytes listed above, except sediment grain size, and for volatile organic compounds and radium-226 and radium-228.

The results of the preliminary survey allowed the elimination of two of the four candidate sites from further consideration. Bottom water and sediments in the vicinity of Ship Shoal, Block 114 contained little or no dissolved oxygen. As a result, the benthic fauna were extremely depauperate throughout the area. The bottom water hypoxia was general throughout the area and was not centered on the platform. Due to bad weather, an insufficient number of stations were sampled at Eugene Island, Block 120 to adequately characterized the local bottom environment. The data for Eugene Island, Block 105 and Lake Pelto Tank Battery, No. 1 indicated that these sites were suitable for the detailed field survey.

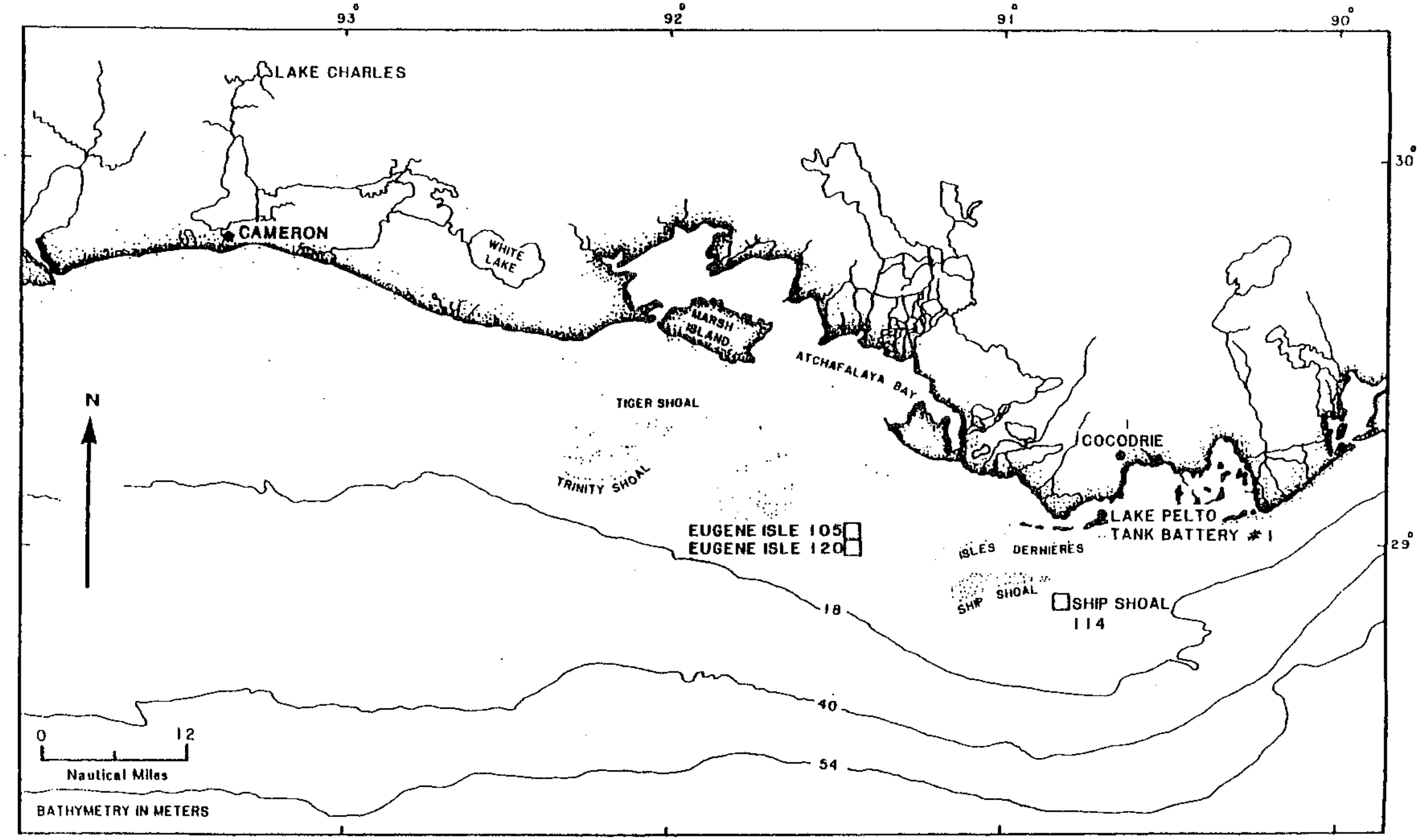

FIGURE i. MAP OF COASTAL LOUISIANA SHOWING LOCATIONS OF THE FOUR PLATFORMS EVALUATED IN THE PRELIMINARY FIELD SURVEY, INCLUDING THE TWO PLATFORMS, EUGENE ISLAND, BLOCK 105, AND LAKE PELTO, TANK BATTERY NO. 1, THAT WERE EVALUATED IN THE DETAILED FIELD SURVEY.

The average rate of discharge of produced water from the separation platform in Eugene Island, Block 105A was 1,570 barrels/day (65,940 gallons/day). The discharge was initiated in May 1981. The average rate of discharge of produced water from Lake Pelto, Tank Battery No. 1 was 2,750 barrels/day (115,500 gallons/day). The discharge was started in the mid-1940s. Water depth at Eugene Island, Block 105A is 7.6 to 8.5 m, whereas that at Lake Pelto, Tank Battery No. 1 is only 1.8 to 3.0 m.

In designing the detailed field survey, we hypothesized that any significant impacts to the marine environment resulting from more or less continuous discharges of produced water for several years would be manifest as gradients of decreasing sediment contamination and alterations of normal benthic community structure with distance from the platforms. The approach taken to determine if such gradients exist was to perform an intensive sediment sampling effort at a grid of 16 stations around each platform and to analyze these samples for a wide variety of chemical, physical, and biological parameters. The research team returned several months later and sampled a representative subset of the original 16 stations at each platform and analyzed samples from these stations for a subset of the parameters measured in samples from the first detailed survey. The purpose of the second survey was to confirm the observations made in the first, more detailed survey and to determine if there was a seasonal component to the patterns of sediment contamination and benthic community structure.

Thus, the detailed field survey consisted of two field sampling cruises, the first from 24 to 29 March 1986 (the spring survey) and the second from 6 to 8 October 1986 (the fall survey). The stations were located in a radial array around each platform at distances of 20, 100, 300, and 1000 meters from the produced water discharge from each platform.

On both surveys, three sediment grab samples for chemical analysis and six sediment grab samples for biological analysis were collected from each station on both surveys. The chemistry samples were analyzed for sediment grain size, total organic carbon, total saturates and aromatics, individual n-alkanes, individual two- through four-ring aromatic hydrocarbons and their alkyl homologues, steranes, triterpanes, phenol and alkyl phenols, and nine metals (barium, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc). The biology samples were analyzed for sediment grain size, and benthic macrofauna, including juveniles, retained on a 0.3-mm screen.

Produced water samples were collected from each platform. They were analyzed for the same analytes as the sediment chemistry samples (other than grain size) and, in addition, for total hydrocarbons by infrared spectrophotometry, and volatile organic compounds.

The organic composition of produced water from Eugene Island, Block 105 and Lake Pelto, Tank Battery No. 1 was similar to that of produced water from other sources (Table i). The concentration of total organic carbon in the samples was in excess of 200 mg/l (parts per million: ppm). Only about 10 percent of this organic carbon was accounted for by hydrocarbons. The remainder consisted of the uncharacterized nonvolatile soluble organic matter noted by others. The only quantifiable nonhydrocarbon organic materials in the produced water samples were phenols and ketones, and these compounds contributed little to the total organic carbon in the samples. It was not possible to quantify naphthenic acids in the produced water samples because of analytical difficulties with this complex class of compounds.

There were short-term (one day) and long-term (six months) variations in the organic composition of produced water from the two platforms. The differences seemed to be greater over the long term than over the short term, and may have been due to

TABLE i. SUMMARY OF CONCENTRATIONS OF SEVERAL CLASSES OF ORGANIC COMPOUNDS IN PRODUCED WATER COLLECTED AT EUGENE ISLAND AND LAKE PELTO DURING THE SPRING SURVEY (VALUES ARE IN μg/l).

Compound Class	Eugene Island	Lake Pelto
Total Organic Carbon	222,000	298,000
Total Hydrocarbons (IR)	36,300	25,500
Total Saturates (GC)	28,400	17,100
Total Aromatics (GC)	2,500	3,300
Total Hydrocarbons (GC)	30,900	20,400
Total Targeted n-Alkanes (C_{10}-C_{34})	2,677	606
Total Targeted PAH (Naph-Peryl)	80-	142
Targeted Volatile Hydrocarbons (Methane-C_3 - Benzenes)	11,308	5,515
Steranes	63	92
Triterpanes	76	80
Priority Pollutants (Ketones)	2,230	1,320
Phenols (C_0-C_4)	2,720	675
TOTAL TARGETED ORGANICS	**19,154**	**8,430**

variability in the efficiency of the oily water separation and treatment system.

The only metals that were present in produced water from the two platforms at concentrations substantially (more than a thousand-fold) higher than those in normal seawater were barium, lead, and zinc. Barium occurred at nearly 100 ppm in two of the samples from the preliminary survey. High concentrations of barium have been reported in solution in produced water from other sources, and apparently are possible if the produced water contains very low concentrations of sulfate and carbonate. Concentrations of lead and zinc in the produced water samples were quite variable and may have been derived from corrosion of galvanized structures on the platform or in the oil-water separator system.

This investigation has provided the most complete analysis of the composition of produced water performed to date. Included here are the first analyses of alkyl phenols, steranes and triterpanes, and the most complete analysis of polycyclic aromatic hydrocarbons (PAHs) performed to date.

During both the spring and fall surveys, hydrographic conditions at both platforms were in the normal range. Most important, concentrations of dissolved oxygen in the bottom water were near saturation at all stations.

Patterns of sediment grain-size distribution were quite different at stations around the two platforms. At Eugene Island, Block 105, sediment texture was finest near the platform and became coarser with distance from the platform. At Lake Pelto, Tank Battery No. 1, the coarsest sediments were located 20 m from the platform, and mean sediment grain size decreased with distance from the platform. Sediment grain size is an important parameter because fine-grained sediments have a greater capacity for binding organic and metal pollutants than do coarse sediments, and sediment grain size is an important determining factor in structure of benthic communities.

Patterns of hydrocarbon distributions in sediments around the platforms tended to parallel those of sediment total organic carbon concentration. At Lake Pelto, Tank Battery No 1, concentrations of total hydrocarbons and total polycyclic aromatic hydrocarbons (PAHs) in sediments were highest at one or more stations 20 m from the platform and decreased with distance from the platform. Total PAHs dropped to essentially background values at all stations 300 and 1000 m from the platform. At Eugene Island, Block 105, there was a gradient of decreasing concentrations of total hydrocarbons in sediments with distance from the platform along most transects. However, concentrations of both total targeted n-alkanes and PAHs were not elevated above apparent background values at any but a few stations in the 20-m ring surrounding the discharge. Sediments at stations 100 to 1000 m from the platform had relatively uniform concentrations of total n-alkanes and PAHs in the range of 0.3 to 1.6 ppm and 0.02 to 0.16 ppm, respectively. Background concentrations of total hydrocarbons and PAH in sediments from the northern Gulf of Mexico are in the range of 3 to 70 ppm and 0.4 to 1.1 ppm, respectively. As a general rule, concentrations of total hydrocarbons, n-alkanes, and PAHs were higher in sediments at Lake Pelto than at Eugene Island.

Several hydrocarbon parameters and diagnostic ratios were used to determine the generic source of hydrocarbons in sediments around the two platforms. The sediments throughout the study area contain a mixture of petrogenic, pyrogenic, and biogenic/diagenic hydrocarbons. Much of this background probably is derived from the Mississippi River outflow, as well as from the extensive petroleum production activities throughout the area. Superimposed on this background are low to moderate concentrations of hydrocarbons in sediments near the platforms; these hydrocarbons appear to have been derived from platform discharges, probably produced water.

At Eugene Island, Block 105, sediments from stations 20 m from the platform contained low concentrations of petroleum hydrocarbons. Sediments from stations 100 m or more from the platform did not contain higher than trace concentrations of petroleum hydrocarbons. Thus, it can be concluded that chronic discharges of produced water at a rate of about 66,000 gallons per day to inner continental shelf waters with a depth of about 8.5 m has resulted in a low level of contamination of surficial sediments with petroleum hydrocarbons out at least to 20 m but not to 100 m from the platform. Contamination of sediments with petroleum hydrocarbons, even at the 20-m stations was not sufficient to cause hypoxia of the bottom water or surficial sediments.

At Lake Pelto, Tank Battery No. 1, sediments out at least to 100 m but not as far as 300 m from the platform contained petroleum hydrocarbons, probably derived from produced water discharges. Thus it can be concluded that discharges of produced water at a rate of about 115,000 gallons per day to a shallow, partially enclosed bay with a water depth of about 2 m has resulted in a low to moderate level of contamination of surficial sediments with petroleum hydrocarbons out at least to 100 m but not as far as 300 m from the platform.

Small amounts of steranes, triterpanes, and phenols were detected in sediments near both platforms. However, because natural marine sediments contain similar compounds, it was not possible in the present investigation to determine the extent of sediment contamination with these compounds from produced water.

Barium was the only one of the nine metals analyzed that was present in sediments at concentrations substantially higher than expected for clean sediments from the northern Gulf of Mexico. Concentrations of barium in sediments from most stations were in the range of 500 to 2000 ppm. There were no gradients of barium in sediments that might indicate that the barium was derived from platform discharges. The excess barium may be from area-wide discharges of barium-laden drilling muds and produced water from many platforms throughout the area and from the Mississippi River outflow.

The benthic fauna at both Eugene Island and Lake Pelto are pioneer communities characteristic of disturbed marine and estuarine environments. The nature of the disturbance is unclear but appears to be area-wide. At Eugene Island, Block 105, the disturbance may be periodic hypoxia of the bottom water. Episodes of bottom water hypoxia are known to occur during the summer in waters of the inner continental shelf off central Louisiana. However, no such episodes were documented at Eugene Island, Block 105 during this study. The Mississippi River outflow with its tremendous load of suspended matter and nutrients probably contributes to environmental stress throughout the area.

At both locations, the benthic fauna were dominated by one or a few species at all stations, even those most distant (1000m) from the platforms and presumably unaffected by the produced water discharges. The dominant taxa were short-lived opportunistic species. Juvenile forms were very abundant, representing more than 50 percent of the total number of individuals of several species at most stations. Despite these faunal characteristics, species diversity was moderate to high at all stations. Benthic communities with similar characteristics have been described by other investigators at several locations in shallow estuarine and coastal waters of the northern Gulf of Mexico. It is probable that benthic community structure throughout the area of this investigation is controlled in large part by factors such as high suspended sediment loads attributable to the Mississippi River outflow and periodic bottom water hypoxia, neither of which are related to discharges from coastal exploration/production operations.

At Eugene Island, Block 105, faunal density was greatest near the platform and decreased with distance from the platform. However, diversity increased with distance from the platform. Patterns of abundance and diversity were the same in the fall as they were in the spring. Similarity analysis revealed that the benthic fauna at stations 20 m from the platform were all similar but differed from the fauna at stations further away.

Benthic communities at Lake Pelto, Tank Battery No. 1, were more diverse than those at Eugene Island, Block 105. Highest diversities were recorded at stations nearest the platform that had the coarsest sediments. Similarity analysis revealed that communities at two stations 20 m from the platform were very similar, but quite different from communities at all other stations. The fauna from stations 1000 m from the platform also were distinct from the fauna from any other stations.

Sediment grain size was the most important parameter contributing to gradients of benthic community structure around the platforms, particularly at Eugene Island, Block 105. Nevertheless, there is an indication that benthic communities within about 20 m of both platforms were influenced by sediment contamination, probably derived from produced water discharges. Benthic communities located 100 to 1000 m from the platforms exhibited no evidence of impacts attributable to platform discharges. Thus, relatively minor effects on benthic communities resulting from chronic produced water discharges to shallow estuarine and coastal waters of the northern Gulf of Mexico were restricted to small areas around the platforms.

1.0 INTRODUCTION

The first offshore oil field in the Gulf of Mexico was developed in the late 1930s and the first production well out of sight of land was completed 12 miles off the Louisiana coast in 1947. By the end of 1982, approximately 27,000 wells had been drilled in U.S. coastal waters (National Academy of Sciences, 1983). In 1981, there was a total of 3843 offshore platforms in operation in U.S. waters, 3470 of them offshore Louisiana (Offshore, 1983). Because of the sharp downturn in the price of oil and gas, there has been a leveling off of offshore exploration and development in U.S. coastal and offshore waters during the last several years. The number of wells drilled on the U.S. outer continental shelf has remained relatively constant with 1151 wells in 1984, 1166 wells in 1985, and 1200 wells drilled in 1986 (Minerals Management Service, 1988). In 1986, the U.S. outer continental shelf accounted for approximately 12 percent of the total domestic oil production and 23 percent of domestic gas production (Minerals Management Service, 1988). The U.S. Geological Survey has estimated that as much as 33.8 percent of the nation's undiscovered recoverable oil and 28.1 percent of natural gas may lie beneath U.S. coastal and outer continental shelf waters (Kash, 1983). Reliance on these offshore resources will increase as onshore fossil fuel reservoirs are depleted.

This magnitude of exploration for and development of petroleum resources in U.S. coastal and outer continental shelf waters has led to a growing concern that such activities may cause serious long-term damage to the marine environment and the living resources it supports. The focus of this concern in recent years has been on the discharge of used drilling fluids and cuttings to the ocean (Neff, 1982; Petrazzuolo, 1983; National Academy of Sciences, 1983; Neff et al., 1987). More recently, concern has grown about the possible environmental impacts of produced water discharges to the ocean (Middleditch, 1984; Neff et al., 1987).

The U.S. Environmental Protection Agency (EPA), under authority of the Clean Water Act (the Federal Water Pollution Control Act Amendments of 1972, 33 U.S.C. 1251 et seq., as amended by the Clean Water Act of 1977, Pub. L. 95-217), regulates the discharge of drilling fluids, produced water, and other materials from offshore exploration and production platforms through issuance of National Pollutant Discharge Elimination System (NPDES) permits. NPDES permits may contain limits for the concentrations of specific substances in the permitted discharges, prohibition of the discharge of certain substances, requirements for rates of discharge, and specific toxicity limits for the discharge. Various discharge limitations usually are based on environmental and performance standards set periodically by EPA. Recently, EPA proposed a new set of effluent guidelines and standards for the offshore segment of the oil and gas extraction point source category (EPA, 1985). New Source Performance Standards (NSPS) were proposed for produced water, drilling fluids, and other major permitted discharges from offshore platforms.

Proposed NSPS and guidelines for produced water include a zero discharge requirement for all new oil production facilities located in or discharging to 20 meters of water or less in the Gulf of Mexico, the Atlantic, and Norton Basin of Alaska; 50 meters of water or less off the California coast, Cook Inlet/Shelikof Strait, Bristol Bay, and the Gulf of Alaska; and 10 meters or less in the Alaskan Beaufort Sea. As proposed, produced water discharges from existing sources will be allowed from all oil production facilities discharging outside these depth limits as well as all gas production facilities, no matter what the location of the discharge. However, the concentration of oil and grease in the produced water discharge must not at any time exceed 59 mg/l.

Proposed NSPS for drilling fluids include a prohibition on the discharge of free oil, oil-based drilling fluids, and diesel oil; a 96-hr LC50 toxicity limit of not less than 3.0 percent by volume of the diluted suspended particulate phase of the discharged drilling fluid; and an upper limit of 1 mg/kg dry weight of mercury and cadmium in the drilling fluid.

1.1 STUDY OBJECTIVES

The research program described here was designed to determine the nature and magnitude of impacts of long-term discharges of produced water to shallow water environments that are the focus of the proposed NSPS. There were three major objectives for this research program:

1. To compare the distribution and biological effects of chemicals from produced water and drilling fluids in sediments around an oil-water separation platform in shallow water (2-5 meters) and in deeper coastal water (5-15 meters);
2. To determine the magnitude and areal extent of long-term (more than 5 years) accumulation in sediments of chemicals from produced water and the resulting effects on benthic communities around oil-water separation platforms in estuarine and coastal waters of Louisiana;
3. To determine the chemical composition and variability over time of produced water from two oil-water separation platforms in the northern Gulf of Mexico.

1.2 TECHNICAL BACKGROUND

During drilling of and production from offshore oil and gas wells, a wide variety of liquid, solid, and gaseous wastes are produced on the platform. Liquid and solid wastes that are currently permitted for discharge to the ocean include cooling water from machinery, deck drainage, domestic sewage following primary treatment, drill cuttings, water-based drilling fluids, and produced water following removal of dispersed oil.

Because the volumes of drilling fluids, drill cuttings, and produced water requiring disposal are large, they are the drilling and production wastes that elicit environmental concern and regulatory attention. Drilling fluids are specially formulated mixtures of natural clays and/or polymers, weighting agents (usually barite), and other materials suspended in water or a petroleum material. With certain restrictions, water-based, but not oil-based, drilling fluids are currently allowed by NPDES permit to be discharged to the ocean. The five major ingredients in water-based drilling fluids (barite, clay, lignosulfonate, lignite, and sodium hydroxide) account for over 90 percent of the total mass of additives used in drilling fluids (National Academy of Sciences, 1983). There is a large variety of other specialty additives that may be added in small amounts to drilling fluids to solve particular down-hole problems.

A water-based drilling fluid is a slurry of solid particles of different sizes and densities in water. Drilling fluid additives may be either water-soluble, colloidal, or particulate. When discharged to the ocean, a drilling fluid separates rapidly into two distinct phases, (1) an upper plume of fine-grained and soluble materials that remains suspended in the water column and is carried away from the site in the prevailing water currents, and (2) a denser particulate phase that sinks rapidly to the bottom. The rapidly-settling phase usually contains more than 90 percent by weight of the drilling fluid solids.

The distance from the platform to which drilling fluid solids are dispersed and their concentration in bottom sediments depend on the types and quantities of drilling fluids discharged, local hydrologic conditions at the time of discharge, and height above the bottom at which discharges are made (Gettleson and Laird, 1980). Because barite (barium sulfate) is a major ingredient of many drilling fluids used to drill in U.S. waters and is both very dense and nearly insoluble in seawater, barium is used frequently as a marker for the settleable fraction of drilling fluid. In several investigations performed to date, barium concentrations in bottom sediments were highest near the rig and decreased markedly with distance from the rig (National Academy of Sciences, 1983; Neff et al., 1987). Barium may reach concentrations 10 to 20 times above background in sediments near the drilling fluid discharge from an exploratory well. Barium concentrations may be much greater than this in sediments near a development platform where many wells have been drilled and drilling fluids have been discharged for long periods of time. However, the accumulation of drilling fluid solids in sediments around a development platform is not directly proportional to the amount of drilling fluid discharged, because drilling fluid solids are continuously being washed out of the sediments or diluted with newly settling natural sediments (Boothe and Presley, 1985).

Several metals are found in drilling fluids. The metals of major environmental concern, because of their potential toxicity and/or abundance in drilling fluids, include arsenic, barium, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc. The metals most frequently present in drilling fluids at concentrations significantly higher than in natural sediments include barium, chromium, lead and zinc. Some of these metals are added intentionally to drilling fluids as metal salts or organometallic compounds. Others are trace contaminants of major drilling mud ingredients.

Most natural reservoirs of gas or petroleum also contain some fossil or connate water. During production of oil and/or gas, some of this connate water is produced with the oil and gas. This water is called formation water, produced water, or oilfield brine effluent. Over the life of a well, the amount of water produced with the oil or gas often increases as the amount of oil or gas produced decreases (Read, 1978). In older fields, such as many in coastal waters of Louisiana and Texas, production may be 95 percent water and 5 percent oil and gas.

Produced water may either be reinjected into the formation or treated to remove dispersed oil and discharged to the ocean. Produced water currently is being discharged to the ocean in the Gulf of Mexico, off southern California, and in Cook Inlet, Alaska. In the early 1980s, an estimated 247 million liters (1.55 million barrels) of produced water were discharged each day to coastal and offshore waters of the northwestern Gulf of Mexico (Walk, Haydel & Associates, 1984). Walk, Haydel & Associates (1984) estimated that the average produced water discharge from a single production platform is 339,000 liters/day (75,600 gallons/day), whereas discharges from large facilities serving several platforms may be as high as 25 million liters/day (Menzie, 1982).

Produced waters are salt solutions with an ionic composition somewhat similar to but usually more concentrated than that of seawater (Neff et al., 1987). The concentration of total dissolved solids (salinity) in produced water from different locations in the United States and Canada ranges from less than 3 to about 300 grams/liter (parts per thousand: ppt) (Rittenhouse et al., 1969). Most produced waters are more concentrated than seawater (35 ppt) and are thought to be of marine origin (Collins, 1975). In addition, produced waters may contain elevated concentrations of several metals and elemental sulfur. Based on available analyses, metals that may be present in produced water at substantially higher concentrations than in seawater include barium, beryllium, cadmium, copper, iron, lead, nickel, silver, and zinc (Neff et al., 1987).

Produced water may contain small amounts of radionuclides, primarily in the form of radium (^{226}Ra and ^{228}Ra). Reid (1983) reported a direct correlation between salinity of the produced water (10-274 ppt) and total radium concentration (30-2800 picocuries/liter:pCi/l) in 32 samples of produced water from gas, oil, and geothermal wells in coastal Louisiana and Texas. The background concentration of total radium isotopes in coastal and marine waters is generally less than 1 pCi/liter.

Produced water may also contain high concentrations of organic compounds. Petroleum hydrocarbons are the best characterized of these compounds (Sauer, 1981; Middleditch, 1984; Neff et al., 1987); other organic components are classified as nonvolatile soluble organic material and have not been characterized further (Lysyj, 1982). This soluble organic material may be present at concentrations up to several hundred parts per million. Its major components are low molecular weight aliphatic acid anions, such as acetate, proprionate, and butyrate (Means and Hubbard, 1987; Somerville et al., 1987). Included with these naturally-occurring organic components are various treatment chemicals added to the produced water during its production, separation, and treatment (Middleditch, 1984).

Current EPA Best Practicable Treatment Guidelines restrict the concentrations of oil and grease in produced water destined for ocean disposal to a monthly average of 48 ppm and a daily maximum of 72 ppm. Proposed NSPS set an upper limit not to be exceeded at any time of 59 ppm oil and grease (EPA, 1985). The oil/water mixture produced from the well is treated to separate the water from the hydrocarbons. The oil and water phases are allowed to separate in gravity separators. The water is then treated further to remove additional dispersed oil so that it meets the EPA effluent guidelines before being discharged to the ocean. The produced water treatment system is designed primarily to remove particulate or dispersed oil, and therefore has little effect on the concentrations of dissolved petroleum hydrocarbons, other organics, and dissolved metals in the produced water (Jackson et al.; 1981, Lysyj, 1982).

Dilution of produced water upon discharge to the ocean is very rapid, the actual rate being dependent on such factors as the total dissolved solids concentration of the produced water, current speed, vertical convective mixing of the water column, and water depth. In the Buccaneer gas and oil field, concentrations of total hydrocarbons in the water column rarely exceeded 30 μg/liter in the vicinity of the produced water discharge (Middleditch, 1981), whereas produced water from the production platform contained about 20 mg/liter total resolved petroleum hydrocarbons. In Trinity Bay, Texas, a shallow estuary, total resolved hydrocarbon concentrations in produced water were diluted by 2400-fold within 15 meters down-current of the discharge pipe located 1 meter above the bottom in 2 to 3 meters of water (Armstrong et al., 1979).

Where suspended sediment concentrations are high, as in parts of the northern Gulf of Mexico, dissolved and colloidal hydrocarbons and metals from produced water tend to become adsorbed to suspended particles and sink to the bottom (Boehm, 1987). In Trinity Bay, Texas, sediments 15 meters down-current from a produced water discharge 1 m above the bottom in 2 to 3 m of water contained high concentrations of C_{10}-C_{28} alkanes (61.9 μg/g) and aromatic hydrocarbons (34.2 μg/g) from C_3-benzene to C_3-phenanthrenes (Armstrong et al., 1979). A gradient of decreasing total naphthalenes concentrations in sediments extended away from the discharge in all directions for up to 500 meters from the discharge. In deeper waters, there is little transport of hydrocarbons to the bottom. As a result, elevated levels of hydrocarbons are restricted to a much smaller area of the bottom, if they are present at all. In the Buccaneer Field located in about 20 meters of water off Galveston, Texas, elevated concentrations of n-alkanes (16.8 μg/g) were detected in surficial sediments within a radius of about 15 to 20 meters of the produced water discharge (Middleditch, 1981). However, sediment resuspension and transport resulted in rapid changes in sediment hydrocarbon concentrations on almost a daily basis.

Elevated levels of barium, cadmium, chromium, copper, lead, strontium, and zinc have been detected in surficial sediments in the vicinity of production platforms in the northwest Gulf of Mexico (Tillery and Thomas, 1980; Wheeler et al., 1980; Boothe and Presley, 1985). These metals may have been derived from discharge of drilling fluids and produced water and from corrosion or leaching of submerged platform structures, antifouling paints, and sacrificial electrodes. The magnitude of the elevation in the concentrations of metals other than barium was usually small.

The only field investigation in which a biological impact of produced water discharges was convincingly documented and correlated to accumulation of produced water hydrocarbons in sediments was the investigation of Armstrong et al. (1979) in Trinity Bay, Texas. Produced water discharges to shallow (3 meters) Trinity Bay produced a zone of severely depressed and depauperate benthic fauna out to about 250-350 meters from the produced water outfall. Further from the outfall, there was an apparent zone of stimulation, much larger in area than the depressed zone, where benthic faunal abundance and diversity were greater than at clean reference stations. Concentrations greater than about 2 ppm naphthalenes in sediments were correlated with adverse impacts on the benthos.

1.3 PROGRAM DESIGN

1.3.1 General Design

The present investigation was divided into two phases:

Phase 1. Preliminary survey to evaluate candidate sites;

Phase 2. Detailed survey at two produced water discharge sites.

The objective of the preliminary survey was to choose two platforms or produced water discharge sites suitable for a more detailed field assessment. The design of this survey was based on a limited characterization of four platform sites from which produced water was being discharged. Because one objective of the overall program was to compare the fate and effects of discharges to shallow water (less than 10 m) with those of discharges to coastal waters (10 to 20 m), candidate sites were chosen by the API Drilling Fluid and Produced Water Taskforce in both of these depth ranges.

Several features were sought at each candidate site. These features were:

1. Production from the platform primarily petroleum, not gas or condensate;
2. The rate of produced water discharge of at least 1800 barrels per day (75,600 gallons per day) which is the average rate of produced water discharge from platforms in the northwestern Gulf of Mexico;
3. Produced water had been discharged from the platform continously for at least 5 years;
4. Water depth at the platform of less than 20 m; preferably a shallow bay site in less than 5 m of water and an open near-coast site in less than 15 m of water;

5. Concentrations of dissolved oxygen in bottom water always in excess of 2 ppm in summer months;
6. A relatively uniform sediment texture, grain size, and hydrography over a radius of several thousand meters around the site, in order to distinguish fate and effects related to the discharges from changes due to variability of the physical environment;
7. Evidence of some contamination of sediments near the discharge with chemicals derived from produced water and drilling fluid discharges so that it might be possible to relate any biological effects observed to a chemical signal; and
8. Evidence of a biologically productive and diverse benthic community in the vicinity of the site so that any subtle biological effects could be detected.

The data generated in the Phase 1 preliminary survey were combined with information provided by the operators of the platforms surveyed in Phase 1 to select two produced water discharge sites for the detailed field survey. Key technical participants in the program from Battelle and the API Drilling Fluids and Produced Water Research Taskforce collaborated in making the selection.

The detailed field program performed in Phase 2 was designed to focus on the detection of chemical contamination and the resulting biological impacts in surface sediments within approximately 1000 m of the discharge sites. The focus of the detailed survey was on sediments because cumulative impacts of chronic point source discharges are likely to be most evident in the benthic environment where contaminants accumulate over time. An underlying assumption was that produced water from the two sites to be monitored had been discharged at a more or less constant rate for some time (5 or more years). Therefore, any potential chemical or biological impacts would have already occurred and a zone of impact would be well established around each platform.

Based on results of the Phase 1 field investigation, Battelle and the API task force concluded that sediments at stations located 1000 and 2000 m from the produced water discharge were not contaminated with produced water chemicals. Thus, stations at 1000 m could serve as reference stations. In such a situation, the detailed field survey maps the distribution and intensity of any chemical and biological differences between sediments from reference and monitoring stations. This is done by conducting a limited number of seasonal surveys with as many sampling stations as necessary, located at different distances in all directions around each platform. Seasonal surveys help distinguish the relative roles of the contaminant inputs and natural seasonal changes in determining the chemical and biological patterns observed at each site. However, the main purpose of the second seasonal, fall, survey in this program was to confirm that the chemical and biological patterns observed in the spring were representative of the sites over the entire year. Therefore, the scope of the fall survey was less than that of the spring survey, and only those measurements that would best indicate the relationship between spring and fall conditions were made.

The Phase 2 field program consisted of two surveys, one each in the spring and fall, to the two platforms selected from the 4 sites that had been examined in Phase 1. Bottom sediments were sampled for chemical and benthic infaunal analyses at 16 stations along 4 transects during the spring survey and at 8 stations in the fall survey. Produced water samples were also taken from each platform for chemical analysis. In the laboratory, the sediment and produced water samples were analyzed for a suite of nine metals characteristic of produced water or drilling fluids, total and individual aliphatic and aromatic hydrocarbons, volatile organic priority pollutants, naphthenic acids, phenols, steranes, triterpanes, and total organic carbon. Grain size of sediment samples was also determined. Sediment samples for benthic infaunal analysis were sieved and all animals were identified and counted.

The biology data were analyzed for various community parameters. Chemical and biological results from reference stations (1000 m) were compared to those from stations closer to the platform. Results for stations along each transect were compared in an effort to discern any gradients of chemical or biological impact with distance form the discharges. The results were evaluated for patterns and trends in fate of produced water chemicals in sediments near the platforms, patterns and gradients of benthic community structure in sediments around each platform, and possible relationships between any observed patterns of altered benthic community structure and concentrations in sediments of chemicals derived from produced water or drilling fluids. Finally, fate of discharges and discharge-related biological effects were compared at the shallow water and the coastal water platforms.

1.3.2 Summary of Results of the Phase 1 Survey

The results of the preliminary survey were discussed in a report to API dated 22 November 1985. A copy of that report, Fate and Effects of Produced Water Discharges in Nearshore Waters: Results of the Preliminary Field Survey, are included in Appendix A of this report. The results of the preliminary survey are summarized here, with emphasis on those aspects that are relevant to interpreting the detailed field survey.

The original study plan called for a preliminary survey at four candidate produced water discharge sites, two in shallow estuarine waters (<5 m) and two in deeper (10 to 20 m) coastal marine waters in the Gulf of Mexico. From the 96 sites considered by Battelle and the API Drilling Fluid and Produced Water Research Taskforce, four candidate sites were chosen, one in a shallow bay and three offshore (Figure 1.1).

The shallow water site selected was Lake Pelto, Tank Battery No. 1, located in Terrebonne Bay, Louisiana, in 2.1 m (7 ft) of water (Table 1.1). The Lake Pelto field consists of a large number of wells and many surface structures, some connected by walkways. This field has been in production for about 40 years and the estimated current rate of produced water discharge is 2750 barrels/day (over 437,000 liters/day). The three offshore sites were 1) Ship Shoal, Block 114, located about 8 miles south-southwest of Lake Pelto in approximately 12 m (40 ft) of water, 2) Eugene Island, Block 105, and 3) Eugene Island, Block 120, located along with Block 105 about 18 miles west-southwest of Lake Pelto in 8.5 and 12 m (28 and 40 ft) of water, respectively. These offshore oil-water separation platforms have been in operation for 6 to 20 years. The current rates of produced water discharge from these platforms are in excess of 1570 BPD (>250,000 liters/day).

The preliminary survey was performed from 28 July to 6 August 1985. Equipment problems and adverse weather conditions made it impossible to sample all stations for all intended parameters. Four produced water samples were obtained from each platform for the analysis of radium isotopes, aromatic hydrocarbons, total organic carbon, trace metals, and volatile organics.

The sediment sampling grid consisted of four concentric rings at 20, 100, 1000, and 2000 m from the produced water discharge from each platform (Figure 1.2). Each ring was divided into four quadrants corresponding to the arcs between the major points of the compass. Within each quadrant, several sediment samples were collected at evenly spaced intervals along each ring. All sediment samples from any one ring within a quadrant were from which, because of time constraints, only four sediment samples were collected, one from each ring along a transect extending to the east-northeast from the platform. Sediments

TABLE 1.1. SUMMARY OF OPERATIONS AND DISCHARGES FROM THE PLATFORMS AT EUGENE ISLAND, BLOCK 105, PLATFORM A, AND LAKE PELTO TANK BATTERY NO. 1.

Feature	Eugene Island	Lake Pelto
Water depth (m)	7.6-8.5	1.8-3.0
Start of production	May 1981[a]	Early-mid 1940's
Average and range of produced water discharge (bbl/day)	1570 (264-3500)	2750 (1700-3000)
Produced water treatment system	Gravity separator (corrugated plate interceptor)	Gravity separator
Location of produced water discharge	3 ft above water surface	6 ft above water surface
Range of oil and grease values in last 5 years (mg/l)	1-64.5	20-46
Treatment of produced sands	Before 1986, discharged to ocean if they contained <72 mg/l oil & grease. Currently hauled to shore.	Washed and discharged or removed to land
Biocide use	No reported use	None used
Treatment chemical use	No reported use	No unusual chemicals used
Nearest produced water discharge	EI 105B, 823 m NNE of site; EI 1050, 761 m SSW of site	Tank Battery No. 2 1646 m WNW of site
Number of wells drilled from platform	None	None
Number of wells drilled within 1000m of platform	23 (Mean depth, 13,400ft)	15 (Mean depth, 7,544ft)

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[a] Prior to 1981, when the Eugene Island, Block 105A produced water separator/treatment platform was installed, produced water was separated and discharged from numerous, individual satellite well stations in the field.

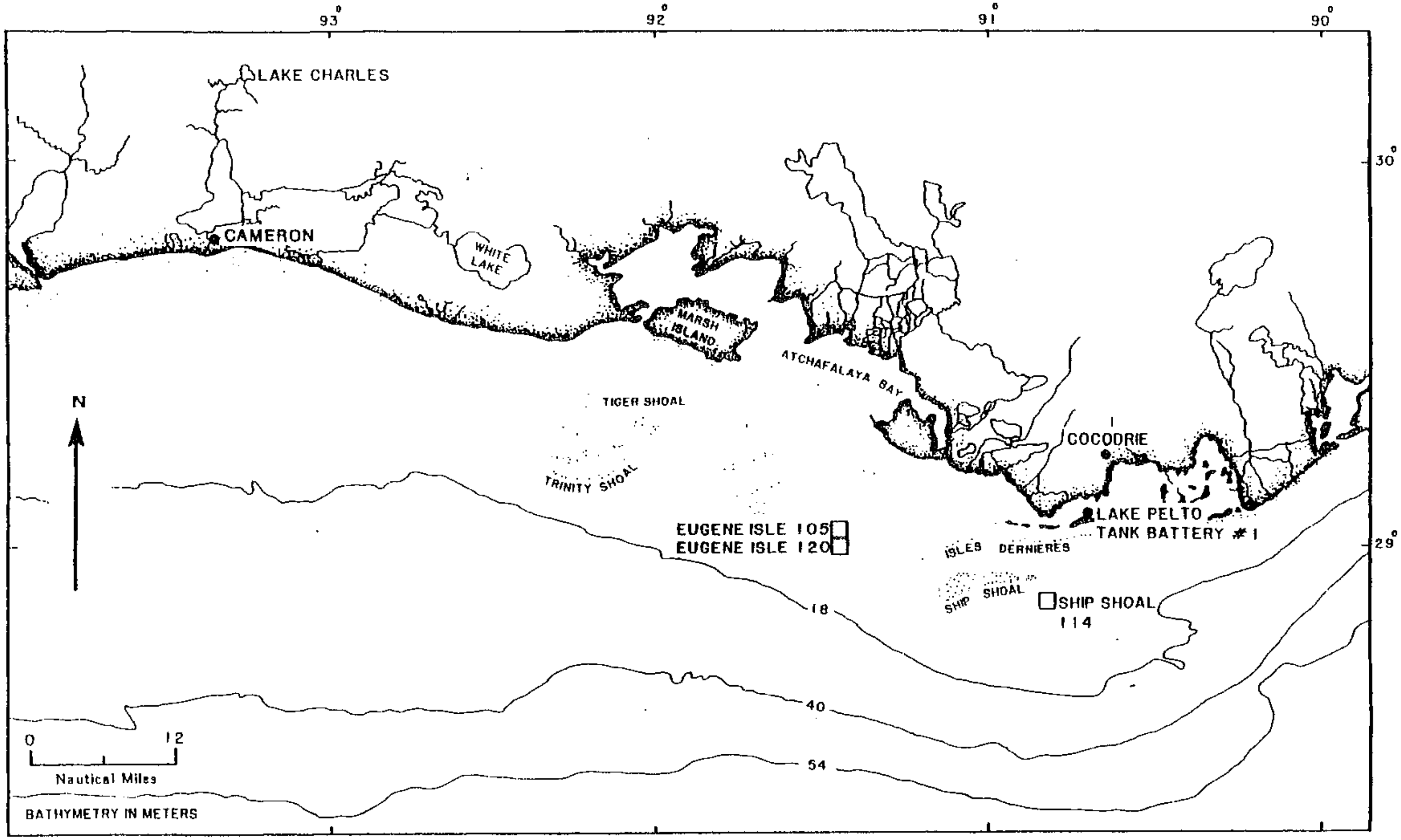


FIGURE 1.1. MAP OF COASTAL LOUISIANA SHOWING LOCATIONS OF THE FOUR PLATFORMS EVALUATED IN THE PRELIMINARY FIELD SURVEY, INCLUDING THE TWO PLATFORMS, EUGENE ISLAND, BLOCK 105, AND LAKE PELTO, TANK BATTERY NO. 1, THAT WERE EVALUATED IN THE [illegible]AILED FIELD SURVEY.

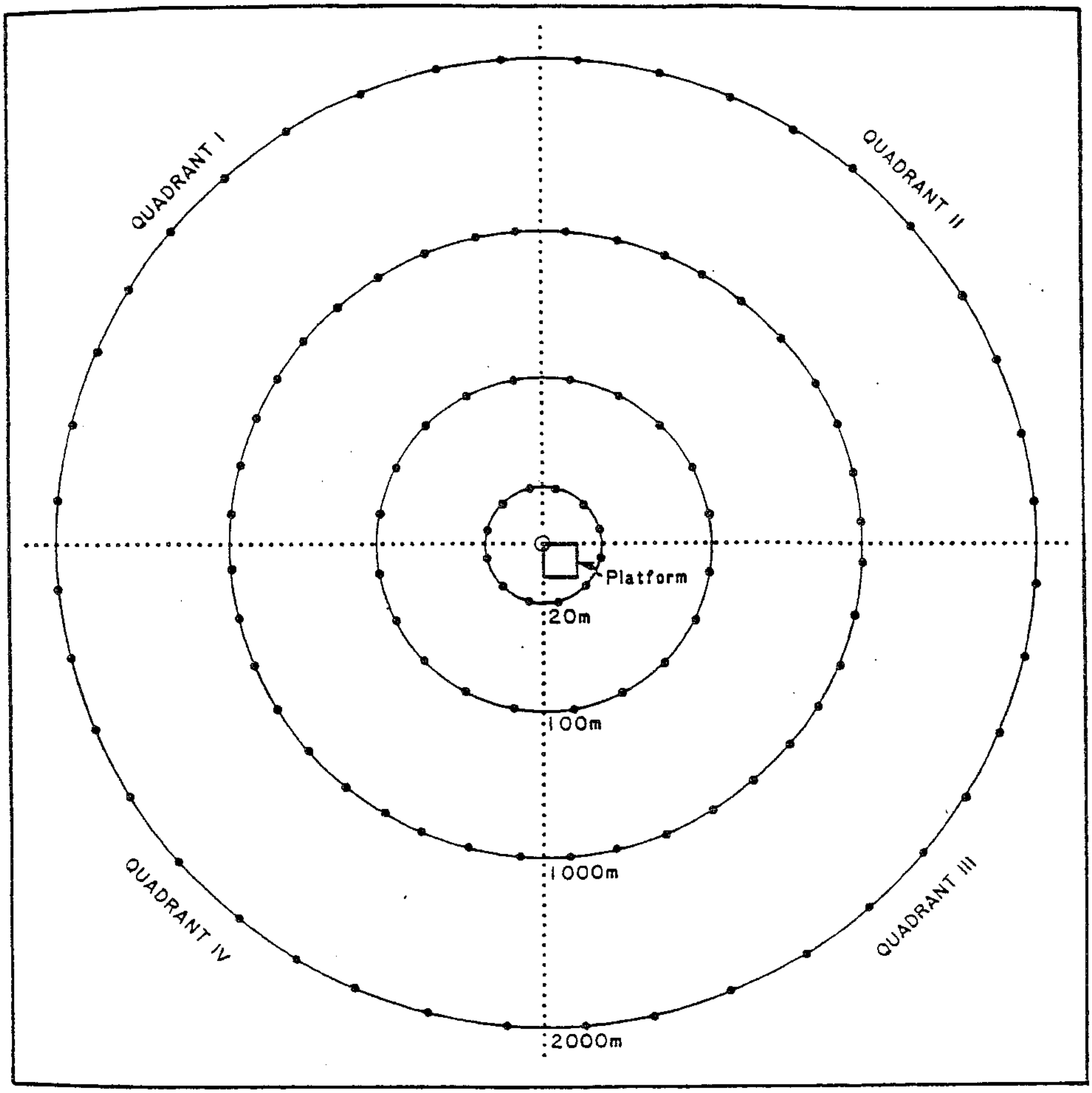


FIGURE 1.2. SAMPLING GRID AROUND THREE OF THE FOUR PLATFORMS VISITED DURING THE PRELIMINARY FIELD SURVEY. SOLID CIRCLES INDICATE SEDIMENT SAMPLING STATIONS.

were collected with a Kynar-coated 0.04-m^2 Van Veen grab sampler. The upper 2 cm of sediment was collected from each grab sample and frozen immediately for shipment to the laboratory.

At a subset of stations in each ring in each quadrant at the four candidate sites, REMOTS (Remote Ecological Monitoring of the Seafloor) sediment profile imaging was used to further characterize the physical, chemical, and biological features of the area. In this technique, a specially designed camera penetrates the sediment and photographs an in situ vertical profile of the upper 10 to 15 cm of sediment. Using REMOTS technology, the dynamics of seafloor processes can be deduced from imaged structures. Information that can be obtained from each photograph includes sediment grain size major mode and range, prism penetration depth (an indication of sediment bearing capacity and water content), small-scale sediment surface boundary relief and bedforms, depth of the apparent redox potential discontinuity (RPD), presence or absence of sedimentary methane, erosional and depositional criteria (detection of sedimentary intervals as small as 1 mm), detection of animals at the sediment-water interface, evaluation of infaunal successional stage, measurement of surface fecal pellet layers, presence or absence of microbial aggregations, and calculation of the REMOTS Organism-Sediment Index (OSI) for mapping of disturbance gradients.

At Lake Pelto, the REMOTS survey was completed at the two inner rings and part of the 1000-m ring. At Eugene Island, Block 120, only the four stations sampled for sediments were surveyed by REMOTS. The complete REMOTS survey was performed at Ship Shoal, Block 114, and Eugene Island, Block 105.

In the laboratory, produced water and sediment samples were analyzed for a suite of target aromatic hydrocarbons that included two- to five-ring aromatic hydrocarbons and their C_1

through C_5 alkyl homologues, four metals (barium, chromium, copper, and zinc), and total organic carbon. In addition, produced water samples were analyzed for volatile organic compounds, and ^{226}radium and ^{228}radium; sediment samples were analyzed for sediment grain size.

1.3.2.1 Lake Pelto, Tank Battery No. 1

Sediments within about 100 m of the tank battery consisted of poorly sorted sands mixed with 30 to 40 percent silt/clay and coarse mollusk shell hash. Sediments from stations 300 and 1000 m from the platform contained higher concentrations of silt-clay and less shell hash than sediments near the platform.

Highest concentrations of total organic carbon and aromatic hydrocarbons were found in sediments collected 20 m northeast of the produced water discharge. These sediments contained 32.3 mg C/g dry sediment and 36.6 ppm (μg/g) total target aromatic hydrocarbons. Nearly 40 percent of the total target aromatics were phenanthrene and alkyl phenanthrenes, even though the produced water from the platform contained higher concentrations of naphthalene and alkyl naphthalenes than phenanthrenes. Generally, sediments in the 20-m ring were the most heavily contaminated and had the shallowest RPD depths and lowest organism-sediment indices (OSI). Sediments from the outer three rings had low or undetectable levels of contaminants related to produced water. The only gradient for sediment metal concentration was for zinc, and that gradient was small and possibly related to sediment grain size.

1.3.2.2 Ship Shoal, Block 114

The sedimentary regime around Ship Shoal, Block 114, was characterized by a low relief ridge and swale topography grading from fine sands inshore to silts and clays offshore. This relict topography may be related to drowned cheniers or other relict marginal deltaic features. Wave and current scouring of the ridges prevents accumulation of silts and clays there. The swale depressions between the ridges appear to be lower kinetic areas and silt and clay tend to accumulate in them. These depressions may also contain higher concentrations of particulate organic materials than the ridges. Thus, these two sedimentary facies probably possess different infaunal assemblages. It was apparent at this location that sediment chemistry and biological communities (OSI based on REMOTS) were greatly influenced by periodic or chronic hypoxia in bottom water. Surficial sediments were virtually anoxic throughout the area at the time of the survey and supported only a depauperate, early successional fauna (small near-surface-dwelling taxa, mainly polychaetes). At some stations, sediments apparently were almost azoic.

Very high concentrations of total organic carbon (1.9 to 19.2 mgC/g) and targeted aromatic hydrocarbons were detected in sediments near the produced water discharge from the platform. Sediments from 20 m southeast of the discharge contained 681 ppm total targeted aromatic hydrocarbons. This aromatic hydrocarbon assemblage was dominated by alkyl benzenes and naphthalenes. Several other composite sediment samples, particularly from the southeast of the platform, contained elevated concentrations of aromatic hydrocarbons. The elevated hydrocarbon concentrations in the sediments around Ship Shoal 114 probably did not contribute in any way to the biologically depauperate and hypoxic condition of the bottom sediments. In fact, the hypoxic conditions probably increased the persistence of hydrocarbons in the sediments. In hypoxic or anoxic conditions, microbial degradation of hydrocarbons occurs at a much lower rate than in oxygenated sediments and the lack of bioturbation also provides favorable conditions for hydrocarbon accumulation and persistence.

The sediment sample from 20 m southeast of the platform that contained the highest concentration of total target aromatic hydrocarbons also contained the highest concentration of barium (2290 mg/kg dry weight) in any sediment sample collected at the four platforms during the preliminary field survey. The hydrocarbon and metals results indicate that large amounts of chemicals from drilling fluids and produced water had accumulated and were persisting in sediments near the platform. However, there were no trends or gradients of hydrocarbon or metals concentrations in sediments from the vicinity of the platform in Ship Shoal, Block 114.

Based on REMOTS, the sedimentological and infaunal characteristics indicated a strong gradient across the site, directed generally north-northwest to south-southeast. This gradient showed no apparent relationship to the platform (i.e., the distribution of sulphidic sediment, low-order successional stages, and low OSI did not appear to be centered on the platform, but rather reflected a gradient of larger scale). The area southeast of the platform was particularly interesting because its sediments were finer grained and had higher concentrations of total organic carbon and aromatic hydrocarbons than sediments in other quadrants, but its benthic community was represented by higher order successional stages. These results suggest that the distribution of the depauperate infauna was not greatly influenced by gradients in concentrations of aromatic hydrocarbons in the sediments.

1.3.2.3 Eugene Island, Block 105, Platform A

Most sediments from stations around Platform A in Eugene Island, Block 105 had a major mode of very fine sand. However, sediments from the inner ring (20 m) and the northern stations 100 m from the platform consisted of silt-clay. Elevated concentrations of fine-grained sediments near the platform may be due to the platform's influence on the deposition of such sediments. Many of the sandy stations lying outside the central mud facies overlie silt-clay muds. This sand-over-mud stratigraphy suggests that the sedimentation regime in the area has changed recently. The cause of this change is unknown. The area covered by this unusual stratigraphy is larger than would be expected if it was caused by installation of the platform at the site.

The areal distribution pattern of RPD depths, successional series, and OSI is difficult to relate directly to the platform structure. However, conditions close to the platform appeared to be stressed. Specifically, the lowest RPD and OSI values were associated with the inner ring of stations. High OSI (>7) were found in the outer two rings (1000 and 2000 m) in all but the northeast quadrant. These areas represent the least disturbed areas sampled around the platform in Eugene Island, Block 105. In general, OSI values increased with distance from the platform.

Aromatic hydrocarbon concentrations in sediments were very low throughout the area. However, they were highest in sediments from the inner two rings (20 and 100 m) of stations. The highest concentration of total target aromatic hydrocarbons was 4.3 ppm at 100 m southeast of the platform. There were no clear patterns of metals distributions in sediments around the platform.

1.3.2.4 Eugene Island, Block 120

Only four stations located along a transect oriented toward the east northeast from the platform were sampled. The limited data from these stations suggest a gradient of sediment physical and chemical characteristics extending away from the platform. This gradient appeared to be related to the presence of the platform or to discharges from it. Sediments contained 62 to 97 percent silt-clay, with the highest silt-clay concentration in sediment collected 20 m from the platform. Well-developed gradients of apparent RPD depth, successional stage, and OSI appeared to be related to a decrease in sediment oxygen concentration as the platform is approached.

However, aromatic hydrocarbon concentrations in sediments were very low, even though sediment total organic carbon concentrations were higher than concentrations in sediments from the other platforms. The highest concentration of total target aromatic hydrocarbons was 0.40 ppm in sediments 20 m from the produced water discharge. The low hydrocarbon and high sediment organic carbon concentrations could be due to lack of significant deposition of petroleum hydrocarbons in the sediments. The high organic carbon concentrations may be derived from natural organics associated with the fine-grained sediments.

1.3.2.5 Produced Water Chemistry

Salinity of the produced water samples ranged from 143 parts per thousand (ppt) at Lake Pelto to 220 ppt at Ship Shoal 114 (Table 1.2). Total organic carbon concentrations ranged from 195.1 ppm in Ship Shoal 114 samples to 333.9 ppm in Eugene Island 120 samples. Concentrations of total radium isotopes ranged from 605 pCi/l in produced water from Ship Shoal 114 to 1215 pCi/l in produced water from Eugene Island 120. There was a direct correlation between the concentrations of total organic carbon and total radium isotopes in the produced water samples.

Concentrations of barium ranged from 14.6 mg/l in produced water from Ship Shoal 114 to 97.6 mg/l in produced water from Eugene Island 105. Concentrations of chromium and copper were similar in all produced water samples (chromium, 0.89 - 1.93 mg/l; copper, 1.31 - 2.02 mg/l). However, concentrations of zinc were quite variable, ranging from 156 mg/l in produced water from Lake Pelto to 8293 mg/l in produced water from Ship Shoal 114.

TABLE 1.2. SUMMARY OF THE CONCENTRATIONS OF SEVERAL ORGANIC AND INORGANIC CHEMICALS IN PRODUCED WATER COLLECTED AT FOUR PLATFORMS DURING THE PRELIMINARY SURVEY. CONCENTRATIONS IN µg/l UNLESS SPECIFIED OTHERWISE.

Compound Class	Eugene Island 105	Eugene Island 120	Lake Pelto No. 1	Ship Shoal 114
Organics				
Total Organic Carbon	220,100	333,900	306,500	195,100
Total Extractable Matter[a]	56,200	74,100	28,900	42,000
Benzenes [b,c]	515	479	570	509
Naphthalenes [b]	331	431	331	486
Dibenzothiophenes [b]	3.7	4.0	10.7	28.3
Fluorenes [b]	0.1	4.3	29.6	59.6
Phenanthrenes [b]	0.7	11.8	60.2	102
Aromatics	850.5	930.1	1,001.5	1,184.9
Inorganics				
Salinity (g/kg)	166.7	163.3	143.3	220
Radium ($^{226}Ra+^{228}Ra$) (pCi/l)	699	1,215	839	605
Solids (mg/l)	179	167	144	223
Barium	97,600	91,700	31,000	14,640
Chromium	0.89	1.93	1.41	1.61
Copper	1.77	1.31	1.38	2.02
Zinc	617	1,423	156	8,293

[a] The dry weight of the methylene chloride extract of the sediment.

[b] Includes the parent compound and the C_1 through C_4 homologues.

[c] Benzene concentrations lower than true values because of sample preparation techniques.

The composition and concentrations of aromatic hydrocarbons were similar in produced water samples from all four platforms. Total target aromatic hydrocarbon concentrations ranged from 900 µg/l in produced water from Eugene Island, Block 105, to 1200 µg/l in produced water from Ship Shoal, Block 114. The dominant aromatic hydrocarbons in all produced water samples were benzene and naphthalene and their alkyl homologues. Concentrations of dibenzothiophenes, fluorenes, and phenanthrenes were much lower in produced water samples from Eugene Island, Blocks 105 and 120, than in produced water samples from Lake Pelto and Ship Shoal 114.

1.3.2.6 Conclusions and Platform Selection

Of the four platform sites sampled in the initial survey, all but Ship Shoal 114 appeared to be reasonable candidates for the detailed survey. Ship Shoal, Block 114 was unsuitable because the fate and effects of produced water discharges were influenced by the intermittent or chronic hypoxia in bottom waters throughout the area. There was a strong indication of an extremely depauperate benthic infauna attributable to hypoxia of the bottom water. In such a stressed benthic community, it would be difficult or impossible to detect any impacts attributable to produced water discharges. In addition, there was strong evidence of gradients of sediment physical characteristics and topography running through the area but not centered on the platform. Any chemical or biological gradients attributable to platform discharges would tend to be obscured by such gradients.

Lake Pelto also had features that might make it difficult to assess impacts of platform discharges. Sediments near the platform had a different texture than those farther away. Because sediment texture is a major determinant of benthic infaunal community structure, such gradients might obscure patterns of impacts due to produced water discharges. However, it was felt that the need to evaluate an inshore shallow water site was great enough that Lake Pelto should be chosen as one of the platform sites for the detailed survey.

Both Eugene Island, Blocks 105 and 120 were considered to be suitable. Produced water from both platforms contained similar concentrations of PAH (897 versus 966 µg/l total PAH at Eugene Island 105 and 120, respectively). To the extent that comparisons could be made, it appeared that concentrations and distributions of PAH in sediments around the two platforms were similar. However, insufficient data were available from the preliminary investigation at Eugene Island, Block 120, to support the choice of this site. Therefore, Eugene Island, Block 105 was chosen.

2.0 MATERIALS AND METHODS

2.1 PHASE 2 FIELD SAMPLING

2.1.1 Sampling Design

The detailed field survey consisted of two field sampling cruises, the first from 24 to 29 March 1986 (the spring cruise) and the second from 6 to 8 October 1986 (the fall cruise). Both cruises were performed aboard the R/V Acadiana operated by Louisiana Universities Marine Consortium (LUMCON). The cruises were staged out of the LUMCON marine laboratory at Cocodrie, Louisiana.

The sampling design for the spring cruise consisted of 16 stations at each platform (Figures 2.1 and 2.2). Selection of distances of stations from the platform along each transect was based on the distribution of grain size and aromatic hydrocarbons in sediments around each platform, and the desire to include stations close enough to the platforms to assure that chemical and biological impacts would be detected. A subset of 8 of the 16 stations was sampled on the fall cruise. These stations represented the two transects from the spring cruise with the most uniform sediment texture and best indication of a gradient of hydrocarbon concentrations in the sediments. The stations were located in a radial array around each platform at distances of 20, 100, 300, and 1000 m from the produced water discharge from the platform. The transects, consisting of four stations each, were oriented toward the north, east, south, and west from Platform A at Eugene Island 105 and toward the northeast, southeast, southwest, and northwest from Tank Battery No. 1 at Lake Pelto.

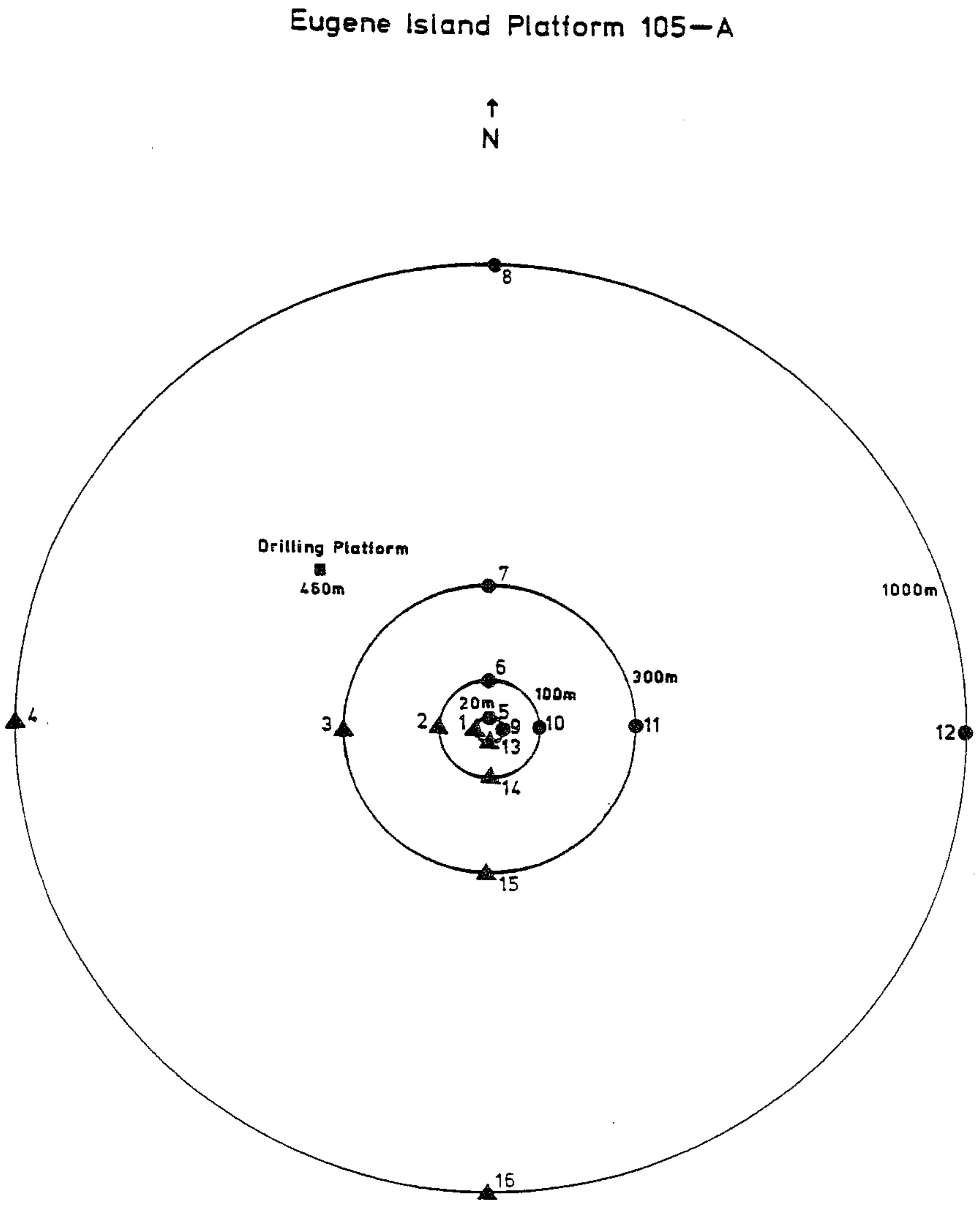


FIGURE 2.1. LOCATIONS OF STATIONS AROUND EUGENE ISLAND, BLOCK 105, PLATFORM A, SAMPLED DURING THE SPRING AND FALL SURVEYS. ALL STATIONS WERE SAMPLED IN THE SPRING SURVEY. THOSE STATIONS MARKED WITH A TRIANGLE WERE SAMPLED IN THE FALL SURVEY.

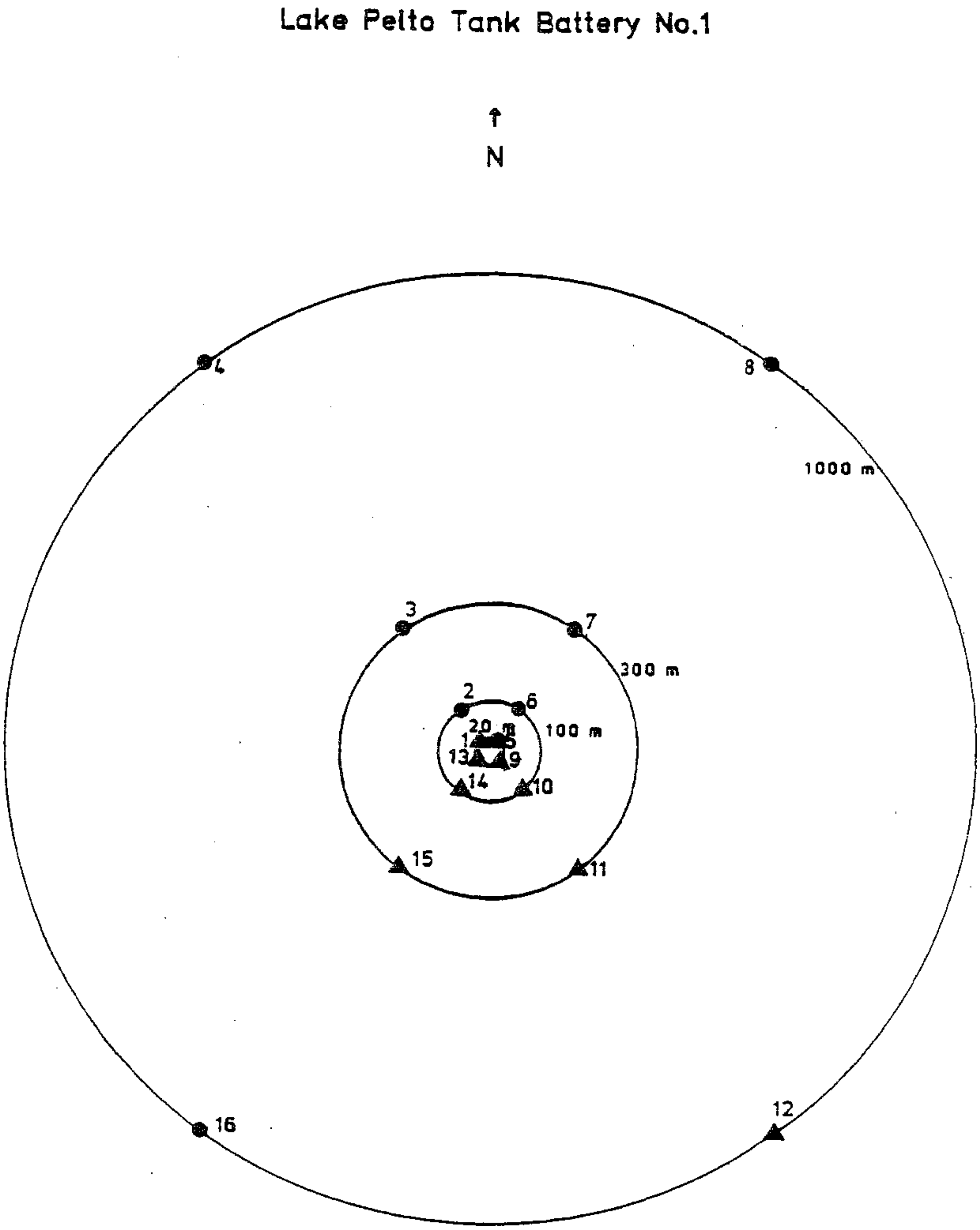


FIGURE 2.2. LOCATIONS OF STATIONS AROUND LAKE PELTO, TANK BATTERY NO. 1, SAMPLED DURING THE SPRING AND FALL SURVEYS. ALL STATIONS WERE SAMPLED IN THE SPRING SURVEY. THOSE STATIONS MARKED WITH A TRIANGLE WERE SAMPLED IN THE FALL SURVEY.

2.1.2 Navigation

A NORTHSTAR 7000 LORAN receiver was the primary navigation aid.An Apple IIe microcomputer and Epson printer were integrated with the LORAN through a navigation software package developed by Mr. Andrew Eliason of Eliason Data Services. The navigation data recorder logged time, date, latitude and longitude, LORAN time delays, samples collected, and general comments. The ship's position was displayed graphically on a plotter and digitally on a monitor and was simultaneously recorded on disk and printed out.

All LORAN time delays were in the 7980 GRI (Group Repetition Interval) using the W and X secondary stations (i.e., the 11-k and 28-k lines, respectively). LORAN time delays established during the preliminary cruise for the discharge pipe from each platform were checked for accuracy prior to sampling on the two detailed cruises.

Station positions were located via range and bearing. Upon locating the proper station, the R/V Acadiana would either tie up to a well head or drop anchor. The appropriate block map was consulted to avoid anchoring on pipelines. This method of station positioning proved efficient and reliable throughout both cruises. Due to the proximity of the inner ring of stations to the platform, LORAN reception fluctuated frequently at these stations. Under such conditions, stations were located by visually siting ranges.

2.1.3 Sample Collection

Four types of samples or field data were collected at each platform on both cruises. These were hydrographic measurements, produced water samples for chemical analysis, sediment grab samples for chemical and grain size analysis, and sediment grab samples for infaunal and grain size analysis. Sediment grain size was determined in subsamples of both the chemistry and biology sediment samples to improve the ability to draw correlations between sediment grain size and chemical and biological parameters. Summaries of all samples collected at each platform on the spring and fall cruises are presented in Tables 2.1 to 2.4.

2.1.3.1 Produced Water Samples

Three produced water samples were collected at both production platforms during both surveys. During the spring survey, one sample was collected at three different times of day from each platform in order to assess short-term variability in the concentration of selected constituents in the produced water. Eugene Island samples were taken from either the small spigot near the bottom of the oil/water separator or the large spigot at the bottom of the separator. The 8:10 a.m. CST (25 March 1986) sample (Replicate 1) was taken from the small spigot; the large spigot was used to collect the 12:45 p.m. and 6:40 p.m. samples (Replicates 2 and 3). It should be noted that before the collection of the 6:40 p.m. sample from Eugene Island, there was an oil spill in the skimmer tank. However, the tank was flushed before collection of the sample. On the spring cruise, all the Lake Pelto samples were collected from the discharge pipe at sampling times of 8:30 a.m., 2:00 p.m., and 5:40 p.m. CST on 28 March 1986. During the fall survey, produced water samples were collected at Eugene Island 105 from the skimmer tank because the spigot near the bottom of the oil/water separator had a vacuum. The overside produced water discharge pipe at Lake Pelto tank battery No. 1 was not discharging produced water at the time of the fall cruise. However, it was possible to obtain enough produced water from a spigot attached to the discharge pipe.

On the spring cruise, each sample was collected in three precleaned containers as follows:

TABLE 2.1. SUMMARY OF SAMPLES COLLECTED ON THE SPRING SURVEY ABOARD THE R/V *Acadiana* AT EUGENE ISLAND, PLATFORM 105-A.

Sample Type	Number of Stations	Number of Replicates/Station	Site Total
Produced Water	1	3*	3
0.04m^2 Van Veen (Biology)	16	6	96
Sediment Grain Size	16	6	96
0.04m^2 Van Veen (Chemistry)	16	3	48
Sediment Trace Metal	16	3	48
Sediment Hydrocarbon	16	3	48
Sediment Profile Core	2	1	2
Dissolved Oxygen (Surface and Bottom)	16	1	16
Salinity (Surface and Bottom)	16	1	16
Temperature (Surface and Bottom)	16	1	16

*Replicate sample collected at morning, noon, and evening.

TABLE 2.2. SUMMARY OF SAMPLES COLLECTED ON THE SPRING SURVEY ABOARD THE R/V *Acadiana* AT LAKE PELTO, TANK BATTERY NO. 1.

Sample Type	Number of Stations	Number of Replicates/Station	Site Total
Produced Water	1	3*	3
0.04m^2 Van Veen (Biology)	16	6	96
Sediment Grain Size	16	6	96
0.04m^2 Van Veen (Chemistry)	16	3	48
Sediment Trace Metal	16	3	48
Sediment Hydrocarbon	16	3	48
Sediment Profile Core	3**	1	16
Dissolved Oxygen (Surface and Bottom)	16	1	16
Salinity (Surface and Bottom)	16	1	16
Temperature (Surface and Bottom)	16	1	16

*Replicate sample collected at morning, noon, and evening.
**Extra core taken during equipment test.

TABLE 2.3. SUMMARY OF SAMPLES COLLECTED ON THE FALL SURVEY ABOARD THE R/V *Acadiana* AT EUGENE ISLAND PLATFORM 105-A.

Sample Type	Number of Stations[1]	Number of Replicates/Station	Site Total
Produced Water	1	3	3
0.04m^2 Van Veen (Biology)	8	6	48
Sediment Grain Size	8	6	48
0.04m^2 Van Veen (Chemistry)	8	3	24
Sediment Trace Metal	8	3	24
Sediment Hydrocarbon	8	3	24
Sediment Profile Core	8	1	8
Dissolved Oxygen (Surface and Bottom)	8	1	8
Salinity (Surface and Bottom)	8	1	8
Temperature (Surface and Bottom)	8	1	8

[1] The eight stations sampled included Stations 1, 2, 3, 4, 13, 14, 15, and 16 (See Figure 2.1). Only samples from Stations 1 through 4 have been analyzed to date.

TABLE 2.4. SUMMARY OF SAMPLES COLLECTED ON THE FALL SURVEY ABOARD THE R/V <u>Acadiana</u> AT LAKE PELTO, TANK BATTERY NO. 1.

Sample Type	Number of Stations[1]	Number of Replicates/Station	Site Total
Produced Water	1	3	3
0.04m^2 Van Veen (Biology)	8	6	48
Sediment Grain Size	8	6	48
0.04m^2 Van Veen (Chemistry)	8	3	24
Sediment Trace Metal	8	3	24
Sediment Hydrocarbon	8	3	24
Dissolved Oxygen (Surface and Bottom)	8	1	8
Salinity (Surface and Bottom)	8	1	8
Temperature (Surface and Bottom)	8	1	8

[1] The eight stations sampled included Stations 1, 9, 10, 11, 12, 13, 14, and 15 (See Figure 2.2). Only samples from Stations 1, 13, 14, and 15 have been analyzed to date.

- 2.5-liter amber jugs--all analytes except trace metals and volatile organics.
- 1-gal cubitainer with 4 ml conc. HNO_3--trace metals.
- 40-ml vial--volatile organics.

On the fall cruise, each sample was collected in four containers as follows:

- 1-gal cubitainer with 4 ml conc. HNO_3--trace metals.
- 250-ml amber bottle--volatile hydrocarbons.
- 40-ml vial--volatile organics.
- 500-ml amber bottle--petroleum hydrocarbons.

The samples for organics analysis were preserved by addition of the extracting solvent, methylene chloride. Water samples for metals analysis were acidified with concentrated nitric acid. Water samples for volatiles analysis were preserved with sodium azide.

2.1.3.2 Hydrographic Measurements

Dissolved oxygen concentration, salinity, and temperature were recorded 0.3 m below the sea surface and 1 m above the bottom at all stations on both cruises. These hydrographic data were collected with a Hydrolab 4041 indicator unit and a Type 70 SONDE unit. The instrument was calibrated regularly by analysis of standard seawater (salinity), comparison with a mercury thermometer calibrated by the National Bureau of Standards (temperature), or comparison with results of a Winkler titration (oxygen concentration).

2.1.3.3 Sediment Samples for Chemical Analysis

Three replicate sediment samples were collected at each of the 16 stations at both platforms during the spring survey and from 8 stations at both platforms during the fall cruise. The stations sampled during the fall cruise were Stations 1, 2, 3, 4, 13, 14, 15, and 16 at Eugene Island 105 and Stations 1, 9, 10, 11, 12, 13, 14, and 15 at Lake Pelto. Selection of these stations was based on preliminary interpretation of the chemical and biological results of the spring survey.

All sediment samples for chemical analysis were collected with a Kynar-coated 0.04-m^2 Van Veen grab sampler. The sampling equipment was rinsed with solvent before deployment. A Kynar-coated scoop was used to subsample the top 2 cm of sediment for grain size, organics, and trace metals. All organic and trace metal samples were immediately stored frozen in dry ice and transported back to the laboratory on dry ice.

2.1.3.4 Sediment Samples for Infaunal Analysis

Sediment grab samples for infaunal analysis were collected at the same stations sampled for sediment chemistry. Sixteen stations at each platform were sampled on the spring survey and eight stations at each platform were sampled on the fall survey. At each station, 6 replicate grab samples for infaunal analysis were collected with a Kynar-coated 0.04 m^2 Van Veen grab sampler.

All biology grab samples were first subsampled for sediment grain size analysis. From each grab sample, a plug of sediment, approximately 20 cm^3, was taken with a plastic syringe barrel. These samples were placed in Whirlpak bags, sealed, and stored frozen until analysis.

The remainder of the sediment sample was transferred to a

9.5-liter bucket. Each sample was elutriated into a large-diameter sieve with a 0.3-mm mesh and washed with filtered seawater. The elutriate samples were divided into a light and a heavy fraction when necessary and stored in 16-oz jars and 1-gal jugs. The samples were preserved with 10 percent buffered formalin in seawater and labeled on both the inside and outside of the containers.

2.1.4 Sample Analysis

2.1.4.1 Produced Water Analysis

All produced water samples from the spring survey were analyzed. The samples from the fall survey were preserved as described previously and archived for possible later analysis.

Subsamples of each replicate 2.5-liter jug sample were taken for analysis of total hydrocarbons by infrared analysis (IR). The remainder of the water in the three replicate jug samples from each platform was composited for analysis of the other organic analytes. The three replicate water samples for metals analysis from each platform were also composited for analysis. Each replicate water sample in the 40-ml vials was analyzed separately for volatile organics. Each individual or composite sample was analyzed for the analytes presented in Table 2.5.

2.1.4.1.1 Analysis of Total Hydrocarbons by IR. Total hydrocarbons were determined in the produced water samples by solvent extraction and infrared spectroscopy. Samples were extracted with approximately 45 ml of Freon and the extracts were analyzed with a Miran-1A CVF infrared spectrometer at a wavelength of 3.425 μm. Quantification was accomplished by producing a standard curve using different concentrations (ranging from 50 mg/l to 400 mg/l) of API 50° Louisiana Light Crude Oil.

TABLE 2.5. ANALYTES DETERMINED IN SAMPLES OF PRODUCED WATER COLLECTED DURING SPRING SURVEY.

Total Hydrocarbons
Total Saturate (f_1) and Aromatic (f_2) Hydrocarbon
n-Alkanes (C_{10} through C_{34})
Parent and Alkyl-Substituted Polycyclic Aromatic Hydrocarbons (Naphthalenes through Perylenes)
Volatile Hydrocarbons
Steranes and Triterpanes
Total Organic Carbon
Volatile Organic Compounds
Phenol and Alkyl-Substituted Phenolic Compounds
Trace Metals--Ba, Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn

2.1.4.1.2 Sample Extraction and Column Chromatography. Samples (1200 ml) were acidified to pH < 4 with 4.0 ml 1N HCl and extracted twice with 100 ml methylene chloride and a third time with 100 ml 50:50 methylene chloride:ethyl ether. Before extraction, 500 µg each of o-terphenyl and androstane were added to each sample as internal standards. The combined organic extracts were dried over Na_2SO_4. The extracts were then split into two aliquots; one was used for hydrocarbon and naphthenic acid analysis and the other for phenol analysis.

The hydrocarbon extract split was passed through an alumina/silica gel column to separate the extract into f_1 (saturates), f_2 (aromatics), and f_3 (polar compounds) fractions. The f_1 fraction was eluted with hexane, the f_2 fraction with 1:1 hexane:methylene chloride, and the f_3 fraction with 100 percent methanol.

2.1.4.1.3 Analysis of Hydrocarbons by GC/MSD. The f_1 and f_2 fractions were analyzed with a Hewlett-Packard (HP) D5790 GC-MSD (gas chromatography with a mass selective detector) equipped with a 30-m x 0.25-mm (i.d.) DB-5 fused silica capillary column. The GC was temperature programmed from 40 to 290°C at 4°C/min with a one minute initial hold. The HP 5790 chemistry station data system was used to quantify specific hydrocarbons in the f_1 and f_2 fractions relative to the internal standards. The n-alkanes from C_{10} through C_{34} were determined in the f_1 fraction. The f_2 fraction was analyzed for the homologous series of benzenes containing 2 to 5 alkyl carbons (C_2-C_5), naphthalenes (C_0-C_5), biphenyls (C_0-C_5), fluorenes (C_0-C_5), phenanthrenes (C_0-C_5), dibenzothiophenes (C_0-C_5), pyrenes (C_0-C_5), chrysenes (C_0-C5), and perylenes (C_0-C_5).

Total n-alkane and aromatic concentrations were determined by GC-MSD analysis of the f_1 and f_2 fractions, respectively. Both resolved and unresolved hydrocarbons were quantified. The resolved concentrations were determined by summing the total resolved area with valley integration, and then using an average n-alkane or PAH response factor to calculate an amount relative to the internal standard. The unresolved concentrations were calculated by integrating the total area of the chromatogram (both the resolved area and the unresolved complex mixture (UCM) area), subtracting the resolved area, and determining the amount relative to the internal standard. The UCM concentrations were not corrected for instrumental response.

2.1.4.1.4 Analysis of Steranes and Triterpanes. Steranes and triterpanes were determined in the f_1 fraction by GC-MSD with selective ion monitoring (SIM). The same column and temperature programming conditions used in analyzing the extracts for n-alkanes were used in analyzing steranes and triterpanes. Mass ions m/e 217 and 218 were used to identify steranes, and mass ions m/e 191 and 192 were used to identify the triterpanes. Many of the sterane and triterpane compounds (peaks on the chromatograms) were tentatively identified by comparison with chromatograms of known compounds (see Tables 3.6 and 3.7 for compound identifications used in this study). The steranes and triterpane concentrations were estimated based on the relative responses of the 191 and 217 mass ions and the response of the internal standard, androstane.

2.1.4.1.5 Analysis of Phenols. The phenolic extracts were partitioned two times with 50-ml 10N NaOH in a separatory funnel. The aqueous phases were combined (organic phase was discarded) and then acidified to pH~1 with 25 ml 6N HCl. The acidified aqueous phase was extracted three times with 30 ml ethyl ether and extracts were combined and dried over 25 g Na_2SO_4. The extract was concentrated by rotary evaporation, and then under a stream of dry N_2 after transfer to a 1-dram vial.

The phenol extract was analyzed by GC-MSD equipped with a 30 m x 0.25 mm DB-5 capillary column for phenol, C_1-phenols, C_2-phenols, C_3-phenols, and C_4-phenols. The instrumental conditions and temperature program were the same as those used for the hydrocarbon analyses. The phenol compounds were quantified relative to the internal standard, d_8p-cresol, and the response factors were generated from standards of each of the phenol groups.

2.1.4.1.6 Analysis of f_3 (Polar) Fraction. The (f_3) fraction of the produced water extracts was initially screened by GC/FID. From the screening results, it was apparent that a derivatization procedure would be necessary before the polar compounds could be chromatographed. The acid fraction was then derivatized with Regisil (N,O-Bis(trimethylsilyl) trifluoro-acetamide) to form trimethylsilyl esters of the acids. However, this derivatization agent did not completely derivatize the sample. A stronger methylating reagent (boron trifluoride in 14 percent methanol) was used to derivatize the f_3 fraction. Both underivatized and BF_3-derivatized extracts were analyzed by GC/MSD. An attempt was made to identify the major peaks on the chromatograms by comparison of mass spectra with those in the Hewlett Packard NBS computer library.

2.1.4.1.7 Analysis of Volatile Hydrocarbons. Volatile hydrocarbons from methane to C_3-benzenes were determined by A.E. Nevissi at the School of Fisheries, University of Washington. The head-space extraction method described by McAuliffe (1974) was used to partition the hydrocarbons from the produced water samples. Gas chromatography with a flame ionization detector (GC-FID) was used to separate and quantify the volatile constituents. Identifications were made based on relative retention indices of known standard mixtures of hydrocarbons.

2.1.4.1.8 Analysis of Volatile Organic Compounds. Produced water samples were analyzed by EPA Method No. 624 (Federal Register, 1984) for the priority pollutants listed in Table 2.6. The method involves headspace stripping of water (purge) and trapping of the volatile compounds on a solid adsorbent (trap)

TABLE 2.6. COMPOUNDS DETERMINED IN PRODUCED WATER SAMPLES BY EPA METHOD NO. 624 (VOLATILE ORGANIC ANALYSIS).

Compound
Chloromethane
Bromomethane
Vinyl Chloride
Chloroethane
Methylene Chloride
1,1-dichloroethylene
1,1-dichloroethane
Trans-1,2-dichloroethylene
Chloroform
1,2-dichloroethane
1,1,1-trichloroethane
Carbon Tetrachloride
Bromodichloromethane
Acrylonitrile
Acrolein
1,2-dichloropropane
Trans-1,3-dichloropropene
Trichloroethylene
Chlorodibromomethane
1,1,2-trichloroethane
Benzene
Cis-1,3-dichloropropene
2-chloroethylvinyl Ether
Bromoform
1,1,2,2-tetrachloroethane
Tetrachloroethylene
Toluene
Chlorobenzene
Ethylbenzene
Total Xylenes
Acetone
Carbon Disulfide
2-Butanone (MEK)
Vinyl Acetate
2-Hexanone (MPK)
4-Methyl-2-pentanone (MIBK)
Styrene

of Tenax and activated charcoal, with subsequent thermal desorption and quantitative analysis by gas chromatography/mass spectrometry (GC/MS). Analysis was conducted by GCA Corporation, Bedford, Massachusetts.

2.1.4.1.9 Analysis of Total Organic Carbon. Total organic carbon (TOC) determinations were by the procedures of Menzel and Vaccaro (1964) as modified by Mills and Quinn (1979). Briefly, the procedure involved acidification of the sample to remove inorganic carbon followed by mild oxidation of the sample to convert organic carbon to carbon dioxide. The amount of carbon dioxide produced from the oxidation was determined with an infrared gas analyzer. The analyses were performed by ERCO/ENSECO, Cambridge, Massachusetts.

2.1.4.1.10 Analysis of Metals. The high concentration of magnesium and salt in the produced water prohibited the use of routine extraction procedures in determining metals in produced waters. An alternate method using coprecipitation (Buchanan and Hannaker, 1984) was found to work and was applied to determine metal concentrations in the composite produced water samples.

The high level of magnesium naturally present in the brine was used to coprecipitate the other metals in the solution. This was accomplished by adding a 5 percent APDC chelate solution (ammonium 1-pyrrolidine dithiocarbamate) and then adjusting the pH of the sample to between 8 and 9 with Ultrex NH_4OH. The sample was shaken and the resulting precipitate was filtered through a precleaned 0.4-μm Nucleopore filter. The precipitate was then redissolved in a heated water bath with a dilute acid solution. Samples were then analyzed with a Zeeman graphite furnace atomic absorption spectrophotometer (Zeeman AAS).

Concentrations of the metals cadmium, chromium, copper, lead, nickel, and silver, were determined by the method of standard additions to avoid problems with interferences. Each sample was divided into three aliquots, two of which were spiked at different concentrations prior to coprecipitation. The instrument absorbance value of the sample was plotted on a graph against the known concentrations of the spiked aliquots. From the curve of plotted data, the metal concentration of the unspiked sample was determined.

The remaining metals, barium, mercury, and zinc, were determined by the following methods. Barium was determined by neutron activation at North Carolina State Nuclear Services Laboratory. For mercury analysis, an aliquot of the composite sample was poured into a Teflon bottle for concentration and analysis by cold vapor AAS. Zinc was determined by direct injection on the AAS without performing the coprecipitation preparation step. The method of standard additions was performed on the composite sample to determine zinc concentrations.

2.1.4.2. Analysis of Sediment Grain Size

Replicate sediment samples for both chemical and benthic infaunal analysis (three replicates for chemistry and three of the six replicates collected for biology at each station) from the spring survey were analyzed for sediment grain size. Sediment grain size was analyzed in three chemistry samples from each of the four stations analyzed from the fall cruise. In addition, sediment grain size was measured in one replicate from each of the additional four stations sampled but not analyzed in the fall survey. Sediment grain size was determined by the procedures described in Folk (1974). Homogenized sediment samples were wet-sieved after agitation in a dispersant to separate the gravel/sand and silt/clay fractions. The gravel/sand fraction was further separated by dry sieving, and the silt/clay fraction was fractionated by wet pipette analysis. Phi sizes from <1 through >10 were determined and reported as percent dry weight. Sediment fractions of gravel, sand, silt, clay, and silt plus clay were also calculated.

2.1.4.3 Analysis of Chemicals in Sediments

Samples from the spring survey were analyzed for the analytes listed in Table 2.7. Each replicate sample was analyzed for total hydrocarbons, selected individual n-alkanes, selected PAHs, total organic carbon, and selected trace metals. Samples along one transect at each platform (Stations 1-4) were analyzed for steranes and triterpanes. Phenols were analyzed in samples from the 20-m stations at each platform (Stations 1, 5, 9, and 13).

For the fall survey, samples from Stations 1, 2, 3, and 4 at Eugene Island and Stations 1, 13, 14, and 15 at Lake Pelto were selected for analysis of PAHs and the metals barium, nickel, and mercury. Samples from the other four stations sampled at each platform in the fall survey were archived. The reduced list of analytes for the fall survey was selected because the results of the spring survey indicated that these analytes would be most appropriate for use in confirming trends observed in the spring survey data.

2.1.4.3.1 Sample Extraction and Column Chromatography. Sediment samples were thawed and mixed thoroughly with a spatula. Rocks, shells, and other large material were removed. A 100-g subsample was extracted and cleaned up by the ambient temperature technique described by Brown et al. (1979). The subsample was placed in a polytetrafluoroethylene tumbler jar with 100 ml of methanol, and the jar was tightly capped and shaken on a shaker platform for 30 minutes. The samples were centrifuged and the liquid phase was decanted into an Erlenmeyer flask to which was added 100 ml of a 9:1 mixture of methylene chloride and methanol. The internal standards o-terphenyl, d_8p-cresol, and 5a-androstane were added and the flask was mixed on an orbital shaker at room temperature for four hours.

TABLE 2.7. **ANALYTES** DETERMINED IN SEDIMENTS COLLECTED FROM THE STUDY SITES DURING THE SPRING SURVEY.

Grain Size

Total Hydrocarbons (Resolved and Unresolved)

n-Alkanes (C_{10} through C_{34})

Parent and Alkyl-Substituted Polycyclic Aromatic Hydrocarbons
(Naphthalenes through Perylenes)

Steranes and Triterpanes

Total Organic Carbon

Phenol and Alkyl-Substituted Phenolic Compounds

Trace Metals--Ba, Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn

The sediment was reextracted two more times with methylene chloride:methanol as described above, and the extracts were combined. The sediment was then dried at 60°C, cooled, and weighed.

The combined extracts from each sample were poured into a 1000-ml separatory funnel and washed with 100 ml of 1.0N HCl. The organic phase was drained into an Erlenmeyer flask containing 50 g Na_2SO_4. The aqueous phase was washed with 50 ml of methylene chloride and then 50 ml of a 50:50 mixture of methylene chloride:ethyl ether, and the organic washes were added to the organic extract. The volume of the extract was measured and divided into two equal aliquots, one for hydrocarbon and the other for phenol analysis.

2.1.4.3.2 Analysis of Total Hydrocarbons, n-Alkanes, PAHs, Steranes, Triterpanes, and Phenols. The hydrocarbon extract was concentrated in a Kuderna-Danish flask on a 70°C water bath to approximately 1 ml. The concentrated extract was transferred to a 1-dram vial with a disposable pipet and the Kuderna-Danish flask was rinsed twice with 1 ml of methylene chloride. The rinses were added to the vial and the volume of the extract was reduced to about 1 ml with a gentle stream of purified nitrogen gas.

A subsample of the extract containing no more than 50 mg of total extractable lipid was displaced into hexane and subjected to column chromatography. The extract was reduced in volume to about 0.25 ml under a gentle stream of N_2. One ml of hexane was added to the extract and the mixture was evaporated to about 0.25 ml under N_2. This step was repeated twice.

The concentrated extract in hexane was added to a 200-ml precleaned glass column containing 1.0 g of 100 percent activated copper powder and 6.5 g 7.5 percent deactivated alumina. Twenty-three ml of 5 percent methylene chloride in hexane was added to the column and the column eluate was collected in a scintillation vial. The extract was then concentrated to about 1 ml under a gentle stream of N_2, and analyzed for alkanes and PAH with a Finnegan MAT 4530 gas chromatograph/quadrupole mass spectrometer equipped with a 30-m x 0.25-mm (i.d.) DB-5 fused silica capillary column. Conditions for analysis of these hydrocarbons are described in Section 2.1.4.1.3. The extract was also analyzed for triterpanes and steranes by the methods described in Section 2.1.4.1.4.

The extract for phenol analysis was partitioned against 1.0N NaOH twice (50 ml NaOH each). The aqueous phases were combined and acidified to a pH of approximately 1 with 24 ml 6N HCl. This mixture was then extracted three times with ethyl ether (30 ml each). The combined ether extracts were dried over approximately 25 g Na_2SO_4 and concentrated to approximately 1 ml on a rotary evaporator at 35°C. The sample extract was then analyzed by GC/MSD by the methods described in Section 2.1.4.1.5.

The individual n-alkanes and PAH were quantified with the Finnegan INCOS 2300 data system. Phenols, triterpanes, and steranes were quantified by the methods described earlier (Sections 2.1.4.1.4 to 2.1.4.1.5). The total hydrocarbon concentrations (resolved and unresolved) determined by Finnegan GC/MS were calculated by summing the total resolved and total unresolved amounts of the combined alkane and aromatic extract. The total resolved concentration was quantified with the internal standard, o-terphenyl (OTP), and an average n-alkane/PAH response factor (0.9). The UCM concentrations were also calculated using OTP, but were uncorrected for response (response factor = 1.0).

<u>2.1.4.3.3 Analysis of Total Organic Carbon</u>. Total organic carbon (TOC) analyses were performed according to procedures described by Froelich (1980). Sediment samples were acidified

to remove calcium carbonate and dried before high temperature combustion with a Carlo Erba Model 1106 CHN analyzer to convert organic carbon to carbon dioxide. Global Geochemistry in Canoga Park, California conducted the analysis.

2.1.4.3.4 Analysis of Metals. The sediment samples were analyzed to determine the total concentrations of cadmium, chromium, copper, mercury, lead, nickel, silver, barium, and zinc in each sample. All metals except barium were prepared by an aqua regia digestion for analysis by flame or Zeeman AAS (Agemian and Chau, 1976). Barium was determined by neutron activation analysis at North Carolina State University.

Sediment samples were freeze-dried and homogenized. For samples from the spring survey, a 5-g sample was mixed with 5-ml aqua regia and then autoclaved overnight in a tightly closed 50-ml Teflon digestion vessel. The digestate solution was decanted into a 50-ml volumetric flask and the vessel was rinsed three times with Milli-Q water, adding each rinse to the flask. Milli-Q water was added to the flask to achieve the final volume.

For samples from the fall survey, a microwave system was used instead of the autoclave to digest the sediment samples. The microwave system is comparable to the autoclave in efficiency of digesting sediment at a great reduction in digestion time (Fisher, 1986; Lamothe et al., 1986). In all other respects, the digestion procedure was the same for the spring and fall samples.

The sediment digests, depending on the expected metal concentrations, were analyzed by either flame or Zeeman AAS. In either case, the instrument was first zeroed and then calibrated with the appropriate commercial calibration standards. The concentration range of the standards depended on the element analyzed; some metals were determined in the parts per million range, whereas others were determined in the parts per billion range. A mid-range check solution was analyzed to verify the calibration and then again after each set of ten samples. If the concentration of the check solution fell outside the plus or minus 10 percent limit of the known value of the standard, the instrument was recalibrated and the previous set of samples was reanalyzed.

<u>2.1.4.3.5 Quality Control</u>. The analysis of a procedural blank and spiked blank was included with the analysis for organic chemical analytes of each batch of twelve sediment and/or produced water samples. The procedural blank was prepared by adding the hydrocarbon and phenol internal standards, o-terphenyl, 5α-androstane, and d_8p-cresol, to extraction solvent. A procedural blank spike included a procedural blank with selected authentic n-alkanes, aromatic hydrocarbons, and phenol compounds. The spiked blank compounds included n-C_{10} through n-C_{34} alkanes, naphthalene, methylnaphthalene, biphenyl, dibenzothiophene, fluorene, phenanthrene, pyrene, chrysene, phenol, o-, m-, p-cresols, C_2-phenol, and C_3-phenol. A blank sample (distilled water) was also processed with the produced water samples analyzed by IR.

One Milli-Q water blank, one filter, and one sample container blank were analyzed with the produced water samples for all nine metals. Each produced water sample was split into three fractions; two of the fractions were spiked with trace metal standard solutions of different concentration, the third fraction was not spiked. Two blanks, one blank spike, one sample spike, one sample duplicate, and two Standard Reference Material (SRM, NBS 1646) samples were analyzed for all the selected trace metals except barium with each batch of sediment samples. A USGS Marine Mud (MAD-1) was analyzed twice for barium. The results from the analysis of the two spiked and one unspiked fractions were used to determine the trace metal concentrations of the sample.

2.1.4.4 Analysis of Benthic Infaunal Samples

2.1.4.4.1. Sample Processing. In the laboratory, each benthic sample was logged into a Battelle laboratory notebook by sample code number, number of containers per sample, and date received. Each sample was sieved through a stack of two screens: the top screen had a mesh of 0.5 mm and the bottom screen had a mesh of 0.3 mm. All samples were transferred from formalin to 80 percent ethanol at this time. The two fractions of each sample were kept separate for all subsequent handling.

Because of the large number of organisms in the samples and, therefore, the length of time needed to process them, some samples were aliquoted to 25 percent of the original sample volume before sieving through the two screens. All spring samples from Eugene Island were processed in their entirety; all fall samples from Eugene Island and both spring and fall samples from Lake Pelto were aliquoted to 25 percent. A large-volume plankton splitter was used to aliquot the samples.

Samples were stained with a saturated solution of Rose Bengal at least 4 hours prior to sorting. Because overstaining impairs the identification process, the Rose Bengal was not allowed to remain in the sample for more than one day. The excess stain was removed by rinsing the sample with fresh water and transferring it to clean 80 percent alcohol.

Samples were initially examined under a dissecting microscope. Compound microscopes were used when needed to examine fine details of the specimens. Each organism or anterior fragment was removed from the 0.5-mm fraction of each sample and sorted to major taxonomic group. Taxa were then identified, enumerated, and placed in species vials, each of which contained ethanol and labels providing collection and identification information. Organisms were not removed from the small amount of sediment residue in the 0.3-mm fractions of each sample, but were identified, enumerated, and returned to the appropriate sample jar. Only specimens to be examined under the compound microscope were actually removed from the 0.3-mm fractions. Each organism was identified to the lowest practicable taxon, usually to the species level. In some cases, designations including "spp. juvenile" or "spp. indeterminate" were used when the stage of development or condition of the specimen precluded further identification. In order to determine the number of juvenile forms in the samples, size criteria were established for a number of polychaete species. In some cases (e.g., for the dominant polychaete *Mediomastus ambiseta* and the dominant bivalve *Mulinia lateralis*), all individuals that passed through the 0.5-mm mesh screen and were found on the 0.3-mm mesh screen were considered to be juveniles. Criteria for 35 polychaete species are given in Table 2.8.

Data recorded for each species included the number of individuals found on each of the two screens (0.5-mm and 0.3-mm mesh) and the number of juveniles of each species found on each of the two screens. Data sheets were filled out for each replicate sample processed.

2.1.4.4.2. Quality Control. Quality control procedures included resorting a minimum of 10 percent of all samples sorted by each experienced technician and 100 percent of samples sorted by each new technician. If the percentage of organisms missed exceeded 5 percent, the sample failed the quality control check. Additional samples sorted both prior and subsequent to the failed sample were also checked until the percentage of organisms missed was below 5 percent in five consecutive samples. When this requirement was met, the number of samples checked was reduced to 1 in 10.

In order to assure that the aliquoting procedure resulted in representative fractions, the four aliquots of each of four samples were processed and the counts of the dominant species in

TABLE 2.8. SIZE CRITERIA ESTABLISHED FOR THE DETERMINATION OF JUVENILES OF 35 POLYCHAETE SPECIES.

Species[a]	Criterion
Ancistrosyllis jonesi and *A. papillosa*	Width of setiger 10 < 0.5 mm
Apopronospio pygmaea	Width of setiger 7 < 0.5 mm
Aricidea taylori	Width of setiger 15 < 0.3 mm
Cirriformia sp. 1	Width of anterior peristomium < 0.4 mm
Clymenella torquata	Width across setiger 2 < 0.5 mm
Cossura delta	Width of seiger 5 < 0.3 mm
Diopatra sp. 1	Five or fewer pairs of branchiae
Eumida sanguinea	Width of ventrum of setiger 10 < 0.5 mm
Glycinde solitaria	Width of setiger 10 (excluding parapodia) < 0.4 mm
Gyptis brevipalpa and *G. vittata*	Width of setiger 4 (excluding dorsal cirri) < 0.5 mm.
Lumbrineris verrilli	Width of setiger 8 < 0.4 mm
Maldanidae sp. 1	Width of setiger 5 < 0.5 mm
Magelona sp. 1	Width of setiger 4 < 0.3 mm
Mediomastus ambiseta	All specimens passing through 0.5-mm mesh
Melinna maculata	Width across segment 7 < 0.6 mm
Myriowenia sp. 1	Width of setiger 4 < 0.5 mm
Neanthes micromma	Width of setiger 5 (excluding parapodia) < 0.7 mm
Neanthes succinea	Width of setiger 5 (excluding parapodia) < 0.75 mm
Owenia sp. 1	Width of setiger 4 < 0.3 mm
Paramphinome sp. 1	Width of setiger 4 < 0.75 mm
Paraprionospio pinnata	Width of setiger 4 < 0.5 mm
Polydora socialis	Width across setiger 7 < 0.6 mm
Prionospio cristata	Width of setiger 8 < 0.4 mm
Prionospio perkinsi	Total length < 4.0 mm
Sabellides sp. 1	Total length (excluding gills) < 1.75 mm
Scolelepis texana	Width of setiger 10 (neuropodium) < 0.5 mm
Scoloplos sp. 1	Width of setiger 10 < 0.5 mm
Sigambra tentaculata	Width of setiger 2 < 0.5 mm
Spiochaetopterus costarum	Width across ventrum of setiger 7 < 0.4 mm
Spiophanes bombyx	Width of setiger 5 < 0.5 mm
Sthenelais sp. 1	Width of setiger 10 (excluding parapodia) < 0.5 mm
Streblospio benedicti	Total length < 3.0 mm
Tharyx sp. 1	Width across widest part of thorax (ca. setiger 9) < 0.4 mm

[a] Species that could not be positively identified (including new species) were designated species 1, 2, 3, etc. (e.g., species 1 in this table).

each aliquot were compared.

Species identifications of amphipods were verified by Dr. James D. Thomas of Newfound Harbor Marine Institute, Florida.

2.1.4.4.3. Data Reduction and Analysis. Each taxon was assigned a unique code number which was entered onto the data sheets. The completed data sheets were keypunched at the University of Rhode Island (URI) and the data entered into the VAX 11/750 minicomputer at Battelle. Most keypunching errors were corrected at URI using a two-operator, double keypunch system. A printout of the data was verified by the taxonomists. Before statistical analysis, the data from the fully analyzed samples from Eugene Island were rarefied to correspond to a 25 percent aliquot (Sanders, 1968). The specimens for which the species identification was uncertain (i.e., juveniles, anterior fragments) were not used for the calculation of diversity indices but were included for calculations of density and dominance. Animals attached to hard surfaces such as rocks and shells, and planktonic and parasitic species, were excluded from all analyses. The excluded species are indicated by an asterisk on the species lists presented in Tables 3.35 and 3.64.

The mean and standard deviation of the density of several dominant species were calculated. T-tests were used to compare mean densities of these species between the spring and the fall cruises. The percent contribution of juveniles to the total fauna at each station was calculated, as was the percent of juveniles for selected species.

Two diversity indices were calculated. Shannon-Wiener diversity (H′) and its associated evenness value (E) were calculated:

$$H'_{(s)} = \sum_{j} p_j \log p_j$$

where s is the total number of species and p_j is the observed proportion of individuals belonging to the jth species

$(j = 1, 2, \ldots, s)$.

The second diversity index, Hurlbert's modification (1971) of the rarefaction method (Sanders, 1968), was used to predict the number of species in a random sample, given a population N:

$$E\left[S_m/N\right] = \sum_{i=1}^{k} 1 - \frac{(N_m - N_i)}{\binom{N}{m}}$$

where N_i is the finite population of species i; N is $(n_1, N_2, \ldots\ldots, N_k)$, a vector representing the entire finite population, N is the total number of individuals in the finite population:

$$\sum_{i=1}^{k} N_i;$$

and S_m is the random variable denoting the number of species in a sample size m (Smith and Grassle, 1977). For the rarefaction analysis, the number of individuals was set at seven points: 50, 100, 250, 500, 750, 1000, and 2000 individuals.

An agglomerative clustering technique was used to determine similarity among samples. The first step in this classification involves measuring similarity between all pairwise combinations of samples, beginning with the most similar pairs, and subsequently combining samples until they all form one large group. The similarity measure used was NESS, the Normalized Expected Species Shared (Grassle and Smith, 1976), in which the comparison of expected species shared is between random samples of a set number of individuals from the initial collection of individuals in each replicate. For the present analysis, the number of individuals (m) was set at 200. The clustering strategy used was group average (Boesch, 1977).

3.0 RESULTS

3.1 CHEMICAL COMPOSITION OF PRODUCED WATER, SPRING SURVEY

Concentrations of total hydrocarbons were determined by infrared spectrophotometry in each replicate sample of produced water collected in the spring survey. The purpose of this analysis was to assess short-term variability in the hydrocarbon concentration of produced water from a single platform. Volatile hydrocarbons and other organic compounds also were analyzed in all replicates. The remainder of the three replicate samples from each platform was composited and analyzed for total organic carbon, individual alkanes and aromatics, steranes and triterpanes, phenols, naphthenic acids, and nine metals (Ag, Ba, Cd, Cr, Cu, Pb, Hg, Ni, and Zn). Results of these analyses are described separately in the sections that follow.

3.1.1 Quality Control

Some of the procedural blanks analyzed for organic constituents contained detectable amounts of alkanes and aromatic hydrocarbons. However, the concentrations of n-alkanes and PAHs of interest in these blanks were negligible and did not contribute to the hydrocarbon levels found in the sediment and produced water samples. Phenol was present in all procedural blanks and spiked blanks at concentrations near those found in the samples. The presence of phenol was attributed to laboratory contamination.

The recoveries of all of the individual n-alkanes in the spiked blank samples (i.e., surrogate recoveries) generally ranged between 60 and 140 percent, which is considered to be within the acceptable range. The recoveries of decane ($n\text{-}C_{10}$) and dodecane ($n\text{-}C_{12}$) occasionally dropped as low as 27 percent, which is below the acceptable range. These results indicate that the concentrations of these volatile analytes in sediment samples may be underestimated. However, analytical methods based on solvent extraction generally are not well suited for recovery of these volatile compounds. However, because of their volatility, these low molecular weight alkanes usually are not persistant in sediments and their concentrations there are generally very low unless there is a gas seep nearby.

Recoveries of the individual PAH analytes in the spiked blank samples ranged, in most cases, from 64 to 150 percent. The recoveries for naphthalene were as low as 24 percent in some spiked blank samples indicating a trend toward lower recoveries for the low boiling point analytes. The low recoveries of the relatively low boiling point compounds such as the C_{10} and C_{12} n-alkanes, and naphthalene are common for extraction methods that use solvents and evaporation/concentration steps.

With the exception of phenol (220 percent recovery), the recoveries for the phenolic compounds ranged between 85 and 130 percent. The high recovery for phenol is considered to be due to laboratory contamination.

The recoveries of the nine metals in the blank spikes, sample spikes, and SRM samples analyzed with the spring survey samples are acceptable. The results of the QC analyses for metals are summarized in Appendix F, Table F1.

The cadmium recovery of the SRM was low (36%) for only one batch of samples; for the other SRM samples (5), the recovery of cadmium ranged from 84 to 92 percent. Because the cadmium recoveries from the blank spike and sample spike were acceptable for the same batch of samples in which the low recovery SRM was determined, the batch of samples was not re-run.

Recoveries of chromium in all SRM samples were low (42 to 49 percent). The reason for the low recovery was that the selected method of digestion was not a total digestion method. Some elements, such as chromium, are part of the solid matrix of the sediment and are not as readily leached with the aqua regia treatment. Recovery results indicate, however, that the analysis is very reproducible.

Recoveries of the three metals analyzed in samples from the fall survey, barium, mercury and nickel, are also acceptable. Results of these analyses are summarized in Appendix F, Table F1. Metal concentrations in all the method blanks were below detection limits.

3.1.2 Hydrocarbons

3.1.2.1 Total Hydrocarbons by IR

The results of the analysis of total hydrocarbons in produced water by infrared spectrophotometry are summarized in Table 3.1. Produced water from Eugene Island contained a mean of about 1.5 times the concentration of total hydrocarbons found in produced water from Lake Pelto. Two of the three replicates of the Eugene Island produced water samples contained approximately the same amount of total hydrocarbons, whereas the first replicate contained about half the total hydrocarbons found in the other two replicates. The possible reason for the lower concentration of replicate 1 is that this sample was taken from a different spigot than the other two samples. The three replicate samples of produced water collected at Lake Pelto had similar total hydrocarbon concentrations (range, 23 to 27 mg/l). These very limited results indicate a limited short-term variability in the concentration of total hydrocarbons in produced water from the two platforms. Results of analyses of composited samples will thus be representative of the composition of the produced water.

Samples of produced water collected during the preliminary survey were analyzed gravimetrically for the total concentration

TABLE 3.1. RESULTS OF INFRARED SPECTROSCOPY (IR) ANALYSIS OF TOTAL HYDROCARBONS IN PRODUCED WATER FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

Station/Replicate	Concentration (mg/l)*
Eugene Island	
Replicate 1	20.05
2	48.13[a,b]
3	40.73[b]
Mean ± S.D.	36.30 ± 11.88
Lake Pelto	
Replicate 1	26.84
2	23.74
3	25.91
Mean ± S.D.	25.50 ± 1.30
Blank	4.30

*Concentrations are based on API 50° Louisiana Light Crude Oil.

[a] Eugene Island Replicate 2 4-ml aliquot was diluted to 8 ml due to an off-scale response of this sample.

[b] Samples taken from a different spigot than the sample in Replicate 1.

of organic compounds extractable with methylene chloride. Concentrations of total extractable organics were 56 mg/l and 29 mg/l for produced water from Eugene Island and Lake Pelto, respectively. These values compare closely with maximum total hydrocarbon concentrations determined by IR of 45 mg/l and 27 mg/l, respectively, reported here for samples from the spring survey.

3.1.2.2 Total Saturated (f_1) and Aromatic (f_2) Hydrocarbons by GC

The concentrations of saturated and aromatic hydrocarbons, as determined by GC-MSD analysis of the f_1 and f_2 fractions, were calculated for the composite samples of produced water from Eugene Island and Lake Pelto. These concentrations and the percent of each fraction that was resolvable by GC (i.e., quantifiable peaks) are presented in Table 3.2.

The concentration of saturates and aromatics combined (total hydrocarbons) in the Eugene Island sample (31 mg/l) is approximately 30 percent higher than that in the Lake Pelto sample (20 mg/l). These values are in good agreement with the values for total hydrocarbon concentrations determined by IR. The percent aromatics in the Eugene Island produced water is about 10 percent of the total hydrocarbons, whereas Lake Pelto produced water has a higher percentage of aromatics at 20 percent. The percent resolvable saturates and aromatics is less than 50 percent in produced water from both platforms, with Eugene Island produced water having more resolvable hydrocarbons in both fractions than Lake Pelto produced water.

3.1.2.3 Individual n-Alkanes (C_{10} through C_{34})

The results of analysis of individual n-alkane concentrations in composite samples of produced water from Eugene Island and Lake Pelto are summarized in Table 3.3. The total concentration of

TABLE 3.2 CONCENTRATIONS OF TOTAL SATURATES (f_1) AND AROMATICS (f_2) (AND PERCENT RESOLVED HYDROCARBONS) IN PRODUCED WATERS COLLECTED DURING SPRING SURVEY.

Analyte	**Eugene Island**	**Lake Pelto**
Total Saturates (f_1)	28.4 mg/l	17.1 mg/l
Percent Resolved Saturates	30	23
Total Aromatics (f_2)	2.5 mg/l	3.3 mg/l
Percent Resolved Aromatics	47	38
Total Hydrocarbons ($f_1 + f_2$)	30.9 mg/l	20.4 mg/l

TABLE 3.3. CONCENTRATIONS OF n-ALKANES IN PRODUCED WATER SAMPLES FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

Compound	Concentration (µg/l) Eugene Island	Concentration (µg/l) Lake Pelto
Decane (C_{10})	19.3	14.1
Undecane (C_{11})	93.1	29.5
Dodecane (C_{12})	193	43.7
Tridecane (C_{13})	272	54.6
Tetradecane (C_{14})	308	56.2
Pentadecane (C_{15})	266	57.2
Hexadecane (C_{16})	177	54.9
Heptadecane (C_{17})	142	56.1
Octadecane (C_{18})	215	33.4
Nonadecane (C_{19})	180	38.3
Eicosane (C_{20})	171	35.6
Heneicosane (C_{21})	123	29.5
Docosane (C_{22})	107	24.7
Tricosane (C_{23})	85.2	21.7
Tetracosane (C_{24})	69.2	19.8
Pentacosane (C_{25})	56.7	18.5
Hexacosane (C_{26})	50.5	16.4
Heptacosane (C_{27})	39.8	11.5
Octacosane (C_{28})	29.9	9.71
Nonacosane (C_{29})	25.7	8.02
Triacontane (C_{30})	18.7	6.36
Hentriacontane (C_{31})	17.5	6.56
Dotriacontane (C_{32})	10.6	4.26
Tetratriacontane (C_{34})	6.57	2.18
TOTAL	2677	606

n-alkanes in the Eugene Island sample (2700 µg/l) is 4.5 times higher than the n-alkane concentration of the Lake Pelto sample (600 µg/l). The C_{10} through C_{34} n-alkanes quantified in produced water from Eugene Island account for 31 percent of the total resolvable saturates (f_1) in the sample, whereas the C_{10} through C_{34} n-alkanes account for only 15 percent of the total resolvable saturates in produced water from Lake Pelto. The remainder of resolvable saturates in the f_1 fraction probably includes a wide variety of branched and cyclic alkanes. In both samples, concentrations of individual n-alkanes increase to a maximum at the C_{14} or C_{15} alkane and then gradually decrease with increasing chain length to C_{34}. Only 25 percent of the n-alkanes quantified in either sample of produced water is represented by the higher molecular weight C_{21} through C_{34} n-alkanes. This alkane composition of produced water is undoubtedly due to the fact that solubility of n-alkanes decreases logarithmically as chain length increases (McAuliffe, 1966), and most crude oils contain a predominance of low over high molecular weight n-alkanes.

3.1.2.4 Individual PAHs

Table 3.4 summarizes the concentrations of parent and alkyl-substituted aromatic hydrocarbons from benzene (1 ring) through perylene (5 rings) in composite samples of produced water from Eugene Island and Lake Pelto. The distribution and concentrations of the PAHs in produced water from the two sites are quite different. Produced water from Eugene Island contains fewer aromatic hydrocarbons at lower concentrations than produced water from Lake Pelto. The total concentration of the PAHs identified and quantified in produced water from Eugene Island is 148 µg/l, compared to a concentration of 204 µg/l in produced water from Lake Pelto. This concentration difference is small and is due mainly to differences in concentrations of phenanthrenes in the two samples. We would not expect it to be reflected in differences in the concentrations of total resolved

TABLE 3.4. CONCENTRATIONS OF AROMATIC HYDROCARBONS IN PRODUCED WATER SAMPLES FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

Compound	Concentration (µg/l)	
	Eugene Island	Lake Pelto
Benzene	-	-
C_1-B	-	-
C_2-B	25.8	24.1
C_3-B	31.5	25.4
C_4-B	9.54	11.6
C_5-B	0.72	0.90
C_6-B	0.0	0.19
Naphthalene	9.64	13.9
C_1-N	18.4	22.5
C_2-N	26.7	36.0
C_3-N	15.1	18.9
C_4-N	3.69	4.31
C_5-N	0.0	0.0
Biphenyl	2.08	1.75
C_1-BL	0.26	0.26
C_2-BL	0.10	0.10
C_3-BL	0.04	0.01
C_4-BL	0.0	0.0
C_5-BL	0.0	0.0
Dibenzothiophene	1.02	0.56
C_1-D	0.20	1.91
C_2-D	0.0	1.15
C_3-D	0.04	0.98
C_4-D	0.004	0.21
C_5-D	0.0	0.0
Fluorene	0.17	1.98
C_1-F	0.31	2.81
C_2-F	0.27	3.89
C_3-F	0.0	2.12
C_4-F	0.0	0.51
C_5-F	0.0	0.0
Phenanthrene	0.85	4.34
C_1-P	0.37	3.75
C_2-P	0.44	10.1
C_3-P	0.26	4.16
C_4-P	0.0	0.0
C_5-P	0.0	0.0
Pyrene	0.0	0.23
C_1-PY	0.0	0.62
C_2-PY	0.0	0.74
C_3-PY	0.0	0.87
C_4-PY	0.0	0.49
C_5-PY	0.0	0.0
Chrysene	0.0	0.33
C_1-C	0.0	0.92
C_2-C	0.0	0.73
C_3-C	0.0	0.26
C_4-C	0.0	0.017
C_5-C	0.0	0.0
Perylene	0.0	0.48
C_1-PL	0.0	0.085
C_2-PL	0.0	0.023
C_3-PL	0.0	0.0
C_4-PL	0.0	0.0
C_5-PL	0.0	0.0
TOTAL	148	204

aromatic hydrocarbons in produced water from the two sites (Table 3.2). Concentrations of total resolved aromatics in produced water from both platforms are about 1.2 mg/l. The individual PAHs identified and quantified in produced water from Eugene Island and Lake Pelto account for 13 and 18 percent, respectively, of the total resolvable aromatics in the samples.

Each of the homologous series quantified (Table 3.4) is present in the produced water from Lake Pelto. The sample of Eugene Island produced water, however, does not contain quantifiable concentrations of the 4- and 5-ring PAHs (pyrene, chrysene, and perylene). For produced water from both sites, the homologous series that is present at the highest concentration is the naphthalenes; the total naphthalenes concentrations in Eugene Island and Lake Pelto produced water samples are 74 μg/l and 96 μg/l, respectively.

The distribution of concentrations of individual alkyl homologues within each of the homologous series in the Lake Pelto sample shows the trend of increasing concentration from the parent compound to a maximum at the C_1-alkyl or C_2-alkyl substituted homologue. This trend in homologue distribution is expected for petroleum. The PAH and n-alkane data strongly indicate that particulate crude oil is present in the produced water, particularly the sample from Lake Pelto, in which the 3-, 4-, and 5- ring aromatics are present.

3.1.2.5 Volatile Hydrocarbons

The major volatile hydrocarbons, including methane through trimethylbenzene, were determined in two of the three replicate samples of produced water from each platform. Replicates were analyzed individually because compositing would have caused the loss of volatile analytes during mixing. The third sample from each platform was analyzed for volatile organics, including the major low molecular weight priority pollutants (see Section

3.1.3.2, Volatile Organic Compounds). The results of the analysis of volatile hydrocarbons in produced water samples from both platforms are summarized in Table 3.5.

The mean concentration of total volatile hydrocarbons (excluding the unidentified peak) in samples of produced water from Eugene Island (approximately 11 mg/l) is 2 to 2.5 times higher than the concentration of total volatile hydrocarbons in produced water samples from Lake Pelto (4.8 to 6.2 mg/l). The difference is attributable to the higher concentration of volatile aromatic compounds in produced water from Eugene Island. The volatile aromatic hydrocarbons accounted for more than 90 percent of the total volatile hydrocarbons, other than the gaseous hydrocarbons, methane, ethane and propane, in the samples of produced water from both platforms. Benzene and toluene were the most abundant hydrocarbons present in the samples. The volatile hydrocarbon composition of these samples is similar to those reported for other samples of produced water (Lysyj, 1982; Sauer, 1981). The variance in results for the replicate analyses was no greater than about 25 percent for the major volatile hydrocarbons. The unidentified peak possibly represents a ketone-type compound; some ketones were found in samples analyzed for volatile organic compounds (Section 3.1.3.2).

The concentrations of total volatile aromatics (benzene, toluene, xylenes, and others) in the Eugene Island and Lake Pelto samples of produced water are greater than the concentrations of total extractable (f_2) aromatics (Table 3.2) and total resolved semivolatile aromatic hydrocarbons (Table 3.4). The relative abundance of different aromatic hydrocarbons in produced water is related in part to the inverse relationship between the aqueous solubility of aromatic hydrocarbons in water and hydrocarbon molecular weight (Neff, 1979). Thus, water (such as produced water) that has been allowed to equilibrate with petroleum will tend to become enriched in the lower

TABLE 3.5. CONCENTRATIONS OF VOLATILE HYDROCARBONS IN PRODUCED WATER FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

	Concentration (µg/l)			
	Eugene Island		Lake Pelto	
Component	Replicate 2	Replicate 3	Replicate 1	Replicate 3
Methane	396	449	663	670
Ethane	215	238	427	510
Propane	175	204	370	476
Isobutane	67	74	79	108
n-Butane	59	62	83	101
Isopentane	40	37	32	37
n-Pentane	16	14	14	15
Unidentified Peak*	1420	685	471	1557
2,2-Dimethylbutane	ND	ND	ND	ND
Cyclopentane+2-Methylpentane	35	31	32	39
3-Methylpentane	10	7	6	8
n-Hexane	10	7	6	6
Methylcyclopentane	20	18	24	25
Benzene	5979	6770	1493	1545
Cyclohexane	ND	ND	79	86
n-Heptane	ND	ND	16	16
Methylcyclohexane	29	26	28	27
Toluene	2050	2246	669	681
Octanes or Cycloheptanes	8	ND	6	6
Octanes or Cycloheptanes	5	5	3	3
Octanes or Cycloheptanes	2	3	4	5
Octanes or Cycloheptanes	2	ND	ND	ND
Octanes or Cycloheptanes	2	1	3	3
Ethylbenzene	37	34	52	48
m-,p-xylene	307	280	123	112
o-Xylene	195	180	91	81
Isopropylbenzene	4	4	8	5
C_3 Benzenes**	ND	1	3	1
o-Methylethylbenzene	81	16	17	21
1,2,4-Trimethylbenzene	12	4	ND	3
1,2,3-Trimethylbenzene	26	19	20	13
TOTALS	**11202**	**11415**	**4822**	**6208**

*The unidentified peak concentration calculation is based on the response factors for n-pentane and 2,2-dimethylbutane.

**n-Propylbenzene; m-,p-methylethylbenzene; and 1,3,5-trimethylbenzene.

ND = Not Detected.

molecular weight, more soluble aromatic hydrocarbons relative to the higher molecular weight hydrocarbons and the relative composition of the petroleum. However, a majority of the saturates and the 4- and 5-ring aromatics in the produced water samples are undoubtedly present as particulate oil.

3.1.2.6 Steranes and Triterpanes

Steranes and triterpanes are polycyclic alkanes that are derived from the diagenesis of plant materials. They are indigenous to petroleum oils, but also are present in other diagenic biological materials. The distribution of individual steranes and triterpanes in oil usually is characteristic of the formation from which the oil was produced. Because these compounds are relatively resistant to biodegradation (Seifert and Moldowan, 1979), their distribution in the environment may indicate the presence and sources of petroleum; that is, they can serve as "biomarkers" of petroleum.

The major purpose for analyzing steranes and triterpanes in produced water in this study was to evaluate their usefulness as tracers of the fate of produced water chemicals in sediments around the platforms. The distribution of the biomarkers in the produced water was compared to the biomarker distribution in sediments. The comparison between the source and surrounding sediments is subjective in this study, based on visual comparison of chromatogram patterns and the values for selected concentration ratios of different homologues.

The biomarkers, C_{27} to C_{29} steranes and triterpanes, were analyzed in composite samples from each of the platforms. The major peaks were identified and the ratios of selected compounds were calculated. Mass ion chromatograms of steranes (m/e-217) and triterpanes (m/e-191) for the sample of produced water from Eugene Island are shown in Figures 3.1 and 3.2, respectively. Chromatograms from the the Lake Pelto sample are shown in

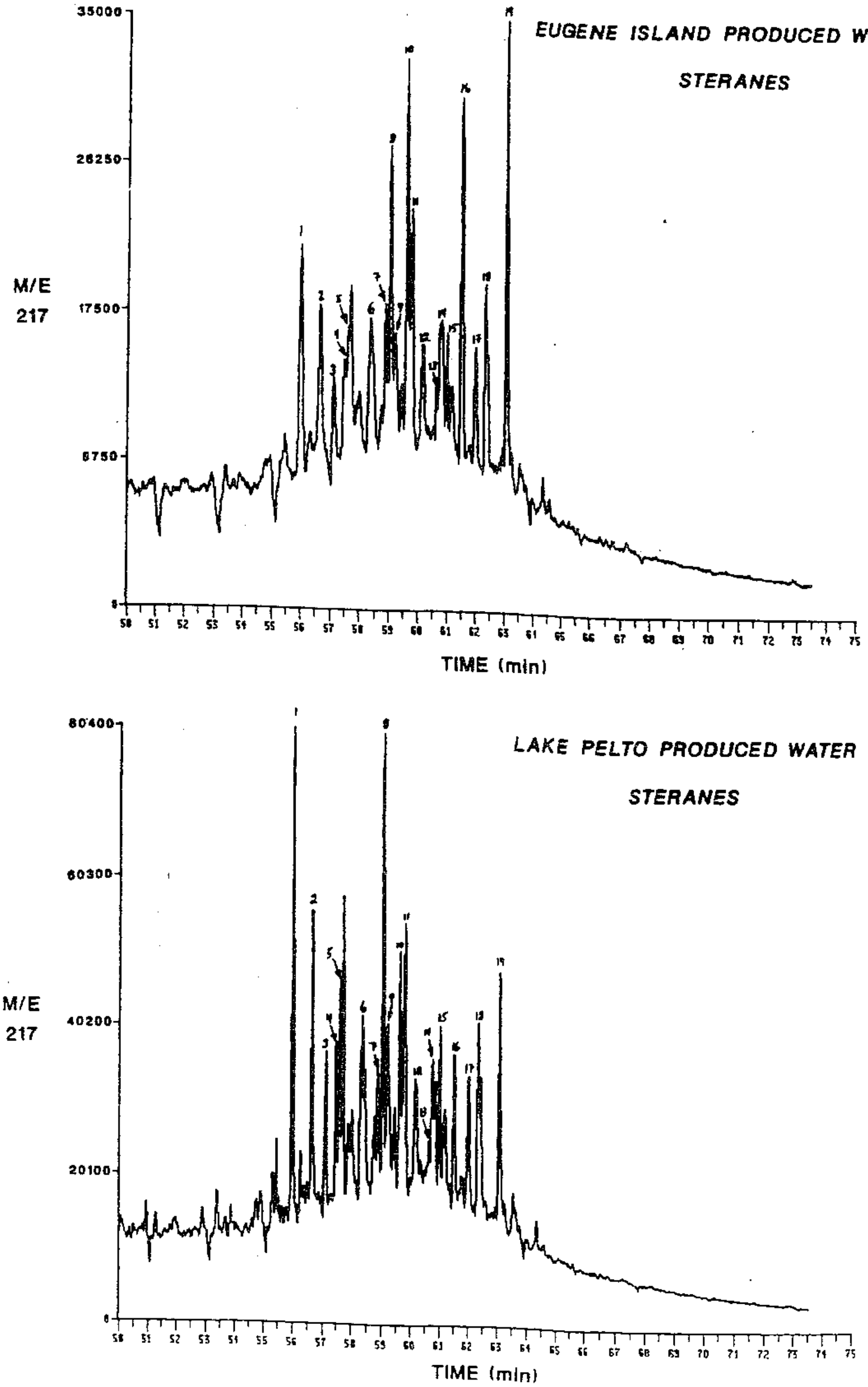
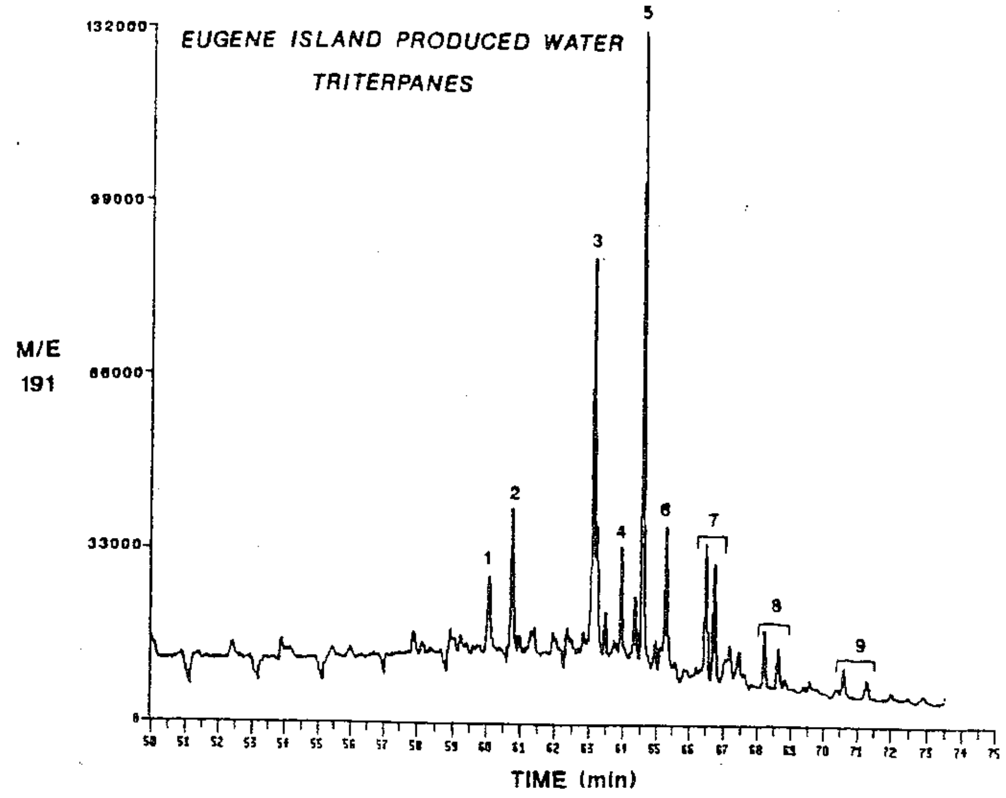


FIGURE 3.1. MASS ION CHROMATOGRAM OF STERANES (m/e - 217) IN A COMPOSITE SAMPLE OF PRODUCED WATER COLLECTED AT EUGENE ISLAND (TOP) AND LAKE PELTO (BOTTOM) DURING THE SPRING SURVEY.



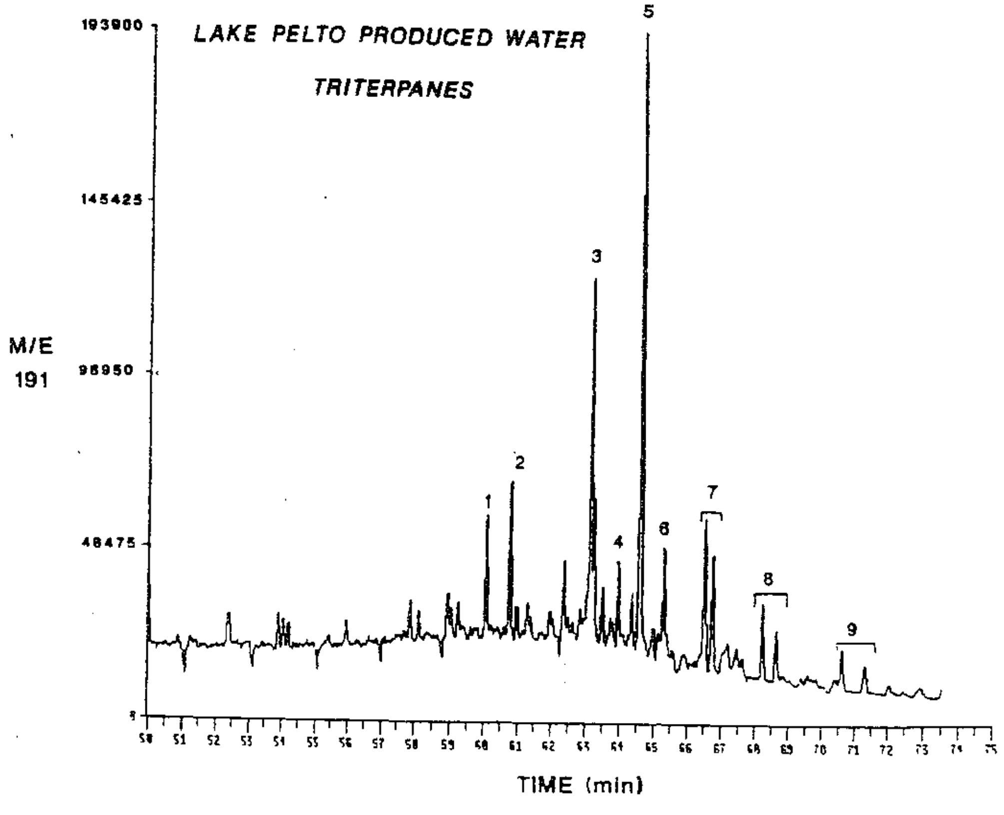


FIGURE 3.2. MASS ION CHROMATOGRAM OF TRITERPANES (m/e - 191) IN A COMPOSITE SAMPLE OF PRODUCED WATER COLLECTED AT EUGENE ISLAND (TOP) AND LAKE PELTO (BOTTOM) DURING THE SPRING SURVEY.

Figures 3.1 and 3.2. The numbered peaks in the figures are identified in Tables 3.6 and 3.7. Ratios of concentrations of selected pairs of steranes and triterpanes are summarized in Tables 3.8 and 3.9.

Based on the internal standard, 5α androstane, the concentrations of total steranes (i.e., the total m/e-217) in Eugene Island and Lake Pelto produced water are estimated to be 60 μg/l and 90 μg/l, respectively. The concentrations of triterpanes (i.e., the total m/e-191) in produced water from Eugene Island and Lake Pelto are estimated to be 75 μg/l and 80 μg/l, respectively. The distributions of individual steranes in produced water from Eugene Island and Lake Pelto, as indicated by the ion chromatograms (Figure 3.1), are distinctly different, with C_{27} steranes (peak numbers 1-4 and 7-10 in Figure 3.1) more abundant in the Lake Pelto produced water than in Eugene Island produced water. The distribution of triterpanes in produced water from the two platforms is similar. However, there are slight differences between the two samples in the abundance of the C_{30} moretanes (peak 6) relative to the C_{31} homohopanes (peak 7) (Figure 3.2). The ratios of 1.2 and 1.3 for the 22S/22R C_{31} hopanes in produced water from Eugene Island and Lake Pelto, respectively (Table 3.8 and 3.9), indicate a significant level of maturity in the source oil in both samples of produced water (Seifert and Moldowan, 1981). The steranes and triterpanes in produced water probably are associated with particulate oil droplets, because these compounds have a very low water solubility.

3.1.3 Other Organic Constituents

3.1.3.1 Volatile Organic Compounds

To identify some of the other types of compounds in produced water, one sample from each platform was analyzed by a standard priority pollutant method for all major volatile organic

TABLE 3.6. STERANE IDENTIFICATIONS CORRESPONDING TO PEAK NUMBERS IN FIGURES.

Peak No.	Abbreviated Notation	Empirical Formula	Molecular Weight	Compound
1	$C_{27}\beta,\alpha(S)$	$C_{27}H_{48}$	372	13β(H), 17α(H)-diacholestane (20S)
2	$C_{27}\beta,\alpha(R)$	$C_{27}H_{48}$	372	13β(H), 17α(H)-diacholestane (20R)
3	$C_{27}\alpha,\beta(S)$	$C_{27}H_{48}$	372	13α(H), 17β(H)-diacholestane (20S)
4	$C_{27}\alpha,\beta(R)$	$C_{27}H_{48}$	372	13α(H), 17β(H)-diacholestane (20R)
5	$C_{28}\beta,\alpha(S)$	$C_{28}H_{50}$	386	24-methyl-13β(H), 17α(H)-diacholestane (20S)
6	$C_{28}\beta,\alpha(R)$	$C_{28}H_{50}$	386	24-methyl-13β(H), 17α(H)-diacholestane (20R)
7	$C_{27}\alpha,\alpha(S)$ + $C_{28}\alpha,\beta(S)$	$C_{27}H_{48}$ $C_{28}H_{50}$	372 386	14α(H), 17α(H)-cholestane (20S) + 24-methyl-13α(H), 17β(H)-diacholestane (20S)
8	$C_{27}\beta,\beta(R)$ + $C_{29}\beta,\alpha(S)$	$C_{27}H_{48}$ $C_{29}H_{52}$	372 400	14β(H), 17β(H)-cholestane (20R) + 24-ethyl-13β(H), 17α(H)-diacholestane (20S)
9	$C_{27}\beta,\beta(S)$ + $C_{28}\alpha,\beta(R)$	$C_{27}H_{48}$ $C_{28}H_{50}$	372 386	14β(H)-cholestane (20S) + 24-methyl-13α(H), 17β(H)-diacholestane (20R)
10	$C_{27}\alpha,\alpha(R)$	$C_{27}H_{48}$	372	14α(H), 17α(H)-cholestane (20R)
11	$C_{29}\beta,\alpha(R)$	$C_{29}H_{52}$	400	24-ethyl-13β(H), 17α(H)-diacholestane (20R)
12	$C_{29}\alpha,\beta(S)$	$C_{29}H_{52}$	400	24-ethyl-13α(H), 17β(H)-diacholestane (20S)
13	$C_{28}\alpha,\alpha(S)$	$C_{28}H_{50}$	386	24-methyl 14α(H), 17α(H)-cholestane (20S)
14	$C_{28}\beta,\beta(R)$ + $C_{29}\alpha,\beta(R)$	$C_{28}H_{50}$ $C_{29}H_{52}$	386 400	24-methyl-14β(H), 17β(H)-cholestane (20R) + 24-ethyl-13α(H), 17β(H)-diacholestane (20R)
15	$C_{28}\beta,\beta(S)$	$C_{28}H_{50}$	386	24-methyl-14β(H), 17β(H)-cholestane (20S)
16	$C_{28}\alpha,\alpha(R)$	$C_{28}H_{50}$	386	24-methyl-14α(H), 17α(H)-cholestane (20R)
17	$C_{29}\alpha,\alpha(S)$	$C_{29}H_{52}$	400	24-ethyl-14α(H), 17α(H)-cholestane (20S)
18	$C_{29}\beta,\beta(R+S)$	$C_{29}H_{52}$	400	24-ethyl-14β(H), 17β(H)-cholestane (20R+20S)
19	$C_{29}\alpha,\alpha(R)$	$C_{29}H_{52}$	400	24-ethyl-14α(H), 17α(H)-cholestane (20R)

TABLE 3.7. TRITERPANE IDENTIFICATIONS CORRESPONDING TO PEAK NUMBERS IN FIGURES.

Peak No.	Abbreviated Notation	Empirical Formula	Molecular Weight	Compound
1	$C_{27}\alpha(T_s)$	$C_{27}H_{46}$	370	18α(H)-22,29,30-trisnorneohopane
2	$C_{27}\alpha(T_m)$	$C_{27}H_{46}$	370	17α(H)-22,29,30-trisnorhopane
3	$C_{29}\alpha,\beta$	$C_{29}H_{50}$	398	17α(H),21β(H)-30-norhopane
4	$C_{29}\beta,\alpha$	$C_{29}H_{50}$	398	17β(H),21α(H)-30-normoretane
5	$C_{30}\alpha,\beta$	$C_{30}H_{52}$	412	17α(H), 21β(H)-hopane
6	$C_{30}\beta,\alpha$	$C_{30}H_{52}$	412	17β(H), 21α(H)-moretane
7	$C_{31}\alpha,\beta$	$C_{31}H_{54}$	426	17α(H), 21β(H)-30-homohopanes (22S + 2
8	$C_{32}\alpha,\beta$	$C_{32}H_{56}$	440	17α(H), 21β(H)-30,31-bishomohopanes (22S + 22R)
9	$C_{33}\alpha,\beta$	$C_{33}H_{58}$	454	17β(H), 21β(H)-30,31,32-trishomohopane (22S + 22R)

TABLE 3.8. RATIOS OF SELECTED STERANES AND TRITERPANES IN PRODUCED WATER AND SEDIMENTS AT EUGENE ISLAND DURING THE SPRING SURVEY.

	Steranes 20S/20R $C_{29}\alpha,\alpha$ Cholestane	Triterpanes 22S/22R C_{31}Hopanes 'Maturity Ratio'
Produced Water	0.17	1.2
Sediments		
Station 1	0.86	0.83
Station 2	0.85	0.83
Station 3	0.53	0.96
Station 4	0.96	0.91

TABLE 3.9. RATIOS OF STERANES AND TRITERPANES IN PRODUCED WATER AND SEDIMENTS FROM LAKE PELTO DURING THE SPRING SURVEY.

	Steranes 20S/20R $C_{29}\alpha,\alpha$ Cholestane	Triterpanes 22S/22R C_{31}Hopanes 'Maturity Ratio'
Produced Water	0.51	1.27
Sediments		
Station 1	0.75	0.80
Station 2	0.73	0.55
Station 3	0.75	0.47
Station 4	0.81	0.54

compounds, including hydrocarbons. The results of the analysis are presented in Table 3.10. The major compound class other than the aromatic hydrocarbons (i.e., benzene and toluene) found in both samples of produced water is the ketones. Of all the volatile ketones found, 2-butanone had the highest concentration (1-2 mg/l) in both samples; 2-hexanone, 3-methyl-2-butanone, and 3-hexanone were also identified. An interesting compound, tetrahydrothiophene, a saturated five-membered ring sulfur compound, was tentatively identified in produced water from Lake Pelto but not from Eugene Island. Although these non-hydrocarbon compounds are not typically found in crude oil, they have been determined in other produced water discharges (Sauer, 1981). The ketones are probably from additives used in processing the produced water in the oil/water separator before discharge.

3.1.3.2 Phenol and Alkyl Phenols

Concentrations of phenol and C_1- through C_4-alkyl phenols in composite samples of produced water from the two platforms are summarized in Table 3.11. The efficiency of recovery of phenol standards is also shown.

Produced water from Eugene Island 105 contains approximately four times more total phenols than produced water from Lake Pelto. All the phenols analyzed are present in both samples but at higher concentration in produced water from Eugene Island than from Lake Pelto. The parent compound, phenol, is the compound in this class that is present at the highest concentration in both samples. However, phenol was consistently found in our laboratory blanks at concentrations as high as 700 ug/l. The unrealistically high phenol recovery value (200 percent) indicates that there was contamination in our sample processing. None of the alkyl-substituted phenols were found in any of the laboratory blanks, however.

TABLE 3.10. CONCENTRATIONS OF VOLATILE ORGANIC (PRIORITY POLLUTANT) COMPOUNDS IN PRODUCED WATER FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

Analyte	Concentration (µg/l)[a]	
	Eugene Island Replicate 1	Lake Pelto Replicate 2
Chloromethane	ND*	ND*
Bromomethane	ND*	ND*
Vinyl Chloride	ND*	ND*
Chloroethane	ND*	ND*
Trichlorofluormethane	ND	ND
1,1 Dichloroethene	ND	ND
1,1 Dichloroethane	ND	ND
Trans 1, 2-Dichloroethene	ND	ND
Chloroform	ND	ND
1,2-Dichloroethane	ND	ND
1,1,1-Trichloroethane	ND	ND
Carbon Tetrachloride	ND	ND
Bromodichloromethane	ND	ND
1,1,2,2-Tetrachloroethane	ND	ND
1,2-Dichloropropane	ND	ND
Trans-1,3 Dichloropropene	ND	ND
Trichloroethene	ND	ND
Dibromochloromethane	ND	ND
1,1,2 Trichloroethane	ND	ND
Benzene	1,300	630
Cis-1,3 Dichloropropene	ND	ND
2-Chloroethylvinylether	ND	ND
Bromoform	ND	ND
Tetrachloroethene	ND	ND
Toluene	627	285
Chlorobenzene	ND	ND
Ethylbenzene	18	37
1,3-Dichlorobenzene	ND	ND
1,2-Dichlorobenzene	ND	ND
1,4-Dichlorobenzene	ND	ND
2-Butanone	2,130	1,210
2-Hexanone	44	29
Total Xylenes	170	124
Cyclohexane[b]	7	16
Tetrahydrothiophene[b]	ND	28
3-Methyl-2-Butanone[b]	23	29
3-Hexanone[b]	11	8
Unknown Aliphatic Hydrocarbon[b]	18	13

[a] Concentration based on a comparison of the total ion area of the compound with that of the internal standard.

[b] Identification is based upon NBS library search and has not been confirmed with standards, hence these should be regarded as tentatively identified compounds.

ND*=less than 1 mg/l

ND=less than 5 µg/l

TABLE 3.11. PHENOL CONCENTRATIONS IN COMPOSITE PRODUCED WATER SAMPLES COLLECTED DURING THE SPRING SURVEY.

Phenolic Compound	Eugene Island (µg/l)	Lake Pelto (µg/l)	Standard Recovery (Percent)
Phenol	1430[a]	291[a]	220
o-Cresol	118	32.1	130
m,p-Cresols	599	146	129
C_2-Phenols	213	72.2	111
C_3-Phenols	291	88.6	85
C_4-Phenols	68.8	45.0	--
TOTAL PHENOL	**2720**	**675**	

[a] Concentrations of phenol listed here probably are substantially higher than the true concentrations in produced water as indicated by the high recovery (220%) of phenol from the spiked blank and the presence of phenol in the laboratory blanks.

3.1.3.3 Total Organic Carbon

The total organic carbon (TOC) concentrations in composite produced water samples are presented in Table 3.12. The TOC concentration in produced water from Lake Pelto is slightly higher (298 mg/l) than that in produced water from Eugene Island (222 mg/l). These TOC concentrations are almost identical to those reported in the preliminary field survey (306 and 220 mg/l, respectively) and are within the range of 57 to 624 mg/l reported by Lysyj (1982).

An estimate of the amount of volatile and nonvolatile hydrocarbons and volatile organics contributing to the total organic carbon indicates that only 20 percent of the TOC is attributable to hydrocarbons. This contribution of hydrocarbons to the total organics in produced water also was observed in the produced waters collected in the preliminary survey. As suggested in Lysyj (1982), the bulk of organic material in produced waters consists of nonvolatile, water soluble compounds. These compounds may include various organic acids such as naphthenic acids indigenous to the source oil, as well as a variety of chemicals added to the produced water during production and treatment (Middleditch, 1984).

3.1.4 Metals and Salinity

Metals that usually are substantially more abundant in produced water and/or drilling fluids or are of major environmental concern were analyzed in the composite samples of produced water from the two platforms. Concentrations of barium, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc in produced water from the two platforms are presented in Table 3.13. The table also includes the detection limits for the method of analysis, the salinity of each composite sample, and comparable data for produced water from the same platforms collected during the preliminary field survey.

TABLE 3.12. CONCENTRATIONS OF TOTAL ORGANIC CARBON IN COMPOSITE PRODUCED WATER SAMPLES FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

Station	Concentration (mg/l)
Eugene Island	222
Lake Pelto	298

TABLE 3.13. TRACE METAL CONCENTRATIONS IN COMPOSITE PRODUCED WATER SAMPLES FROM LAKE PELTO AND EUGENE ISLAND COLLECTED DURING THE SPRING SURVEY AND THE PRELIMINARY SURVEY.

Composite Sample	Trace Metals (µg/l)									Salinity (mg/g)
	Cd	Cu	Cr	Pb	Ni	Ag	Zn	Hg	Ba	
Spring Survey										
Eugene Island 105	0.32	6.36	1.11	17.90	0.40	<0.2	1220	0.06	37400	183
Lake Pelto	0.12	0.40	0.71	1.50	1.27	<0.2	125	0.07	11500	150
Detection Limits	<0.05	<0.25	<0.50	<0.25	<0.28	<0.2	<5.0	<0.00001	<500	-
Preliminary Survey										
Eugene Island 105	-	1.77	0.89	-	-	-	617	-	97000	179
Lake Pelto	-	1.38	1.41	-	-	-	156	-	31000	146

3.1.4.1 Salinity

The salinity of the Eugene Island sample is a little higher (183 ppt) than that of the Lake Pelto sample (150 ppt). These values are very similar to the values recorded for samples from the preliminary survey and are 4 to 5 times higher than the salinity of seawater (35 ppt).

3.1.4.2 Metals

Concentrations of the metals copper, lead, zinc, and barium are 4 to 10 times higher in the Eugene Island sample of produced water than in the Lake Pelto sample. Concentrations of the other metals are about the same in both samples. The concentrations of only Zn and Ba in produced water from Eugene Island are substantially higher than their concentrations in produced water from the Buccaneer platform off Galveston, Texas, but the concentrations of even these metals are well within the range encountered in produced waters from a wide variety of land and offshore sources (Neff et al., 1987).

Only four metals were analyzed in samples of produced water from the preliminary survey. In a few cases, concentrations of a metal were quite different in samples collected at different times from the same platform. Barium concentrations were 2 to 3 time higher in produced water collected from both platforms in the preliminary survey than in samples collected in the spring survey. Copper and zinc concentrations in produced water from Eugene Island were higher in samples from the spring survey than in samples from the preliminary survey. The reason for this variability is not known.

3.2 HYDROGRAPHY

3.2.1 Eugene Island, Block 105

3.2.1.1 Temperature

3.2.1.1.1 Spring Survey. Temperature was recorded one meter below the water surface and within one meter of the bottom at all stations sampled at Eugene Island in the spring survey (Table 3.14). Surface water temperatures range from 17.7°C at Station 16, 1000 m south (offshore) of the platform to 19.8°C at Stations 6, 7, and 8, 100, 300, and 1000 m, respectively, north of the platform. Temperature of the bottom water is similar to that of the surface water. The difference between the surface and bottom water temperature at any station is never greater than 0.9°C. The temperature of bottom water ranges from 17.7°C at Station 16 to 18.9°C at Stations 6, 7, and 8.

3.2.1.1.2. Fall Survey. Hydrographic parameters were measured in surface and bottom water at all eight stations at Eugene Island sampled in the fall survey (Table 3.15). Temperature of surface water ranges from 28.8°C at Station 15 to 29.8°C at Station 4. The temperature of bottom water is similar to that of surface water at all stations, and ranges from 28.8 °C at Station 15 to 29.4°C at Station 3. The largest difference in temperature of surface and bottom water at any station is 0.5°C at Station 4. At most stations, there is no difference in temperature between surface and bottom water. Water temperatures at the time of the fall survey are about 10°C higher than water temperatures at the time of the spring survey.

3.2.1.2 Salinity

3.2.1.2.1 Spring Survey. Salinity was measured at the same locations as temperature. Results are summarized in Table 3.14.

TABLE 3.14. TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN CONCENTRATIONS OF SURFACE AND BOTTOM WATER AT 16 STATIONS AROUND THE PRODUCTION PLATFORM AT EUGENE ISLAND, BLOCK 105 DURING THE SPRING SURVEY.

	Temperature(°C)		Salinity(ppt)		Dissolved Oxygen(ppm)	
Station	Surface	Bottom	Surface	Bottom	Surface	Bottom
West						
1	18.2	18.2	29.67	29.81	8.4	8.1
2	18.0	18.0	30.39	30.47	7.5	7.4
3	18.2	18.0	30.39	30.39	8.1	7.4
4	18.7	18.1	30.32	30.54	8.2	7.2
North						
5	18.1	18.1	29.67	29.74	8.4	8.1
6	19.8	18.8	29.31	30.11	8.6	7.2
7	19.8	18.9	29.16	29.96	8.0	7.2
8	19.5	18.9	28.94	29.59	7.1	6.3
East						
9	18.0	18.1	29.74	29.88	7.9	7.6
10	18.8	18.6	29.52	29.59	7.6	6.9
11	18.6	18.5	29.67	29.74	7.6	6.9
12	18.5	18.3	29.74	29.81	7.7	7.0
South						
13	18.3	18.1	29.67	29.67	8.6	8.1
14	18.3	18.1	29.67	29.74	8.3	7.8
15	18.2	18.1	29.31	29.81	8.3	8.5
16	17.7	17.7	29.31	29.96	8.7	8.6

TABLE 3.15. TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN CONCENTRATIONS OF SURFACE AND BOTTOM WATER AT EIGHT STATIONS AROUND THE PRODUCTION PLATFORM AT EUGENE ISLAND, BLOCK 105 DURING THE FALL SURVEY.

	Temperature(°C)		Salinity(ppt)		Dissolved Oxygen(ppm)	
Station	Surface	Bottom	Surface	Bottom	Surface	Bottom
West						
1	29.0	29.0	32.81	32.81	6.0	6.1
2	29.1	29.0	32.59	32.66	5.9	6.1
3	29.6	29.4	32.81	33.25	6.3	6.0
4	29.8	29.3	32.66	33.25	6.0	5.9
South						
13	29.0	29.0	32.66	32.74	6.0	6.1
14	29.0	29.0	32.52	32.52	6.1	6.1
15	28.8	28.8	33.03	33.03	6.0	6.0
16	29.3	29.3	33.10	33.47	6.1	5.9

The salinity of surface and bottom water throughout the study area is quite uniform. The salinity of surface water ranges from 28.94 parts per thousand (ppt) at Station 8 to 30.39 ppt at Stations 2 and 3. The salinity of bottom water ranges from 29.59 ppt at Stations 8 and 10 to 30. 54 ppt at Station 4. The largest difference between the salinity of surface and bottom water at any station is 0.8 ppt at Station. At most stations, the difference is less than 0.2 ppt, indicating good vertical mixing of the water column.

3.2.1.2.2 Fall Survey. Salinity also is very uniform throughout the study area (Table 3.15). The salinity of surface water ranges from 32.52 to 33.10 ppt, and that of bottom water ranges from 32.52 to 33.47 ppt. The largest difference in salinity of surface and bottom water at a station is 0.59 ppt, indicating very good vertical mixing of the water column in the study area at the time of the fall survey. Salinities are 2 to 3 ppt higher at the time of the fall survey than at the time of the spring survey.

3.2.1.3 Dissolved Oxygen Concentration

3.2.1.3.1 Spring Survey. Dissolved oxygen concentrations are uniformly high in surface and bottom waters throughout the area (Table 3.14). Dissolved oxygen concentrations in surface waters range from 7.1 ppm at Station 8 to 8.7 ppm at Station 16. Except at Station 15, concentrations of dissolved oxygen are lower in bottom water than in surface water at all stations, and range from 6.3 ppm at Station 8 to 8.6 ppm at Station 16. Thus, bottom waters of the study area are 80 to 106 percent saturated with oxygen at the ambient temperatures and salinities. Concentrations of oxygen in bottom water from the four 20-m stations range from 7.3 to 8.2 ppm, indicating that produced water discharges, which may have an elevated biological oxygen demand, are not depleting oxygen in the bottom waters of the site. The difference in dissolved oxygen concentration of surface and bottom water at all stations range from 0.1 ppm to 1.0 ppm.

3.2.1.3.2. Fall Survey. Dissolved oxygen concentrations are quite uniform throughout the study area at the time of the fall survey (Table 3.15). Concentrations of dissolved oxygen in both surface and bottom waters range from 5.9 to 6.3 ppm. These values are 92 to 95 percent of the values for the aqueous solubility of oxygen in seawater at the ambient salinities and temperatures. Bottom water at Stations 1 and 13, 20 m from the platform contain 6.1 ppm dissolved oxygen, indicating that produced water discharges are not depleting oxygen in the bottom waters of the site. Concentrations of dissolved oxygen in surface and bottom water do not differ by more than 0.3 ppm at any station. Oxygen concentrations in waters of the study area are 1 to 2 ppm lower at the time of the fall survey than at the time of the spring survey. This merely reflects the inverse relationship between water temperature and the aqueous solubility of oxygen.

3.2.2 Lake Pelto, Tank Battery No. 1

3.2.2.1 Temperature

3.2.2.1.1 Spring Survey. Values for temperature, salinity, and dissolved oxygen concentration in surface and bottom waters at all 16 stations around Lake Pelto, Tank Battery No. 1 sampled in the spring survey are summarized in Table 3.16. Surface and bottom temperatures throughout the study area range from 19.9 to 21.8°C. The largest difference in temperature of surface and bottom water at any station is 0.8°C.

3.2.2.1.2 Fall Survey. At the time of the fall survey, temperature is quite uniform at all eight stations sampled (Table 3.17). Temperature of surface and bottom water varies from 27.5 to 27.8°C. There is no difference in temperature of

TABLE 3.16. TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN CONCENTRATIONS OF SURFACE AND BOTTOM WATER AT 16 STATIONS AROUND LAKE PELTO, TANK BATTERY NO. 1 DURING THE SPRING SURVEY.

Station	Temperature(^{o}C)		Salinity(ppt)		Dissolved Oxygen(ppm)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
NW						
1	21.0	20.7	26.78	26.78	8.8	8.2
2	21.3	20.9	27.78	27.78	6.9	6.9
3	21.0	20.8	27.57	27.64	7.1	7.2
4	21.8	21.0	27.35	27.21	7.5	7.7
NE						
5	20.3	20.2	26.78	26.78	7.7	7.3
6	20.2	20.2	27.06	27.06	8.2	7.8
7	19.9	19.9	26.85	26.85	7.7	7.6
8	20.2	20.2	25.92	25.92	8.5	8.0
SE						
9	29.7	20.5	26.99	26.99	8.4	8.2
10	20.2	20.2	27.50	27.50	6.9	6.9
11	20.1	20.3	25.85	26.14	7.5	7.1
12	20.4	20.4	26.42	26.42	8.2	7.7
SW						
13	21.1	20.7	26.92	26.92	8.3	8.2
14	20.9	20.8	26.35	26.28	7.9	7.8
15	20.9	20.9	26.71	26.64	8.2	8.1
16	20.8	20.7	26.99	26.99	8.4	8.2

TABLE 3.17. TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN CONCENTRATIONS OF SURFACE AND BOTTOM WATER AT EIGHT STATIONS AROUND LAKE PELTO, TANK BATTERY NO. 1 DURING THE FALL SURVEY.

Station	Temperature(°C)		Salinity(ppt)		Dissolved Oxygen(ppm)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
NW						
1	27.5	27.5	28.51	28.44	5.8	5.8
SE						
9	27.6	27.6	28.95	28.94	5.3	5.3
10	27.6	27.6	28.80	28.80	5.5	5.7
11	27.6	27.6	28.80	28.80	5.5	5.4
12	27.8	27.8	29.16	29.16	5.1	5.3
SW						
13	27.7	27.7	28.87	28.87	5.8	5.8
14	27.7	27.7	28.94	29.02	5.5	5.5
15	27.6	27.6	29.09	29.09	5.3	5.3

surface and bottom water at any station. Temperatures are approximately 6°C higher in the fall than in the spring.

3.2.2.2 Salinity.

3.2.2.2.1 Spring Survey. The range of salinities of surface and bottom water at the 16 stations is very narrow, from 25.85 to 27.78 ppt (Table 3.16). At most stations, surface and bottom salinities do not differ by more than 0.10 ppt. The largest difference in salinity of surface and bottom water at a station is 0.29 ppt. The uniform vertical and horizontal distribution of temperature and salinity indicate that waters of the study site are very well mixed, as would be expected for a shallow coastal bay such as this.

3.2.2.2.2 Fall Survey. Salinity also is quite uniform throughout the study area (Table 3.17). Salinity ranges from 28.44 ppt in bottom water at Station 1 to 29.16 ppt in surface and bottom water at Station 12, 1000 m southeast of the platform. The largest difference in salinity of surface and bottom water at a station is 0.8 ppt at Station 14. Salinity is approximately 2.0 ppt higher in the fall than in the spring.

3.2.2.3 Dissolved Oxygen Concentration

3.2.2.3.1 Spring Survey. There is very little difference in the concentration of dissolved oxygen in surface and bottom water at any station (Table 3.16). The maximum difference is 0.5 ppm. Concentrations of dissolved oxygen in surface and bottom waters of the site range from 6.9 ppm in surface and bottom water at Station 2, 100 m northwest of the platform, to 8.8 ppm in surface water at Station 1, 20 m northwest of the outfall. These values are 88 to 112 percent of saturation for oxygen at the ambient temperature and salinity conditions at the site. Bottom water at Station 1, closest to the platform contains 8.2 ppm dissolved oxygen, indicating that produced water discharges are not depleting oxygen in the bottom waters of the site.

3.2.2.3.2 Fall Survey. At most stations sampled in the fall survey, there is no difference in the oxygen concentration of the surface and bottom water (Table 3.17). Oxygen concentrations of surface and bottom waters of the site range from 5.1 to 5.8 ppm, 77 to 88 percent of saturation at the ambient temperature and salinity conditions. Bottom water at Station 1, closest to the produced water outfall, contains 5.8 ppm oxygen, indicating that produced water discharges were not depleting oxygen in bottom water.

3.3 PHYSICAL, CHEMICAL, AND BIOLOGICAL PROPERTIES OF SEDIMENTS

During the spring survey, three replicate sediment samples for chemical analysis and six replicate sediment samples for infaunal analysis were collected at each of 16 stations around the produced water discharge from Eugene Island, Block 105, Platform A and Lake Pelto, Tank Battery No. 1. During the fall survey, eight of the stations at each site sampled during the spring survey were sampled again with three replicate samples per station for chemistry and six replicate samples per station for infaunal analysis. All chemistry samples from the spring survey were analyzed for the same suite of analytes that were analyzed in produced water, with a few exceptions. Total hydrocarbons by IR, volatile hydrocarbons, volatile organics, and naphthenic acids were not analyzed in sediments. Total hydrocarbons in sediments were determined by GC-IMS. In addition, sediment grain size was determined for all sediment samples taken for chemistry and three of the six replicate samples taken for infaunal analysis from each station.

Six replicate samples were analyzed for infauna from 14 of the 16 stations sampled at Eugene Island during the spring survey. Samples from Stations 7 and 8 were not processed due to an error in laboratory procedures. The error resulted in the light density fractions of each set of six replicates being combined rather than kept separate. These combined samples have been archived.

Six replicate infaunal samples were analyzed from 13 of the 16 stations sampled at Lake Pelto during the spring survey. Three stations (Stations 4, 8, and 16) contained sediments with more than 70 percent silt plus clay. Three replicate samples from Station 16 were analyzed. It was determined that the high percentages of silt plus clay and the associated faunal differences at these stations, compared to other stations, would obscure any differences due to produced water discharges from Lake Pelto, Tank Battery No. 1. Therefore, no samples from Stations 4 and 8 were analyzed.

Sediment samples from four of the eight stations sampled in the fall cruise were analyzed. The other samples were archived. Sediment samples collected at Stations 1 through 4 during the fall survey were analyzed for grain size, individual PAHs, and three metals (barium, mercury, and nickel), and infauna. The samples selected for grain size and trace metal analyses included all three replicates from Station 1 and three replicates each from Stations 2, 3, and 4. Sediment grain size also was measured in one replicate sample from each of the four other stations. One replicate from Stations 1, 2, and 3 and the three replicates from Station 4 were selected for PAH analysis. The analysis of replicate samples at one station was conducted in order to provide information on sample analyte variability. The mean values for the replicates are used for comparison with the single values from other stations.

3.3.1 Eugene Island, Block 105, Platform A

3.3.1.1 Sediment Grain Size

3.3.1.1.1 Spring Survey. The mean percent gravel, sand, silt, and clay in sediments from Eugene Island is summarized in Table 3.18. Mean percent silt plus clay is also included in the table and shown in plan view in Figure 3.3. The detailed data for each replicate analyzed are presented as percent phi distributions in Appendix B (Table B1).

Mean percent silt/clay as determined for chemistry replicates is highest at the stations closest to the platform (20 m), with a significant decrease in the percent silt/clay with distance away from the platform (100 m and 300 m). Sediments at three of the four stations 20 m from the platform contain about 80 percent silt/clay. Silt plus clay concentrations decrease to 14 to 27 percent at stations in the 300-m ring. At the stations 1000 m from the platform, however, the concentration of silt plus clay in the sediment rises in most cases to 35 to 50 percent. A similar pattern is evident in the biology replicates. The sediment grain size at several stations is highly variable, as indicated by the large standard deviations and by differences in the mean values for the chemistry and biology samples at some stations (Table 3.18).

The platform at Eugene Island may decrease local current speeds, thereby increasing net deposition of fine-grained sediments. The silt/clay over fine sand stratigraphy detected by REMOTS in the preliminary survey supports the hypothesis that the presence of the platform has changed the local current regime. Only on the eastern side of the platform (E, 20 m) does sediment grain-size distribution suggest that current velocities are similar to those in the rest of the area.

3.3.1.1.2. Fall Survey. Grain-size distributions in sediments

TABLE 3.18. MEAN PERCENT ($\bar{X}$) AND STANDARD DEVIATION (SD) OF MAJOR SEDIMENT SIZE CLASSES IN BIOLOGY (B) AND CHEMISTRY (C) SEDIMENT SAMPLES COLLECTED AT EUGENE ISLAND STATIONS IN SPRING 1986.

Station		Gravel		Sand		Silt		Clay		Total Silt plus Clay
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	
1	B	0.07	0.12	17.31	2.76	47.58	2.32	35.04	2.72	82.6
	C	0.06	0.05	22.09	1.52	48.58	3.96	29.27	2.90	77.9
2	B	0.03	0.03	45.70	22.49	32.00	7.13	22.27	15.70	54.3
	C	0.33	0.14	65.83	7.76	25.33	4.54	8.51	3.15	33.8
3	B	1.35	0.85	83.97	0.92	12.48	1.37	2.20	0.19	14.7
	C	0.41	0.15	81.13	4.47	12.96	2.29	5.51	2.40	18.5
4	B	0.02	0.02	63.38	8.66	28.05	4.90	8.55	4.28	36.6
	C	0.03	0.04	49.76	19.54	31.46	9.93	18.75	9.66	50.3
5	B	0	0	26.04	3.38	50.01	3.53	24.0	2.70	74.0
	C	0	0	14.64	10.49	61.27	7.47	24.10	3.55	85.4
6	B	0	0	30.15	26.45	35.87	7.06	33.98	20.97	69.8
	C	0.04	0.06	57.63	10.04	29.28	6.71	13.05	3.43	42.3
7	B	Not analyzed								
	C	3.28	1.66	82.66	3.05	9.88	2.25	4.19	2.16	14.1
8	B	Not analyzed								
	C	0.40	0.52	64.19	23.21	22.51	15.13	12.90	8.62	35.4
9	B	0.03	0.05	56.20	2.87	33.21	3.25	10.56	3.29	42.8
	C	0.04	0.04	66.06	3.33	28.24	3.38	5.66	0.21	33.9
10	B	0.04	0.04	68.87	9.69	20.19	5.75	10.90	3.99	31.1
	C	0.07	0.06	80.34	5.04	15.26	3.96	4.34	1.18	19.6
11	B	0.19	0.04	87.17	3.96	10.62	3.49	2.90	0.26	13.5
	C	0.38	0.11	83.10	1.73	13.17	1.35	3.37	0.53	16.6
12	B	0.04	0.03	73.09	2.78	22.85	1.55	3.94	0.98	26.7
	C	0.48	0.74	56.40	26.46	33.23	19.49	9.79	7.27	43.0
13	B	0	0	26.40	7.86	49.49	3.27	24.10	7.45	73.6
	C	0	0	20.81	5.06	57.75	2.91	29.44	4.51	82.2
14	B	0	0	71.49	6.63	21.63	21.63	4.73	6.88	28.5
	C	0.20	0.17	68.63	15.03	21.17	6.23	10.00	9.04	31.2
15	B	0.33	0.28	72.36	5.11	19.02	0.60	8.28	4.88	27.3
	C	1.29	1.14	68.62	2.47	22.26	1.08	7.84	1.06	30.1
16	B	0.25	0.22	70.86	16.08	19.46	7.19	9.44	9.17	28.9
	C	2.71	3.54	76.20	2.42	15.70	2.92	5.09	1.20	20.8

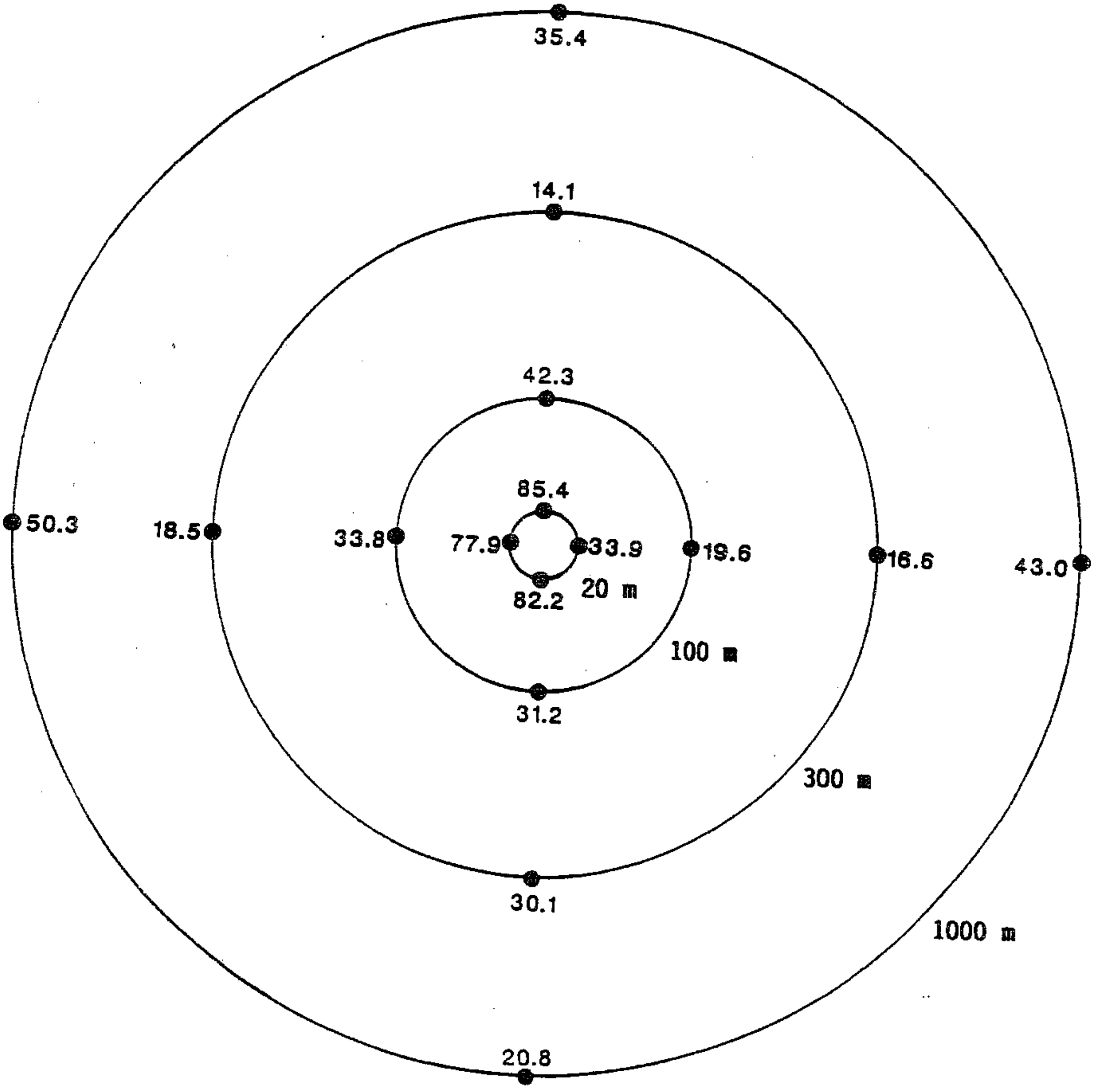


FIGURE 3.3. PERCENT SILT PLUS CLAY IN SEDIMENT SAMPLES COLLECTED FOR CHEMICAL ANALYSIS AT EUGENE ISLAND, STATIONS 1-16, DURING THE SPRING SURVEY (TABLE 3.18).

from the stations evaluated in the fall survey are presented in Table 3.19. Phi-class grain size distributions for each replicate sediment sample from Eugene Island are presented in Appendix B (Table B2). The percent silt/clay is highest at the station closest to the platform (Station 1), with a concentration of 43 percent. The percent silt/clay decreases at the 100-m station to 30 percent and remains approximately the same out to 1000 m from the platform. The trend of decreasing percent silt/clay was also observed in sediments collected from this transect during the spring survey (Table 3.18). However, in the spring, percent silt/clay at Stations 1 and 4 was much higher than in the fall, whereas percent silt/clay in sediments from Stations 2 and 3 was about the same in the spring and fall.

3.3.1.2 Total Hydrocarbons by GC/MS

Total hydrocarbon concentrations were determined by GC/MS in all sediment samples from Eugene Island. Hydrocarbon concentrations in each replicate sample, as well as the mean value and standard deviation for each station, are presented in Table 3.20. The percent resolved hydrocarbons is also given in the table (in parentheses). In each transect, the mean concentration of total hydrocarbons in sediments is highest (46-90 μg/g) at the station closest to the platform and decreases at stations further from the platform. Figure 3.4 shows the trends in sediment hydrocarbon concentrations throughout the study site.

The distribution of total hydrocarbons seems to be similar to the distribution of silt/clay and TOC. As shown in Figure 3.5, the correlation between the concentration of total hydrocarbons in sediments and the percent silt/clay is very strong: the correlation coefficient is 0.88. With one exception (>200 ppm at Station 5, Replicate 2), total hydrocarbon concentrations in sediments around Eugene Island are typical of concentrations observed in coastal sediments in the Gulf of Mexico (10 to 50

TABLE 3.19. PERCENT GRAIN-SIZE DISTRIBUTION IN SEDIMENTS FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE FALL SURVEY ($\bar{X}$ - MEAN, S.D. - Standard Deviation). TOTAL PERCENT SILT PLUS CLAY IN SAMPLES FROM THE FALL AND SPRING SURVEYS ARE COMPARED.

Station	Gravel		Sand		Silt		Clay		Total Silt Plus Clay	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	Fall	Spring
Eugene Island										
1 (W, 20 m)	0.23	0.20	56.82	15.73	34.73	16.96	8.21	3.65	42.9	82.6
2 (W, 100 m)	0.03	0.03	67.86	5.11	23.62	3.02	8.49	2.13	32.1	54.3
3 (W, 300 m)	0.31	0.13	74.36	1.73	18.78	0.47	6.55	1.37	25.3	14.7
4 (W, 1000 m)	0.14	0.06	71.01	1.73	23.96	1.15	4.88	0.84	28.8	36.6
Lake Pelto										
1 (NW, 20 m)	5.93	1.18	68.76	4.30	16.15	3.32	9.16	1.81	25.3	21.8
13 (SW, 20 m)	2.49	0.94	72.55	5.37	17.41	3.58	7.53	2.79	24.9	28.4
14 (SW, 100 m)	0.00	0.00	12.12	1.36	57.18	3.54	30.70	4.87	87.9	53.5
15 (SW, 300 m)	1.04	0.95	37.83	5.80	46.36	3.33	14.77	3.11	61.1	59.8

TABLE 3.20. CONCENTRATION OF TOTAL HYDROCARBONS BY GC/MS (AND PERCENT RESOLVED HYDROCARBONS) IN SEDIMENTS FROM EUGENE ISLAND COLLECTED DURING THE SPRING SURVEY.

Station	Concentration (μg/g Dry Weight)				
	Replicate				Standard Deviation
	1	2	3	Mean	
1 (W, 20 m)	57 (44%)	39 (41%)	59 (42%)	52 (42%)	11 (1.5%)
2 (W, 100 m)	13	(42)	36 (28)	53 (17)	34 (29)
3 (W, 300 m)	13	(55)	13 (49)	20 (18)	15 (41)
4 (W, 1000 m)	8.0	(45)	52 (44)	27 (44)	29 (44)
5 (N, 20 m)	30 (40)	210 (48)	30 (37)	90 (42)	100 (5.7)
6 (N, 100 m)	28	(46)	25 (44)	30 (53)	28 (48)
7 (N, 300 m)	9.0	(64)	17 (50)	7.0 (58)	11 (57)
8 (N, 1000 m)	23	(52)	27 (44)	11 (48)	20 (48)
9 (E, 20 m)	21 (43)	9.0 (48)	30 (43)	20 (45)	10 (2.9)
10 (E, 100 m)	12	(56)	11 (54)	12 (56)	12 (55)
11 (E, 300 m)	6.7	(54)	4.8 (58)	5.2 (54)	5.6 (55)
12 (E, 1000 m)	11	(44)	5.0 (56)	10 (55)	8.7 (52)
13 (S, 20 m)	50 (46)	44 (48)	44 (45)	46 (46)	3.5 (1.5)
14 (S, 100 m)	8.0	(45)	30 (43)	8.7 (47)	16 (45)
15 (S, 300 m)	14	(51)	14 (48)	21 (46)	16 (48)
16 (S, 1000 m)	6.6	(54)	9.6 (50)	10 (53)	8.7 (52)

BLANKS (Range) 1.0-2.0 μg/g

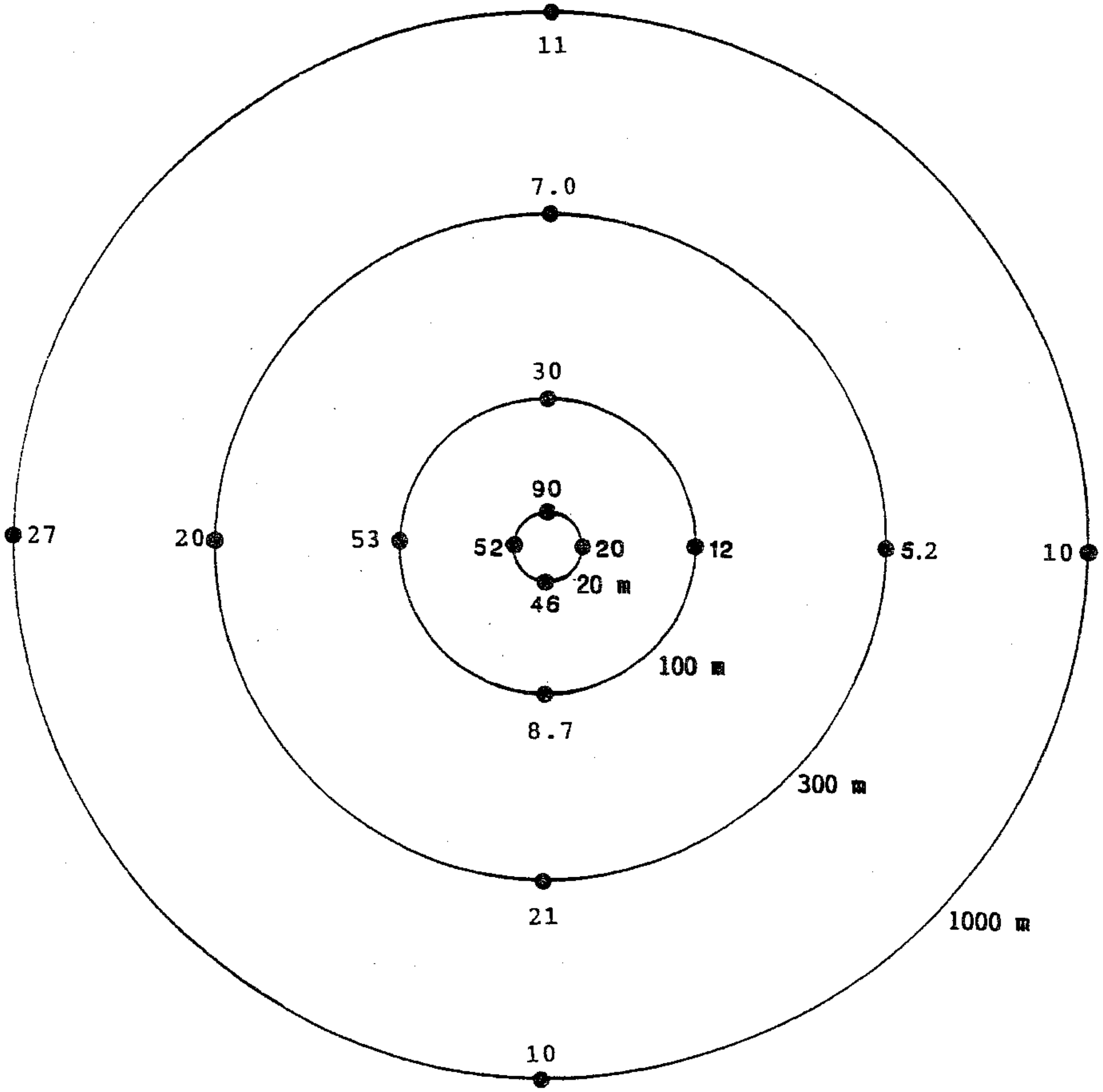


FIGURE 3.4. MEAN TOTAL HYDROCARBON CONCENTRATIONS (μg/g) IN SEDIMENT SAMPLES COLLECTED AT EUGENE ISLAND, STATIONS 1-16, DURING THE SPRING SURVEY (TABLE 3.20).

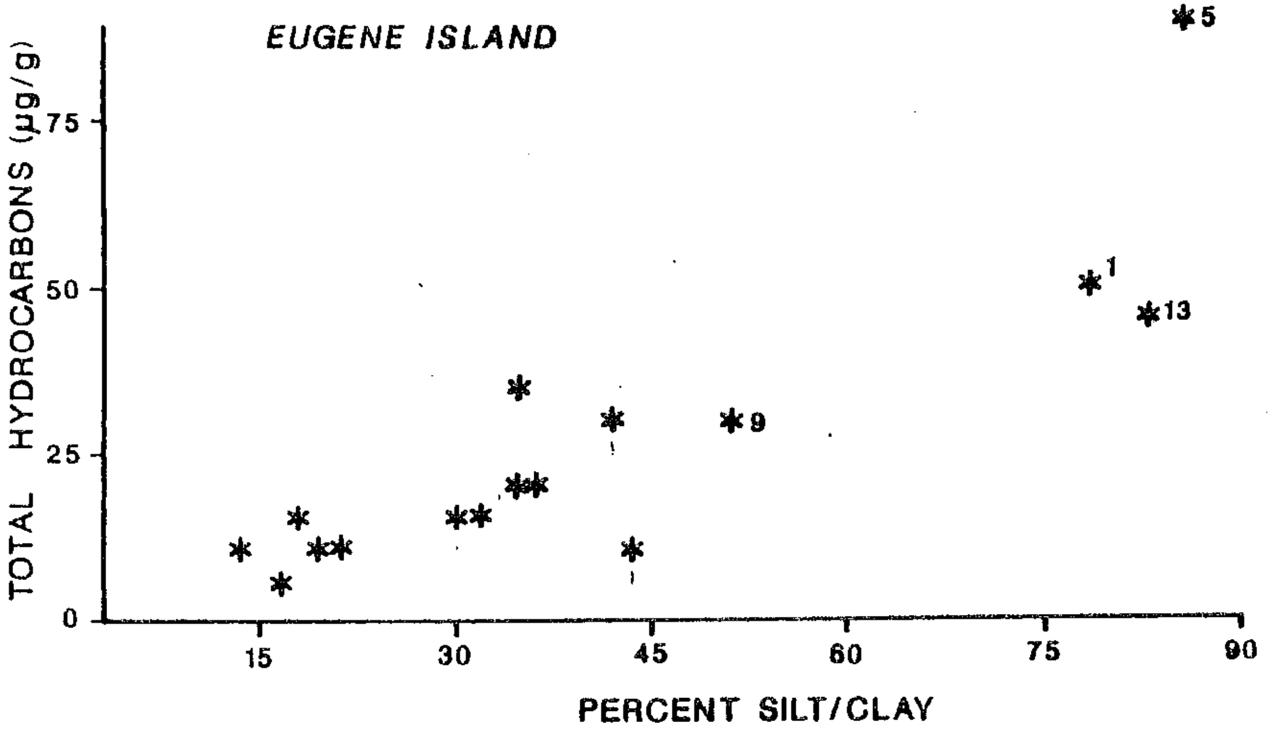


FIGURE 3.5. RELATIONSHIP BETWEEN THE HYDROCARBON CONCENTRATION (TABLE 3.20) AND PERCENT SILT PLUS CLAY (TABLE 3.18) IN SEDIMENT SAMPLES COLLECTED AT EUGENE ISLAND DURING THE SPRING SURVEY.

μg/g) (Boehm and Requejo, 1986).

3.3.1.3 n-Alkanes

Concentrations of n-alkanes including decane (C_{10}) through tetratriacontane (C_{34}) in each replicate sediment sample from all 16 stations at Eugene Island are presented in Appendix C (Tables C1 through C17). Mean concentrations of each n-alkane and total n-alkanes are summarized in Tables 3.21 and 3.22. Mean concentrations of total n-alkanes are also presented in a plan view of the study site (Figure 3.6).

As with total hydrocarbons, concentrations of n-alkanes in sediments are highest at the stations 20 m from the platform, ranging from 1.4 μg/g to 7.3 μg/g. The concentrations decrease with distance from the platform to values of 0.3 to 0.8 μg/g at most outer stations. The correlation between percent silt/clay and n-alkane concentrations in sediments is good. Elevations in n-alkane concentrations, even in replicate samples, are associated with increases in percent silt/clay.

3.3.1.4 PAHs

3.3.1.4.1 Spring Survey. One- to four-ring aromatic hydrocarbons (PAHs) and their alkyl homologues were analyzed in all replicate sediment samples from all 16 stations at Eugene Island. The mean concentration of each PAH and total PAHs in sediments from each station are presented in Tables 3.23 and 3.24. Analytical results for all replicate samples are given in Appendix D (Tables D1 through D16). Concentrations of benzene and C_1 and C_2 benzenes listed in Tables 3.23 and 3.24 are underestimated. Substantial quantities of these volatile compounds are lost during sample preparation by solvent extraction, and therefore, recoveries are low. Mean total PAH concentrations are presented in a plan view of the study site (Figure 3.7).

TABLE 3.21. MEAN n-ALKANE CONCENTRATIONS IN SEDIMENTS FROM EUGENE ISLAND, STATIONS 1 THROUGH 8, COLLECTED DURING THE SPRING SURVEY.

Compound	Concentration (µg/g Dry Weight)							
	Station							
	1	2	3	4	5	6	7	8
Decane (C_{10})	0.038	0.014	0.007	0.006	0.070	0.027	0.012	0.017
Undecane (C_{11})	0.125	0.048	0.036	0.047	0.112	0.257	0.231	0.248
Dodecane (C_{12})	0.124	0.025	0.005	0.010	0.066	0.044	0.011	0.013
Tridecane (C_{13})	0.180	0.042	0.009	0.025	0.075	0.058	0.014	0.010
Tetradecane (C_{14})	0.186	0.042	0.007	0.019	0.072	0.061	0.009	0.009
Pentadecane (C_{15})	0.204	0.048	0.010	0.032	0.096	0.073	0.023	0.017
Hexadecane (C_{16})	0.173	0.040	0.008	0.022	0.105	0.073	0.018	0.020
Heptadecane (C_{17})	0.343	0.056	0.011	0.045	0.121	0.160	0.033	0.030
Octadecane (C_{18})	0.155	0.043	0.014	0.060	0.205	0.066	0.016	0.010
Nonadecane (C_{19})	0.145	0.037	0.008	0.024	0.138	0.071	0.024	0.024
Eicosane (C_{20})	0.110	0.035	0.016	0.036	0.091	0.052	0.022	0.023
Heneicosane (C_{21})	0.156	0.050	0.023	0.062	0.294	0.086	0.027	0.051
Docosane (C_{22})	0.078	0.026	0.022	0.024	0.601	0.054	0.021	0.016
Tricosane (C_{23})	0.099	0.031	0.033	0.043	0.991	0.067	0.024	0.032
Tetracosane (C_{24})	0.080	0.029	0.035	0.033	1.341	0.047	0.022	0.022
Pentacosane (C_{25})	0.097	0.042	0.042	0.068	0.957	0.073	0.032	0.044
Hexacosane (C_{26})	0.073	0.025	0.035	0.037	0.796	0.043	0.023	0.027
Octacosane (C_{28})	0.058	0.030	0.027	0.040	0.531	0.043	0.022	0.029
Triacontane (C_{30})	0.058	0.030	0.032	0.048	0.203	0.047	0.022	0.030
Hentriacontane (C_{31})	0.244	0.114	0.080	0.231	0.308	0.168	0.047	0.125
Dotriacontane (C_{32})	0.038	0.019	0.020	0.026	0.100	0.026	0.011	0.016
Tetratriacontane (C_{34})	0.015	0.013	0.008	0.013	0.044	0.008	0.002	0.038
TOTAL	**2.779**	**0.838**	**0.488**	**0.951**	**7.317**	**1.604**	**0.666**	**0.851**

TABLE 3.22. MEAN n-ALKANE CONCENTRATIONS IN SEDIMENTS FROM EUGENE ISLAND, STATIONS 9 THROUGH 16, COLLECTED DURING THE SPRING SURVEY.

Compound	Concentration (µg/g Dry Weight)							
	Station							
	9	10	11	12	13	14	15	16
Decane (C_{10})	0.023	0.019	0.007	0.006	0.018	0.005	0.043	0.009
Undecane (C_{11})	0.064	0.181	0.042	0.037	0.116	0.031	0.041	0.047
Dodecane (C_{12})	0.075	0.023	0.005	0.004	0.058	0.012	0.012	0.007
Tridecane (C_{13})	0.106	0.028	0.005	0.017	0.081	0.022	0.029	0.020
Tetradecane (C_{14})	0.111	0.031	0.005	0.009	0.093	0.032	0.027	0.019
Pentadecane (C_{15})	0.118	0.036	0.006	0.005	0.125	0.049	0.031	0.026
Hexadecane (C_{16})	0.098	0.034	0.005	0.004	0.125	0.053	0.028	0.031
Heptadecane (C_{17})	0.136	0.048	0.009	0.011	0.165	0.077	0.045	0.036
Octadecane (C_{18})	0.084	0.029	0.010	0.007	0.087	0.029	0.019	0.021
Nonadecane (C_{19})	0.092	0.042	0.005	0.009	0.078	0.035	0.027	0.017
Eicosane (C_{20})	0.069	0.036	0.008	0.013	0.085	0.032	0.027	0.018
Heneicosane (C_{21})	0.073	0.040	0.014	0.021	0.116	0.039	0.037	0.024
Docosane (C_{22})	0.065	0.023	0.012	0.006	0.053	0.023	0.020	0.008
Tricosane (C_{23})	0.067	0.025	0.018	0.013	0.079	0.029	0.032	0.013
Tetracosane (C_{24})	0.062	0.016	0.020	0.009	0.060	0.023	0.022	0.011
Pentacosane (C_{25})	0.047	0.021	0.021	0.017	0.111	0.038	0.036	0.018
Hexacosane (C_{26})	0.013	0.016	0.018	0.009	0.061	0.022	0.021	0.014
Octacosane (C_{28})	0.018	0.011	0.016	0.012	0.080	0.031	0.019	0.014
Triacontane (C_{30})	0.022	0.010	0.014	0.016	0.068	0.003	0.020	0.018
Hentriacontane (C_{31})	0.060	0.041	0.044	0.071	0.361	0.134	0.092	0.075
Dotriacontane (C_{32})	0.009	0.006	0.007	0.007	0.034	0.013	0.009	0.007
Tetratriacontane (C_{34})	0.006	0.002	0.004	0.005	0.023	0.006	0.009	0.004
TOTAL	**1.418**	**0.718**	**0.295**	**0.308**	**2.077**	**0.738**	**0.646**	**0.457**

TABLE 3.23. **MEAN CONCENTRATIONS OF AROMATIC HYDROCARBONS IN SEDIMENTS FROM EUGENE ISLAND, STATIONS 1 THROUGH 8, COLLECTED DURING THE SPRING SURVEY.**

	Concentration (µg/g Dry Weight)							
	Station							
Compound	1	2	3	4	5	6	7	8
Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_1-B	0.0	0.0	0.0	0.0	0.0	0.001	0.0	0.0
C_2-B	0.008	0.009	0.009	0.006	0.060	0.019	0.011	0.026
C_3-B	0.006	0.004	0.003	0.002	0.064	0.013	0.006	0.018
C_4-B	0.004	0.0	0.0	0.0	0.030	0.0	0.0	0.009
C_5-B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_6-B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Naphthalene	0.001	0.0	0.0	0.001	0.038	0.0	0.0	0.001
C_1-N	0.009	0.001	0.0	0.001	0.009	0.003	0.001	0.003
C_2-N	0.020	0.0	0.0	0.0	0.012	0.0	0.0	0.002
C_3-N	0.018	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-N	0.0	0.0	0.0	0.0	0.001	0.0	0.0	0.0
C_5-N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biphenyl	0.0	0.0	0.0	0.0	0.002	0.0	0.0	0.0
C_1-BL	0.004	0.0	0.0	0.0	0.002	0.0	0.0	0.0
C_2-BL	0.008	0.0	0.0	0.0	0.0	0.001	0.0	0.0
C_3-BL	0.006	0.0	0.0	0.0	0.002	0.001	0.0	0.001
C_4-BL	0.0	0.0	0.0	0.0	0.020	0.001	0.0	0.0
C_5-BL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dibenzothiophene	0.001	0.0	0.0	0.0	0.001	0.0	0.0	0.0
C_1-D	0.0	0.0	0.0	0.0	0.012	0.0	0.0	0.0
C_2-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_3-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-D	0.0	0.0	0.0	0.0	0.020	0.001	0.0	0.0
C_5-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorene	0.0	0.0	0.0	0.0	0.013	0.0	0.0	0.0
C_1-F	0.0	0.0	0.0	0.0	0.009	0.0	0.0	0.0
C_2-F	0.022	0.003	0.0	0.0	0.026	0.030	0.004	0.016
C_3-F	0.0	0.0	0.0	0.0	0.003	0.0	0.0	0.0
C_4-F	0.057	0.0	0.0	0.006	0.032	0.0	0.0	0.017
C_5-F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phenanthrene	0.103	0.001	0.0	0.006	0.013	0.006	0.001	0.004
C_1-P	0.015	0.0	0.0	0.010	0.029	0.0	0.0	0.0
C_2-P	0.023	0.0	0.0	0.010	0.043	0.003	0.0	0.005
C_3-P	0.005	0.0	0.0	0.003	0.031	0.001	0.0	0.002
C_4-P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyrene	0.011	0.001	0.002	0.006	0.031	0.005	0.0	0.003
C_1-PY	0.004	0.0	0.0	0.001	0.011	0.0	0.0	0.001
C_2-PY	0.0	0.0	0.0	0.0	0.012	0.0	0.0	0.001
C_3-PY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-PY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-PY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chrysene	0.008	0.0	0.003	0.002	0.003	0.003	0.0	0.001
C_1-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_2-C	0.0	0.0	0.0	0.0	0.014	0.0	0.0	0.0
C_3-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Perylene	0.076	0.029	0.014	0.078	0.085	0.047	0.010	0.046
C_1-PL	0.0	0.0	0.0	0.0	0.002	0.0	0.0	0.0
C_2-PL	0.0	0.0	0.0	0.0	0.001	0.0	0.0	0.0
C_3-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	**0.409**	**0.048**	**0.031**	**0.132**	**0.621**	**0.134**	**0.033**	**0.156**

TABLE 3.24. MEAN CONCENTRATIONS OF AROMATIC HYDROCARBONS IN SEDIMENTS FROM EUGENE ISLAND, STATIONS 9 THROUGH 16, COLLECTED DURING THE SPRING SURVEY.

	Concentration (μg/g Dry Weight)							
	Station							
Compound	9	10	11	12	13	14	15	16
Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_1-B	0.001	0.0	0.002	0.0	0.0	0.0	0.0	0.0
C_2-B	0.006	0.019	0.007	0.007	0.010	0.002	0.006	0.006
C_3-B	0.004	0.012	0.002	0.001	0.002	0.0	0.002	0.001
C_4-B	0.003	0.004	0.0	0.0	0.0	0.0	0.004	0.0
C_5-B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_6-B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Naphthalene	0.005	0.0	0.001	0.0	0.003	0.0	0.002	0.0
C_1-N	0.001	0.001	0.0	0.0	0.006	0.001	0.005	0.0
C_2-N	0.004	0.0	0.0	0.0	0.011	0.003	0.004	0.0
C_3-N	0.008	0.0	0.0	0.0	0.0	0.0	0.002	0.0
C_4-N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-N	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biphenyl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_1-BL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_2-BL	0.001	0.0	0.0	0.0	0.003	0.0	0.0	0.0
C_3-BL	0.003	0.0	0.0	0.0	0.0	0.0	0.002	0.0
C_4-BL	0.0	0.0	0.0	0.0	0.004	0.0	0.0	0.0
C_5-BL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dibenzothiophene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_1-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_2-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_3-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorene	0.0	0.0	0.0	0.0	0.001	0.0	0.0	0.0
C_1-F	0.0	0.0	0.0	0.0	0.003	0.001	0.0	0.0
C_2-F	0.001	0.0	0.001	0.0	0.005	0.0	0.015	0.0
C_3-F	0.0	0.0	0.0	0.0	0.0	0.0	0.004	0.0
C_4-F	0.0	0.0	0.0	0.003	0.027	0.005	0.0	0.0
C_5-F	0.0	0.0	0.0	0.0	0.001	0.0	0.0	0.0
Phenanthrene	0.004	0.0	0.003	0.001	0.011	0.003	0.042	0.0
C_1-P	0.0	0.0	0.002	0.0	0.019	0.004	0.0	0.0
C_2-P	0.0	0.0	0.0	0.0	0.015	0.005	0.006	0.0
C_3-P	0.0	0.0	0.0	0.0	0.0	0.003	0.002	0.0
C_4-P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyrene	0.003	0.0	0.002	0.001	0.012	0.002	0.004	0.001
C_1-PY	0.0	0.0	0.0	0.0	0.003	0.002	0.0	0.0
C_2-PY	0.0	0.0	0.0	0.0	0.001	0.0	0.0	0.0
C_3-PY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-PY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-PY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chrysene	0.003	0.0	0.001	0.0	0.015	0.002	0.003	0.0
C_1-C	0.0	0.0	0.0	0.0	0.002	0.001	0.001	0.0
C_2-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_3-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Perylene	0.013	0.010	0.006	0.012	0.136	0.045	0.023	0.011
C_1-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_2-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_3-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	**0.061**	**0.046**	**0.027**	**0.025**	**0.290**	**0.079**	**0.127**	0.019

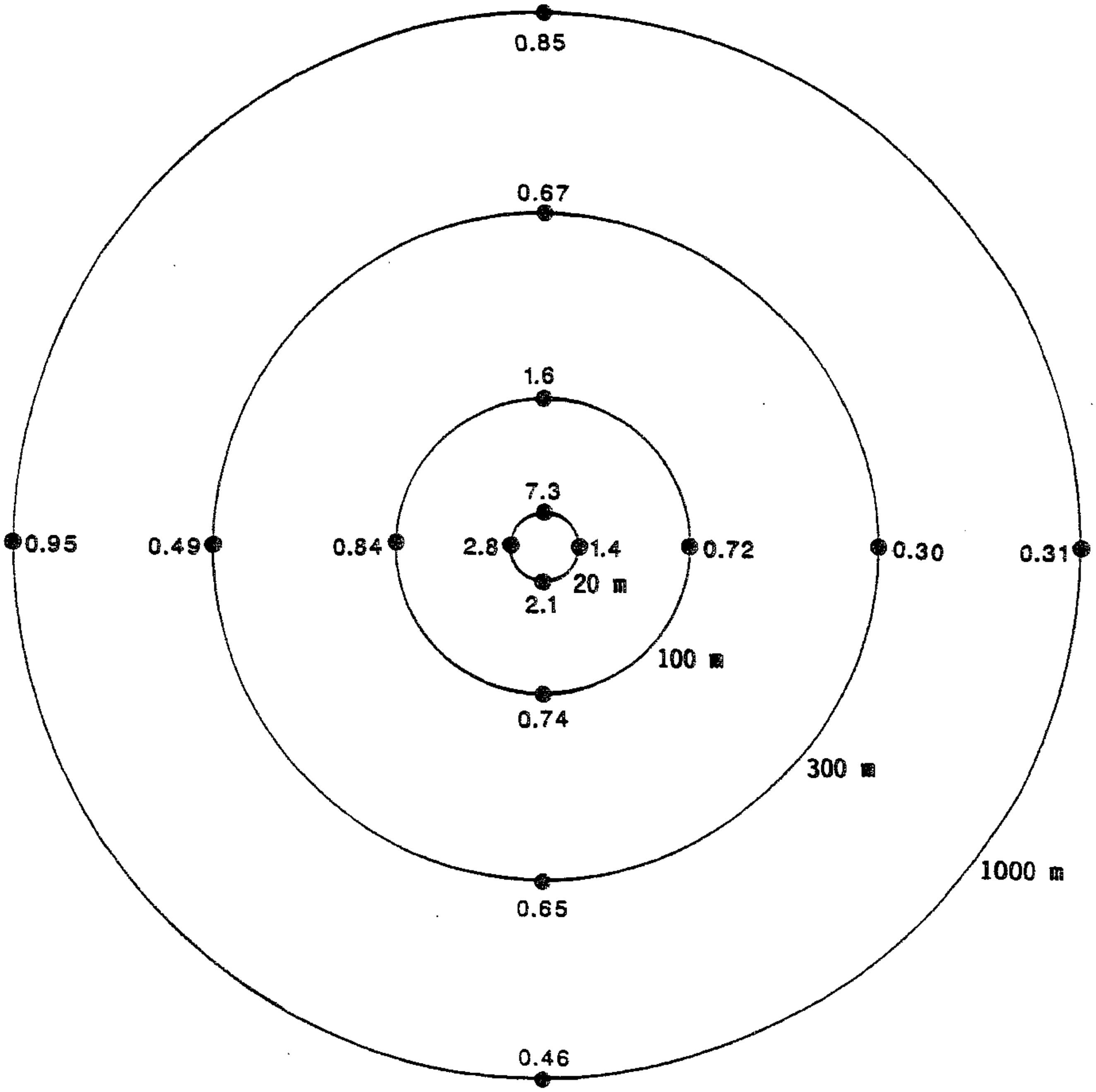


FIGURE 3.6. TOTAL MEAN n-ALKANE CONCENTRATIONS (μg/g) IN SEDIMENT SAMPLES COLLECTED AT EUGENE ISLAND, STATIONS 1-16, DURING THE SPRING SURVEY (TABLES 3.21 AND 3.22).

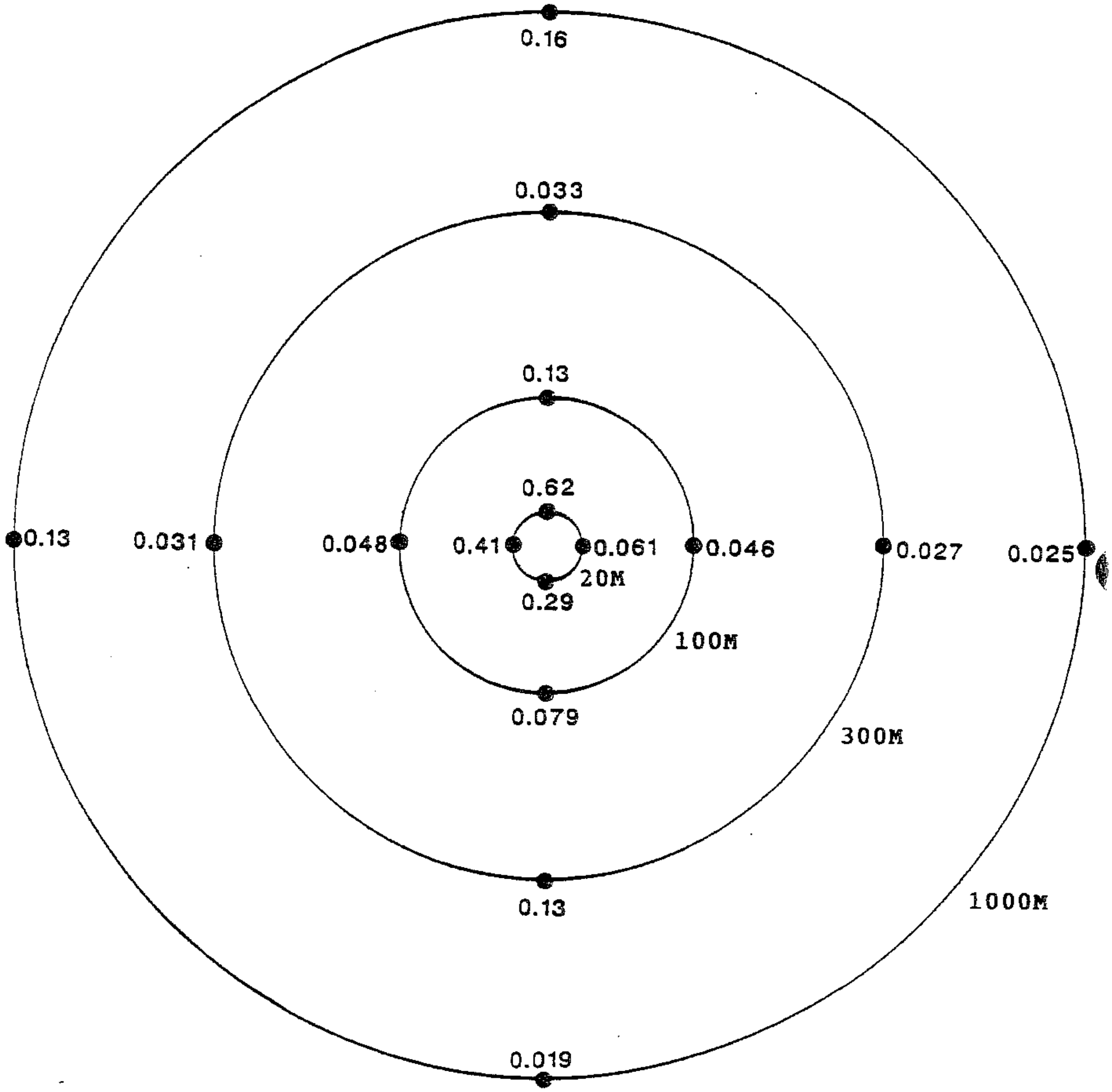


FIGURE 3.7. TOTAL MEAN PAH CONCENTRATIONS (μg/g) IN SEDIMENT SAMPLES COLLECTED AT EUGENE ISLAND, STATIONS 1-16, DURING THE SPRING SURVEY (TABLES 3.23 AND 3.24).

Concentrations of individual and total PAHs in sediments at stations around Eugene Island, Block 105 are very low, except at three stations close to the platform (Stations 1, 5, and 13). At nearly all other stations, concentrations of individual PAH are near or below the detection limits. Sediments at Station 5 have the highest mean total PAH concentration, 0.6 µg/g; sediments at most stations have total PAH concentrations ranging from 0.02 to 0.13 µg/g. The alkyl homologues of naphthalene, dibenzothiophene, fluorene, and phenanthrene are well represented in sediments from Station 5; however, this is evident for only one of the replicate samples (Replicate 2) from the station. The other replicates from this station contain only low concentrations of parent and alkyl PAH, as is the case for sediments from most other stations. Replicate 2 also has the highest silt/clay content (94 percent) of all Eugene Island sediment samples. Alkyl homologues are also present in sediments from two other stations 20 m from the platform, Stations 1 and 13. Although the total and individual concentrations are lower than at Station 5, the variability among sample replicates is small. In comparing these data with the results from the preliminary survey, none of the spring survey samples possess the high total PAH concentration found in the Ring B, Quadrant 4 sample collected during the preliminary survey (4.29 µg/g dry weight).

Overall, concentrations of PAH in these sediment samples are low and are highly correlated to the percent silt/clay. Stations with the highest PAH (Stations 1, 5, and 13) have the highest silt/clay content. Because the distribution of alkyl-substituted PAHs is for the most part consistent among sediment samples and does not closely reflect that found in produced water (Table 3.4), the PAHs in the sediments around the Eugene Island study site, except possibly those in sediments close to the platform (<100 m), could be considered the natural background concentrations of PAH for the area.

3.3.1.4.2 Fall Survey. Concentrations of individual and total resolved PAHs in each sediment replicate from Stations 1 through 4 are summarized in Tables 3.25 and 3.26. Concentrations of total PAH in sediments are highest (0.37 µg/g) at the station closest to the platform (Station 1); concentrations decrease with distance from the platform to a mean of 0.03 µg/g at distances of 300 and 1000 m from the platform. This gradient of decreasing sediment PAH concentrations with distance from the platform correlates with the similar gradient of decreasing percent silt/clay in the sediments. The concentrations and distribution of PAHs in these fall survey samples are almost exactly the same as those determined in the spring survey samples (Table 3.23), indicating very little change occurred during the six months between surveys. The only difference was a higher concentration of total PAH in the sediment from Station 4 in the spring than in the fall, due almost exclusively to the presence of alkyl phenanthrenes in the former sample.

3.3.1.5 Steranes and Triterpanes

The biomarkers, C_{27} through C_{29} steranes and triterpanes, were analyzed in sediment samples collected during the spring survey from the west transect (Stations 1 through 4) of the Eugene Island site to determine whether these biomarkers are a viable tool to trace constituents of produced water in sediments. Mass ion chromatograms of steranes (m/e-217) and triterpanes (m/e-191) for representative sediment samples are presented in Figures 3.8 and 3.9, respectively. Peak numbers in the figures correspond to compounds listed in Tables 3.6 and 3.7. Estimates for the total concentrations of these two groups of compounds in sediments, based on the internal standard, androstane, are given in Table 3.27. Ratios of selected steranes and triterpanes in sediments are presented in Table 3.8.

Comparison between the distributions of steranes in produced water (Figure 3.1) and sediments (Figure 3.8) indicates higher

TABLE 3.25. CONCENTRATIONS OF AROMATIC HYDROCARBONS IN THREE REPLICATE SEDIMENT SAMPLES FROM EUGENE ISLAND, STATION 4, COLLECTED DURING THE FALL SURVEY.

Compound	Concentration (µg/g Dry Weight)				
	Replicate				
	1	2	3	Mean	Standard Deviation
Benzene	0.0	0.0	0.0	0.0	0.0
C_1-B	0.0	0.0	0.0	0.0	0.0
C_2-B	0.008	0.008	0.008	0.008	0.0
C_3-B	0.001	0.003	0.003	0.002	0.001
C_4-B	0.0	0.0	0.0	0.0	0.0
C_5-B	0.0	0.0	0.0	0.0	0.0
C_6-B	0.0	0.0	0.0	0.0	0.0
Naphthalene	0.0	0.001	0.002	0.001	0.001
C_1-N	0.0	0.001	0.001	0.001	0.0
C_2-N	0.0	0.0	0.0	0.0	0.0
C_3-N	0.0	0.0	0.0	0.0	0.0
C_4-N	0.0	0.0	0.0	0.0	0.0
C_5-N	0.0	0.0	0.0	0.0	0.0
Biphenyl	0.0	0.0	0.0	0.0	0.0
C_1-BL	0.0	0.0	0.0	0.0	0.0
C_2-BL	0.0	0.0	0.0	0.0	0.0
C_3-BL	0.0	0.0	0.0	0.0	0.0
C_4-BL	0.0	0.0	0.0	0.0	0.0
C_5-BL	0.0	0.0	0.0	0.0	0.0
Dibenzothiophene	0.0	0.0	0.0	0.0	0.0
C_1-D	0.0	0.0	0.0	0.0	0.0
C_2-D	0.0	0.0	0.0	0.0	0.0
C_3-D	0.0	0.0	0.0	0.0	0.0
C_4-D	0.0	0.0	0.0	0.0	0.0
C_5-D	0.0	0.0	0.0	0.0	0.0
Fluorene	0.0	0.0	0.0	0.0	0.0
C_1-F	0.0	0.0	0.0	0.0	0.0
C_2-F	0.0	0.0	0.0	0.0	0.0
C_3-F	0.0	0.0	0.0	0.0	0.0
C_4-F	0.0	0.0	0.0	0.0	0.0
C_5-F	0.0	0.0	0.0	0.0	0.0
Phenanthrene	0.0	0.0	0.002	0.001	0.001
C_1-P	0.0	0.0	0.0	0.0	0.0
C_2-P	0.0	0.0	0.0	0.0	0.0
C_3-P	0.0	0.0	0.0	0.0	0.0
C_4-P	0.0	0.0	0.0	0.0	0.0
C_5-P	0.0	0.0	0.0	0.0	0.0
Pyrene	0.0	0.0	0.002	0.001	0.001
C_1-PY	0.0	0.0	0.0	0.0	0.0
C_2-PY	0.0	0.0	0.0	0.0	0.0
C_3-PY	0.0	0.0	0.0	0.0	0.0
C_4-PY	0.0	0.0	0.0	0.0	0.0
C_5-PY	0.0	0.0	0.0	0.0	0.0
Chrysene	0.0	0.0	0.0	0.0	0.0
C_1-C	0.0	0.0	0.0	0.0	0.0
C_2-C	0.0	0.0	0.0	0.0	0.0
C_3-C	0.0	0.0	0.0	0.0	0.0
C_4-C	0.0	0.0	0.0	0.0	0.0
C_5-C	0.0	0.0	0.0	0.0	0.0
Perylene	0.012	0.018	0.027	0.019	0.008
C_1-PL	0.0	0.0	0.0	0.0	0.0
C_2-PL	0.0	0.0	0.0	0.0	0.0
C_3-PL	0.0	0.0	0.0	0.0	0.0
C_4-PL	0.0	0.0	0.0	0.0	0.0
C_5-PL	0.0	0.0	0.0	0.0	0.0
TOTAL	0.021	0.031	0.045	0.033	0.012

TABLE 3.26. CONCENTRATIONS OF AROMATIC HYDROCARBONS IN SINGLE SEDIMENT SAMPLES FROM EUGENE ISLAND, STATIONS 1, 2, AND 3 DURING THE FALL SURVEY.

	Concentration (µg/g Dry Weight)		
	Station		
Compound	1	2	3
Benzene	0.0	0.0	0.0
C_1-B	0.0	0.0	0.0
C_2-B	0.025	0.013	0.007
C_3-B	0.013	0.005	0.002
C_4-B	0.004	0.0	0.0
C_5-B	0.0	0.0	0.0
C_6-B	0.0	0.0	0.0
Naphthalene	0.011	0.002	0.0
C_1-N	0.034	0.001	0.0
C_2-N	0.053	0.0	0.0
C_3-N	0.056	0.0	0.0
C_4-N	0.0	0.0	0.0
C_5-N	0.0	0.0	0.0
Biphenyl	0.005	0.0	0.0
C_1-BL	0.0	0.0	0.0
C_2-BL	0.0	0.0	0.0
C_3-BL	0.0	0.0	0.0
C_4-BL	0.0	0.0	0.0
C_5-BL	0.0	0.0	0.0
Dibenzothiophene	0.002	0.0	0.0
C_1-D	0.0	0.0	0.0
C_2-D	0.0	0.0	0.0
C_3-D	0.0	0.0	0.0
C_4-D	0.0	0.0	0.0
C_5-D	0.0	0.0	0.0
Fluorene	0.002	0.0	0.0
C_1-F	0.0	0.0	0.0
C_2-F	0.0	0.0	0.0
C_3-F	0.0	0.0	0.0
C_4-F	0.0	0.0	0.0
C_5-F	0.0	0.0	0.0
Phenanthrene	0.008	0.002	0.002
C_1-P	0.0	0.0	0.0
C_2-P	0.0	0.0	0.0
C_3-P	0.0	0.0	0.0
C_4-P	0.0	0.0	0.0
C_5-P	0.0	0.0	0.0
Pyrene	0.007	0.0	0.0
C_1-PY	0.0	0.0	0.0
C_2-PY	0.0	0.0	0.0
C_3-PY	0.0	0.0	0.0
C_4-PY	0.0	0.0	0.0
C_5-PY	0.0	0.0	0.0
Chrysene	0.0	0.0	0.0
C_1-C	0.0	0.0	0.0
C_2-C	0.0	0.0	0.0
C_3-C	0.0	0.0	0.0
C_4-C	0.0	0.0	0.0
C_5-C	0.0	0.0	0.0
Perylene	0.137	0.024	0.022
C_1-PL	0.0	0.0	0.0
C_2-PL	0.0	0.0	0.0
C_3-PL	0.0	0.0	0.0
C_4-PL	0.0	0.0	0.0
C_5-PL	0.0	0.0	0.0
TOTAL	0.366	0.047	0.033

TABLE 3.27. ESTIMATED CONCENTRATIONS OF TOTAL STERANES AND TRITERPANES IN COMPOSITE SAMPLES OF PRODUCED WATER AND SEDIMENT FROM EUGENE ISLAND COLLECTED DURING THE SPRING SURVEY.

Sample	Steranes	Triterpanes
Produced Water	63 μg/l	76 μg/l
Sediment		
Station 1	0.47 μg/g Dry Wt.	1.5 μg/g Dry Wt.
Station 2	0.18	0.61
Station 3	0.09	0.27
Station 4	0.11	0.36

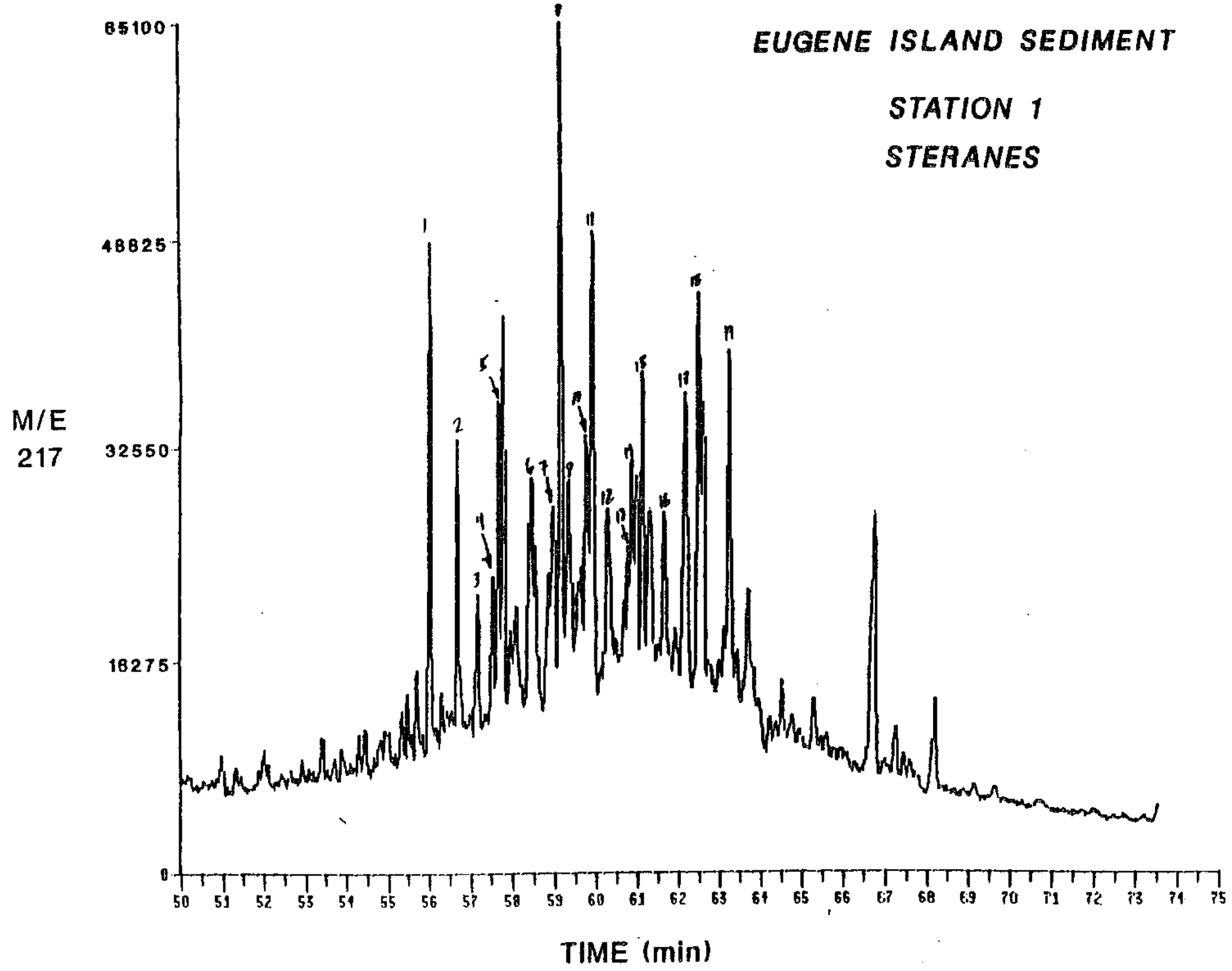


FIGURE 3.8. MASS ION CHROMATOGRAM OF STERANES (m/e - 217) IN SEDIMENTS FROM STATION 1, REPLICATE 1, FROM EUGENE ISLAND COLLECTED DURING IE SPRING SURVEY

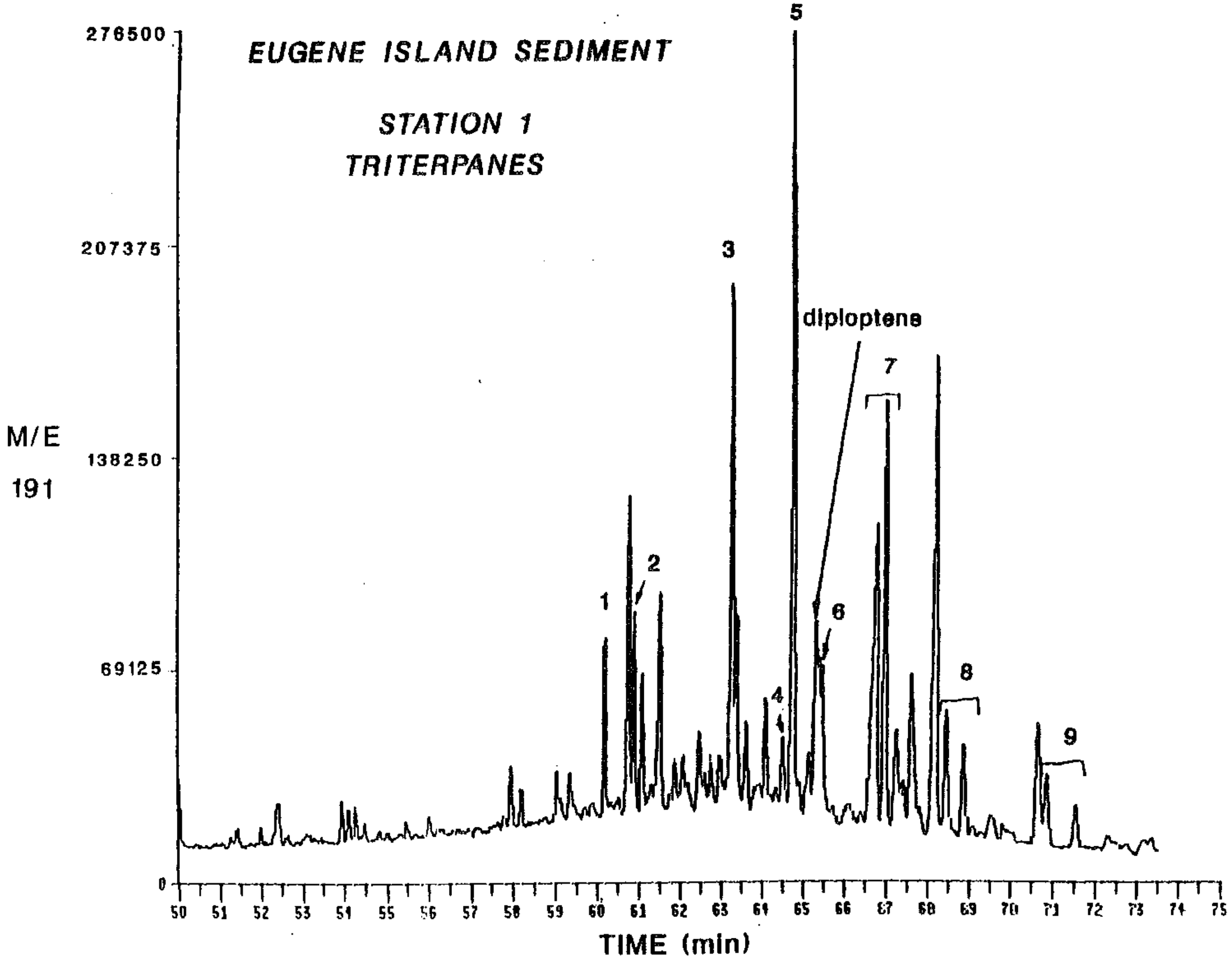


FIGURE 3.9. MASS ION CHROMATOGRAM OF TRITERPANES (m/e - 191) IN SEDIMENTS FROM STATION 1, REPLICATE 1, FROM EUGENE ISLAND COLLECTED DURING THE SPRING SURVEY.

relative amounts of C_{27} αα(R)(peak 10), C_{28}αα(R) (peak 16), and C_{29}αα(R) (peak 19) in produced water than in sediments. The series of 17α(4)-cholestane (20R) compounds is dominant in most sediment samples. The total sterane concentration (Table 3.27) in sediments from Station 1 (20 m) is more than twice as high as that in sediments from the other three stations, all of which are further away from the discharge. This concentration gradient is similar to that observed for other hydrocarbons and is correlated with percent silt/clay in sediments.

Significant differences are evident in the source-indicator ratio of the 24-ethyl 14α(H), 17α(H)-cholestane (20S) and the (20R) isomer (peaks 17 and 19, respectively) between the produced water and the sediment samples (see Figure 3.1 and 3.8 and Table 3.8). In addition, the relative abundance of C_{27}αα(R) cholestane (peak 10) is much different in produced water than in sediments. These differences are sufficient to suggest that produced water is not the sole or primary source of the steranes in the Eugene Island sediments.

The number of triterpanes in the sediment samples (Figure 3.9) is higher than the number in the produced water (Figure 3.2). Triterpanes are ubiquitous throughout the marine environment, not just in fossil fuels. These additional triterpanes may be attributed to biogenic inputs, as indicated by the presence of diplotene. Diploptene (17β(H)-hop-22(29)-ene), which is observed in all the sediment samples analyzed (Figure 3.11), is a biogenic triterpane. High concentrations of diplotene are associated with correspondingly high levels of other biogenic triterpanes. In addition, the low ratios of C22(S) to C22(R) isomers of the C31 hopanes relative to the expected 60:40 22S/22R distribution of higher maturity (Requejo et al., 1986) indicate an immature source for the sediment triterpane assemblage. The maturity ratio in sediments (Table 3.8) differs significantly from the ratio observed in the produced water. The maturity ratios of the sediments range from 0.83 to 0.91, whereas the ratio for produced water is 1.2. The total triterpane concentration (Table 3.27) is highest in the Station 1 sediment sample. Concentration estimates for triterpanes in Eugene Island sediments follow the same trend as those of steranes and other hydrocarbons.

3.3.1.6 Total Organic Carbon

Total organic carbon (TOC) concentrations were determined in all replicate sediment samples collected during the spring survey. Mean concentrations are presented in Table 3.28; results for replicate analyses are listed in Appendix E (Table E1). As observed with the other analytes determined in the sediment samples, the samples collected at stations nearest the platform (Station 1, 5, and 13) have the highest concentrations of TOC. With the exception of two samples from stations 1000 m from the platform, TOC concentrations decrease with distance from the platform. There is a positive correlation between the percent silt/clay and the TOC concentration in sediments.

3.3.1.7 Phenol and Alkyl Phenols

Phenols (C_0 through C_4 phenols) were determined in replicate sediment samples from all the 20-m stations (Stations 1, 5, 9, and 13) at the Eugene Island site. Tables 3.29 through 3.32 present the concentrations of phenols in all replicate samples from the four stations.

o-Cresol, C_2-phenols, and C4-phenols are not present at quantifiable concentrations in the sediment samples, with the exception of one replicate sample from Station 1 that contains 29 µg/kg o-cresol. With the exception of another replicate sample from Station 1 in which they were not detected, C_3-phenols are present in all sediment samples at concentrations ranging from 96 to 428 µg/kg. Phenol is present at a higher concentration than any of the alkyl phenols, with concentrations

TABLE 3.28. PERCENT TOTAL ORGANIC CARBON IN SEDIMENTS FROM EUGENE ISLAND COLLECTED DURING THE SPRING SURVEY.

Station	Mean	Standard Deviation
1 (W, 20 m)	0.69	0.20
2 (W, 100 m)	0.27	0.08
3 (W, 300 m)	0.13	0.04
4 (W, 1000 m)	0.64	0.46
5 (N, 20 m)	0.53	0.33
6 (N, 100 m)	0.34	0.17
7 (N, 300 m)	0.14	0.03
8 (N, 1000 m)	0.31	0.13
9 (E, 20 m)	0.16	0.02
10 (E, 100 m)	0.14	0.01
11 (E, 300 m)	0.13	0.02
12 (E, 1000 m)	0.16	0.05
13 (S, 20 m)	0.67	0.10
14 (S, 100 m)	0.29	0.27
15 (S, 300 m)	0.22	0.09
16 (S, 1000 m)	0.17	0.03

TABLE 3.29. PHENOL CONCENTRATIONS IN SEDIMENTS COLLECTED AT EUGENE ISLAND, STATION 1, DURING THE SPRING SURVEY.

Compound	Concentration (µg/kg Dry Weight)				
	Replicate				
	1	2	3	Mean	Standard Deviation
Phenol	785[a]	592[a]	582[a]	653[a]	114
o-Cresols	ND	29.0	ND	9.67	16.7
m,p-Cresols	ND	ND	ND	--	--
C_2-Phenols	ND	ND	ND	--	--
C_3-Phenols	255	173	ND	143	130
C_4-Phenols	ND	ND	ND	--	--
		TOTAL PHENOLS		**806**	

[a] Concentrations of phenol here probably are substantially higher than the actual concentrations in sediments as indicated by the excessively high recovery of phenol from the spiked blanks (220%) and the presence of phenol in the laboratory blank.

TABLE 3.30. PHENOL CONCENTRATIONS IN SEDIMENTS COLLECTED AT EUGENE ISLAND, STATION 5, DURING THE SPRING SURVEY.

	Concentration (µg/kg Dry Weight)				
	Replicate				
Compound	1	2	3	**Mean**	**Standard Deviation**
Phenol	1540[a]	1150[a]	798[a]	1160[a]	371
o-Cresols	ND	ND	ND	--	--
m,p-Cresols	ND	37.0	74.2	37.1	37.1
C_2-Phenols	ND	ND	ND	--	--
C_3-Phenols	132	177	127	145	27.5
C_4-Phenols	ND	ND	ND	--	--
		TOTAL PHENOLS		**1340**	

[a] Concentrations of phenol listed here probably are substantially higher than actual concentrations in sediments as indicated by the excessively high recovery of phenol from the spiked blanks (220%) and the presence of phenol in the laboratory blanks.

TABLE 3.31. PHENOL CONCENTRATIONS IN SEDIMENTS COLLECTED AT EUGENE ISLAND, STATION 9, DURING THE SPRING SURVEY.

	Concentration (µg/kg Dry Weight)				
	Replicate				Standard
Compound	1	2	3	**Mean**	**Deviation**
Phenol	1210[a]	818[a]	1280[a]	1100[a]	249
o-Cresols	ND	ND	ND	--	--
m,p-Cresols	28.7	8.8	13.3	16.9	10.4
C_2-Phenols	ND	ND	ND	--	--
C_3-Phenols	117	95.8	131	115	17.7
C_4-Phenols	ND	ND	ND	--	--
		TOTAL PHENOLS		1230	

[a] Concentrations of phenol listed here probably are substantially higher than actual concentrations in sediments as indicated by the excessively high recovery of phenol from the spiked blanks (220%) and the presence of phenol in the laboratory blanks.

TABLE 3.32. PHENOL CONCENTRATIONS IN SEDIMENTS COLLECTED AT EUGENE ISLAND, STATION 13, DURING THE SPRING SURVEY.

	Concentration (μg/kg Dry Weight)				
	Replicate				Standard Deviation
Compound	1	2	3	Mean	
Phenol	3010[a]	1620[a]	1540[a]	2060[a]	.826
o-Cresols	ND	ND	ND	--	--
m,p-Cresols	57.6	45.4	42.2	48.4	8.13
C_2-Phenols	ND	ND	ND	--	--
C_3-Phenols	428	307	338	358	62.8
C_4-Phenols	ND	ND	ND	--	--
		TOTAL PHENOLS		**2470**	

[a] Concentrations of phenol listed here probably are substantially higher than actual concentrations in sediments as indicated by the excessively high recovery of phenol from the spiked blanks (220%) and the presence of phenol in the laboratory blanks.

in some cases above 1 ppm. However, because phenol was found in laboratory blanks, these reported phenol concentrations probably are higher than actual concentrations.

Produced water samples from Eugene Island 105 contain all the alkyl phenols analyzed (Table 3.11). If the phenols present in sediments near the platform were derived from produced water, it is expected either that all the phenols would be found in the sediments or that a trend of increasing concentration with increasing molecular weight (decreasing water solubility) would be evident in the sediment samples. Neither of these situations was observed. The different distribution of phenols in sediments and in produced water could be due to differences in the rate of chemical or biological degradation of phenols in marine sediments. The ubiquitous presence of C_3-phenols indicates that the source of phenols could be from another anthropogenic source or that the suite of phenols found represents a natural biogenic assemblage for coastal sediments. The C_3-phenols are not dominated by one C_3-phenol. Because this study is one of the first in which phenols have been determined in marine sediments, the natural background levels of phenols in coastal sediments are uncertain.

3.3.1.8 Metals

3.3.1.8.1 Spring Survey. Nine metals, barium, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc, were determined in replicate sediment samples from all 16 stations at the Eugene Island, Block 105. The concentrations of these metals in each sample are presented in Appendix F (Tables F1 through F9). Mean concentrations of the nine metals are shown with their standard deviations in Table 3.33.

Overall, all metals except barium are present in the sediments at concentrations that could be considered background for coastal waters of the northern Gulf of Mexico (Boothe and

TABLE 3.33. CONCENTRATIONS OF TRACE METALS IN SEDIMENTS FROM EUGENE ISLAND COLLECTED DURING SPRING SURVEY (MEAN OF THREE REPLICATES ± STANDARD DEVIATION).

Station (Distance, M)	Direction From Platform W	 N	 E	 S
	(Concentrations in mg/kg Dry Weight)			
	Barium			
20	1164 ± 420	979 ± 208	1017 ± 294	1080 ± 149
100	1088 ± 273	1092 ± 188	1061 ± 93	1407 ± 494
300	1354 ± 563	994 ± 328	837 ± 297	2017 ± 290
1000	809 ± 265	1099 ± 230	797 ± 276	1597 ± 407
	Cadmium			
20	0.041 ± 0.005	0.051 ± 0.020	0.023 ± 0.001	0.048 ± 0.002
100	0.041 ± 0.016	0.029 ± 0.003	0.017 ± 0.002	0.032 ± 0.006
300	0.024 ± 0.002	0.020 ± 0.002	0.025 ± 0.006	0.060 ± 0.050
1000	0.034 ± 0.007	0.026 ± 0.004	0.029 ± 0.002	0.027 ± 0.004
	Chromium			
20	12.31 ± 1.25	11.09 ± 1.20	7.68 ± 0.66	11.71 ± 2.60
100	8.41 ± 0.82	8.15 ± 0.99	6.29 ± 2.02	9.98 ± 1.43
300	6.24 ± 1.45	12.08 ± 5.10	8.73 ± 1.71	10.04 ± 1.67
1000	9.36 ± 0.82	7.66 ± 2.82	9.15 ± 0.58	8.47 ± 0.55
	Copper			
20	7.57 ± 0.91	7.22 ± 0.75	2.59 ± 0.31	7.08 ± 0.69
100	3.53 ± 0.78	4.40 ± 0.81	2.20 ± 0.32	3.39 ± 2.03
300	2.24 ± 0.82	2.05 ± 0.22	2.08 ± 0.34	3.36 ± 0.65
1000	5.74 ± 2.55	3.63 ± 1.61	2.71 ± 0.61	2.36 ± 0.19
	Lead			
20	10.73 ± 2.76	10.42 ± 0.56	6.09 ± 0.28	10.03 ± 0.99
100	6.84 ± 0.70	7.92 ± 1.84	5.43 ± 0.29	6.77 ± 1.44
300	5.09 ± 0.75	34.48 ± 51.68	5.22 ± 0.18	6.37 ± 0.67
1000	8.05 ± 2.10	7.36 ± 0.30	5.28 ± 0.43	4.84 ± 0.28
	Mercury			
20	0.017 ± 0.002	0.020 ± 0.001	0.014 ± 0.001	0.015 ± 0.003
100	0.013 ± 0.003	0.015 ± 0.002	0.011 ± 0.000	0.012 ± 0.001
300	0.024 ± 0.023	0.013 ± 0.004	0.013 ± 0.001	0.013 ± 0.001
1000	0.013 ± 0.003	0.013 ± 0.001	0.014 ± 0.004	0.011 ± 0.001
	Nickel			
20	12.7 ± 1.50	13.5 ± 0.70	8.62 ± 0.29	11.6 ± 1.30
100	9.64 ± 0.57	10.2 ± 0.63	8.36 ± 0.30	8.62 ± 1.47
300	8.19 ± 0.56	7.23 ± 0.67	7.95 ± 0.38	8.35 ± 0.31
1000	11.5 ± 1.81	8.66 ± 2.44	8.37 ± 0.44	7.85 ± 0.24
	Silver			
20	0.019 ± 0.003	0.023 ± 0.003	0.009 ± 0.001	0.031 ± 0.004
100	0.009 ± 0.002	0.015 ± 0.002	0.010 ± 0.005	0.018 ± 0.008
300	0.008 ± 0.004	0.008 ± 0.001	0.006 ± 0.002	0.018 ± 0.003
1000	0.018 ± 0.008	0.013 ± 0.003	0.014 ± 0.002	0.009 ± 0.004
	Zinc			
20	55.4 ± 7.40	58.6 ± 2.90	38.1 ± 1.70	52.2 ± 6.00
100	40.0 ± 1.30	46.2 ± 3.40	35.7 ± 1.10	38.0 ± 6.20
300	35.0 ± 3.30	38.0 ± 9.00	33.1 ± 1.20	38.0 ± 2.30
1000	47.9 ± 8.40	39.1 ± 12.8	35.7 ± 2.00	33.7 ± 1.20

Presley, 1985). Mean barium concentrations in sediments in the study area range from 800 mg/kg to 2000 mg/kg, which is above the typical background concentrations of 500 to 700 mg/kg for barium in Gulf of Mexico coastal sediments (Boothe and Presley, 1985). However, natural marine sediments may contain up to about 8000 ppm barium (Neff et al., 1987), so it is uncertain whether the higher than expected concentrations of barium in sediments near the platform in Eugene Island 105 are of natural or anthropogenic origin. Barium is present at higher than expected concentrations in surficial sediments throughout the study site without any discernible pattern. This type of distribution was also observed in the samples taken in the study area during the preliminary survey. The elevated concentrations of barium in sediments around the platform may be the result of area-wide historic discharges of drilling fluids and produced water (both high in barium), or they may be natural.

There is an unusually high concentration of lead in one sediment replicate at one station (Station 7) of the site; the other replicates are within the normal range for lead. The concentration of lead in this replicate is 94 mg/kg, whereas the concentrations of lead in the other two replicates for the station are 4 mg/kg. This high lead concentration could be due to a variety of reasons unrelated to produced water, such as sample contamination or paint chips in the sediment sample. It is likely that these elevated concentrations of lead in single replicate samples are due to inclusion of foreign materials in the sediment sample and are not an indication of accumulation of metal contaminants from the platform.

For most of the metals (i.e., copper, lead, mercury, silver, and zinc, and perhaps cadmium and chromium), the concentration of the metal varies with the percent silt/clay fraction in the sediments. Usually, concentrations are higher in sediments that have a higher percent silt/clay than in sediments with a low percent silt/clay. The correlation, however, is not as obvious for metals as it is for hydrocarbons.

3.3.1.8.2 Fall Survey. Barium, nickel, and mercury were analyzed in samples from the fall survey. The concentrations of these metals are presented in Table 3.34.

As was observed in the spring survey, concentrations of barium are above apparent background levels and fall in the range of 900 to 1100 mg/kg. Concentrations of nickel are in the range of 10 to 14 mg/kg, similar to the concentration range for nickel in samples from the spring survey. The distribution of these metals along the transect in the fall survey is similar to that in the spring survey.

Mercury concentrations in these fall survey samples range from 0.034 to 0.234 mg/kg. Except for the exceptionally high and probably anomalous value for mercury in the sediment sample from Station 3 (0.234 mg/kg), mercury levels are 3 to 5 times higher in the fall survey samples than in the spring survey samples (Table 3.33). The reason for this increase between surveys is not known. Although methods used for mercury analysis were different for samples from the two surveys, results of quality control checks indicated acceptable precision and accuracy for analyses by both techniques. No other metal parameters exhibited this large change between surveys.

3.3.1.9 Species Composition

3.3.1.9.1 Spring Survey. A total of 179 taxa of benthic fauna were recorded in surficial sediments from stations around the platform in Eugene Island, Block 105 (Table 3.35). This total includes taxa collected in both the spring and fall collections. Table 3.36 shows the number of taxa that are present only in the spring samples, only in the fall samples, or in samples from both seasons. The major phyla typically present in marine habitats (Arthropoda, Mollusca, and Annelida) are represented by

TABLE 3.34. CONCENTRATIONS OF TRACE METALS (μg/kg) IN SEDIMENTS FROM FOUR STATIONS AT EUGENE ISLAND COLLECTED DURING THE FALL SURVEY.

Station	Replicate	Ni	Hg	Ba
1	1 (W, 20 m)	11.6	0.042	1000
	2	11.0	0.041	1100
	3	18.6	0.112	572
	$\bar{x}$ ± S.D.	**13.7 ± 4.22**	**0.065 ± 0.041**	**891 ± 280**
2	1 (W, 100 m)	13.2	0.039	972
3	1 (W, 300 m)	13.9	0.234	997
4	1 (W, 1000 m)	10.4 (10.2)[a]	0.034 (0.46)[a]	887
Blank		<0.5	<0.025	NA

[a] Duplicate analysis of sample.

TABLE 3.35. SPECIES RECORDED FROM INFAUNAL SAMPLES COLLECTED AT EUGENE ISLAND STATIONS. SPECIES MARKED WITH AN ASTERISK (*) WERE NOT INCLUDED IN STATISTICAL ANALYSES.

CNIDARIA
- Hydrozoa
    - **Clytia coronata*
    - **Clytia cylindrica*
    - **Halecium bermudense*
    - Hypolytidae sp. 1
    - **Lovenella* cf. *gracilis*
    - **Lovenella* sp. 1
    - **Obelia geniculata*
    - **Obelia hyalina*
- Anthozoa
    - *Bunctactis texaensis*
    - Anthozoa sp. 1, 2, 3

PLATYHELMINTHES
- *Turbellaria

NEMERTEA
- *Cerebratulus* sp. 1
- *Micrura* sp. 1
- Nemertea sp. 1, 2, 3, 4, 5

ANNELIDA
- Polychaeta
    - Ampharetidae
        - *Melinna maculata*
        - *Sabellides* sp. 1
    - Amphinomidae
        - *Paramphinome* sp. 1
    - Capitellidae
        - *Capitella capitata*
        - *Mediomastus ambiseta*
        - *Notomastus hemipodus*
        - *Notomastus latericeus*
    - Chaetopteridae
        - *Spiochaetopterus costarum*
    - Chrysopetalidae
        - *Bhawnia heteroseta*
    - Cirratulidae
        - *Chaetozone* sp. 2
        - *Cirriformia* sp. 1, 2, 3
        - *Tharyx acutus*
    - Cossuridae
        - *Cossura delta*
    - Eulepethidae
        - *Grubeulepis mexicana*
        - *Goniada* sp. 1
    - Glyceridae
        - *Glycera americana*
    - Goniadidae
        - *Glycinde solitaria*
    - Hesionidae
        - *Gyptis brevipalpa*
        - *Gyptis vittata*
    - Lumbrineridae
        - *Lumbrineris verrilli*
    - Magelonidae
        - *Magelona* sp. 1, 2
    - Maldanidae
        - *Asychis elongata*
        - *Maldane* sp. 1
    - Nephtyidae
        - *Aglaophamus verrilli*
    - Nereididae
        - *Neanthes micromma*
        - *Neanthes succinea*
    - Onuphidae
        - *Diopatra* sp. 1
        - Onuphidae sp. 1
    - Opheliidae
        - *Armandia maculata*
    - Orbiniidae
        - *Leitoscoloplos fragilis*
        - *Scoloplos* sp. 1
    - Oweniidae
        - *Galathowenia* nr. *oculata*
        - *Myriowenia* sp. 1
        - *Owenia* sp. 1
    - Paraonidae
        - *Aricidea catherinae*
        - *Aricidea* nr. *fragilis*
        - *Aricidea* nr. *taylori*
        - *Aricidea* sp. 1, 2, 3, 4
        - *Paradoneis* sp. 1, 2
    - Pectinariidae
        - *Amphictene* sp. 1
    - Phyllodocidae
        - *Phyllodoce arenae*
    - Pilargidae
        - *Ancistrosyllis jonesi*
        - *Ancistrosyllis papillosa*
        - *Cabira incerta*
        - *Litocorsa antennata*
        - *Sigambra tentaculata*
        - *Sigambra* sp. 1

TABLE 3.35. (Continued)

- Polynoidae
  - Polynoidae sp. 1
- Sabellariidae
  - *Sabellaria* sp. 1
- Sabellidae
  - *Chone* sp. 1
- Sigalionidae
  - *Sthenelais* sp. 1
- Spionidae
  - *Apoprionospio pygmaea*
  - *Carazziella hobsonae*
  - *Paraprionospio pinnata*
  - *Polydora socialis*
  - *Polydora* sp. 1
  - *Prionospio cristata*
  - *Prionospio perkinsi*
  - *Scolelepis texana*
  - *Spiophanes bombyx*
  - *Spiophanes* nr. *missionenis*
  - *Streblospio benedicti*
- Terebellidae
  - *Loimia medusa*
- Oligochaeta
  - Oligochaeta spp.

ECHIURA

- *Echiura spp. indeterminate

SIPUNCULA

- *Aspidosiphon albus*
- *Golfingia* cf. *trichocephala*
- *Golfingia* sp. 1
- *Phascolion strombi*

MOLLUSCA

- Bivalvia
  - *Anadara transversa*
  - *Chione* sp. 1
  - *Corbula* cf. *caribaea*
  - *Crassostrea virginica*
  - *Dosinia elegans*
  - *Linga amiantus*
  - *Lucinoma filosa*
  - *Macoma tenata*
  - *Macoma* sp. 1
  - *Mulinia lateralis*
  - Nuculanidae sp. 1
  - *Pandora arenosa*
  - *Parvilucina mattilineata*
  - *Solen vividis*
  - *Tellina alternata*
  - *Tellina vesicolor*
- Gastropoda
  - *Acteon schuctostriatus*
  - *Anachis obesa*
  - *Crepidula fornicata*
  - *Cyclostremella humilis*
  - *Epitonium albidum*
  - *Limacina* spp. juvenile
  - Mellanellidae sp. 1
  - *Nassarius acutus*
  - *Nassarius vibex*
  - *Natica pusilla*
  - *Odostomia* cf. *gibbosa*
  - *Polynices duplicatus*
  - Pyramidellidae sp. 1
  - *Terebra protexta*
  - *Turbonilla* sp. 1, 3

ARTHROPODA

- Arachnida
  - *Acarina
- Crustacea
- Cirripedia
  - Cirripedia sp. 1
  - Decapoda
    - *Albunea parettii*
    - Brachyura sp. 1
    - *Callinectes similis*
    - *Euceramus praelongus*
    - *Hepatus ephiliticus*
    - *Hepatus pudibundus*
    - *Leptochaela serratorbita*
    - Majidae spp. juvenile
    - *Ogryides alphaerostris*
    - *Pagurus* sp. 1
    - Penaeidea sp. 1
    - *Persephona crinata*
    - *Pinnixa sayana*
    - *Pinnixa* sp. 1
    - Portunidae spp. juvenile
    - *Processa hemphilli*
    - Xanthidae spp. juvenile
  - Cumacea
    - *Cyclaspis pustulata*
    - *Oxyurostylis* sp. 1
  - Isopoda
    - *Munna* sp. 1

TABLE 3.35. (Continued)

- Amphipoda
  - _Ampelisca verrilli_
  - _Ampelisca_ sp. 2
  - _Batea catharinensis_
  - _Callianassa_ sp. 1, 2
  - Caprellidea spp. juvenile
  - _Corophium acherusicum_
  - _Corophium tuberculatum_
  - Gammaridea sp. 7
  - *Hyperiidea sp. 1
  - _Listriella barnardi_
  - _Microprotopus shoemakeri_
  - _Monoculodes nyei_
  - _Paracaprella pusilla_
  - Stenothoidae sp. 1
  - _Synchelidium americanum_
  - _Tiron tricellatus_
  - Amphipoda sp. 1
- Pycnogonida
  - _Anoplodactylus petiolatus_

PHORONIDA

- _Phoronis architecta_

BRYOZOA

- *_Aeverrilla armata_
- *_Anguinella palmata_
- *_Bowerbankia gracilis_
- *_Membranipora tenuis_
- *_Membranipora tuberculata_

ECHINODERMATA

- Ophiuroidea
  - _Hemipholis elongata_
  - _Micropholis atra_

CHAETOGNATHA

- *_Sagitta_ spp.

CHORDATA

- _Branchiastoma caribaeum_
- _Myrophis punctata_

TABLE 3.36. NUMBER OF TAXA (INCLUDING JUVENILES AND INDETERMINATES) PRESENT IN SPRING, FALL, OR BOTH SEASONS AT EUGENE ISLAND.

	Station			
	1	2	3	4
Spring Only	25	44	32	23
Fall Only	36	37	38	32
Both Seasons	17	25	28	28
Total Taxa	78	106	98	83

40, 32, and 70 species, respectively. The Oligochaeta were not identified to species, but this taxon probably is represented in the samples by more than one species. Additionally, several minor phyla are present in sediments from Eugene Island, including four species of sipunculans, seven species of nemerteans, and one species of phoronid. Five species of bryozoans and eight species of hydrozoans are present in the samples; these colonial taxa are not included in the statistical analyses because it is not possible to determine numbers of individuals for these forms.

3.3.1.9.2 Fall Survey. Samples from Stations 1 through 4 from the fall survey were analyzed for infauna. As presented above in Table 3.36, there are several species present in the fall collections at Eugene Island Stations 1 through 4 that are not present in the spring samples. Three species of polychaetes that dominate the spring samples are not present at any of the four stations sampled in the fall. These three species are *Spiophanes bombyx*, *Sabellides* sp. 1, and *Scoloplos* sp. 1. Additional differences in species composition between the spring and fall samples are presented below in the Section 3.3.1.11 *Dominance* and Section 3.3.1.13 *Percent Juveniles*.

3.3.1.10 Diversity

3.3.1.10.1 Spring Survey. The values for the Shannon-Wiener diversity index (H′) at the 16 stations at Eugene Island sampled in the spring survey are summarized in Table 3.37 and plotted in Figure 3.10. A more detailed presentation of this index and several other diversity measures is given in Appendix G. The value of H′ at the Eugene Island stations ranges from 1.50 to 2.64. In general, diversity is lowest at the stations closest to the platform (Figure 3.10). At these stations, the H′ value ranges from 1.52 (Station 1) to 1.96 (Station 5). Diversities are similar at the stations 100 m to the west (1.95 at Station 2) and north (1.38 at Station 6) and higher at Stations 10 and

TABLE 3.37 BENTHIC COMMUNITY PARAMETERS FOR SAMPLES COLLECTED AT EUGENE ISLAND IN SPRING 1986. VALUES ARE FOR SIX REPLICATES COMBINED.

Station	Distance from Platform (m)	Mean Density per 0.01 m^2[a] (± S.D.)	Total Taxa[a]	H'[b,c]	Evenness	Spp/100[b,d]	Spp/500[b,d]	Spp/1000[b,d]
1	20	180.7 ± 58.3	41	1.52	0.30	11.2	23.7	32.0
2	100	286.2 ± 84.5	68	1.95	0.34	12.5	32.4	44.8
3	300	93.5 ± 50.5	62	3.26	0.58	20.0	46.0	c
4	1000	111.7 ± 30.0	52	1.81	0.33	16.4	41.5	c
5	20	188.0 ± 32.2	49	1.96	0.36	12.3	29.7	40.3
6	100	487.0 ± 179.4	74	1.38	0.23	9.3	26.7	40.1
9	20	173.3 ± 70.0	46	1.89	0.36	12.9	29.5	39.5
10	100	124.0 ± 38.1	61	2.71	0.47	19.0	47.3	c
11	300	117.5 ± 34.9	58	3.26	0.57	20.5	46.1	c
12	1000	103.3 ± 41.2	56	3.00	0.54	20.2	44.6	c
13	20	224.0 ± 47.7	42	1.55	0.29	10.8	25.0	34.5
14	100	159.5 ± 50.2	64	2.74	0.46	18.7	46.4	c
15	300	209.0 ± 66.7	54	2.37	0.43	14.1	33.2	43.8
16	1000	116.0 ± 25.7	63	2.72	0.46	20.6	51.2	c

[a] These values are based on the total numbers of individuals in the six replicates collected at each station and correspond to density and number of taxa reported in Appendix H.

[b] Diversity measures were calculated after removing "indeterminate" and unidentified juveniles from the total density for each station. The densities and number of taxa on which these values are based are reported in Appendix 6.

[c] Shannon-Wiener diversity index.

[d] Hurlbert rarefaction index (estimated number of species per X individuals).

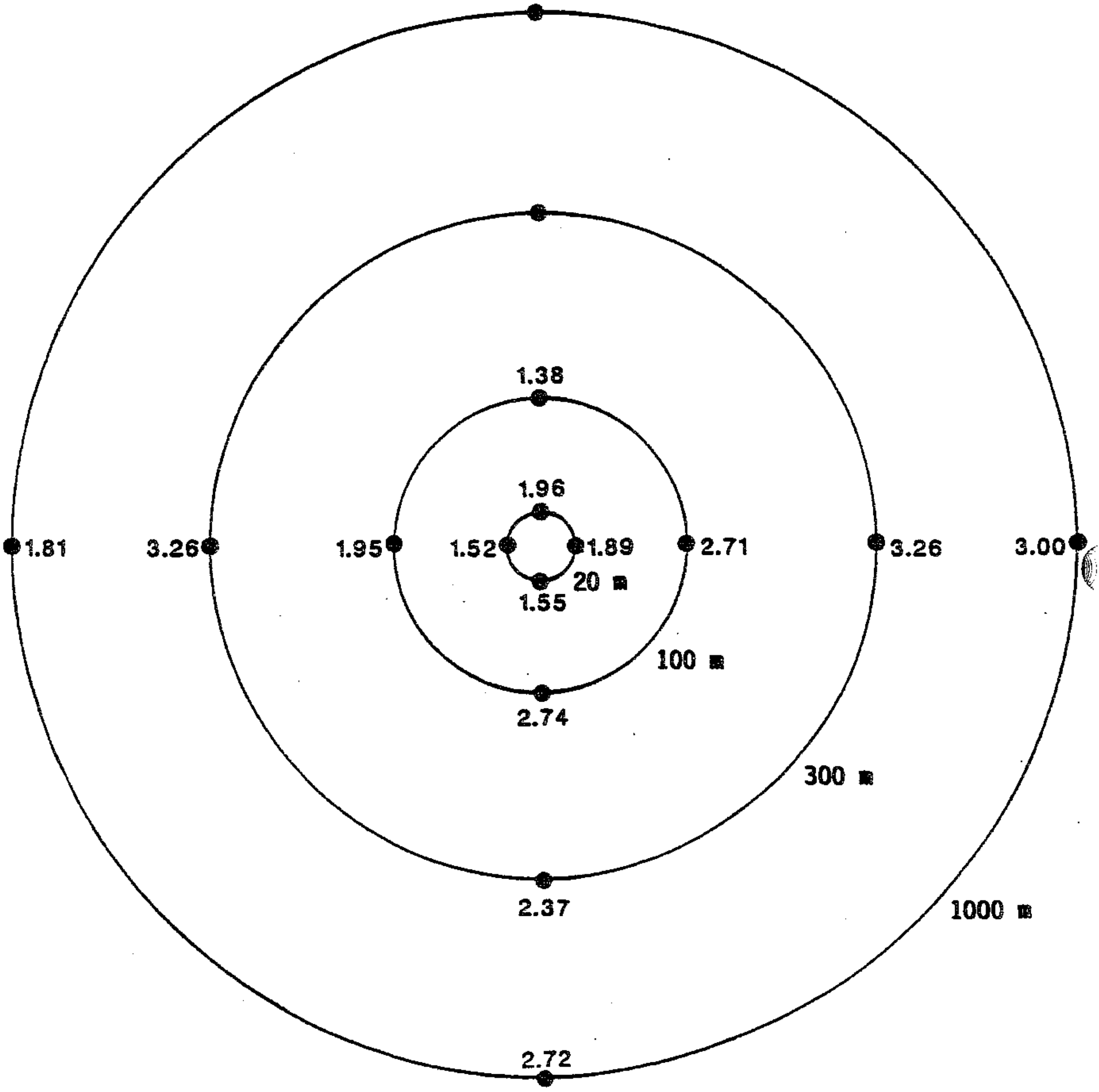


FIGURE 3.10. SHANNON-WIENER DIVERSITY INDEX (H′) FOR BENTHIC FAUNA IN SAMPLES COLLECTED AT EUGENE ISLAND, STATIONS 1-6 AND 9-16, DURING THE SPRING SURVEY.

14, 100 m to the east and south, respectively. With one exception, diversities are similar or higher at stations farther from the platform, i.e., at distances of 300 and 1000 m. The exception is Station 4, located 1000 m to the west; this station has an H′ value of 1.81, similar to the lower values seen at the stations near the platform.

The H′ values appear to be highly correlated with the percent silt-plus-clay: the highest diversities are seen at stations with the lowest percentages of silt-plus-clay. Therefore, the low value of 1.81 at Station 4, which is 1000 m from the platform, compared to the higher value of 3.26 at Station 3, which is only 300 m from the platform, can be related to the differences in sediment texture at the two stations. Sediment samples for infauna from Station 3 have only 14.7 percent silt/clay, whereas those from Station 4 have 36.6 percent silt/clay (see Table 3.18).

Hurlbert rarefaction values are given in Table 3.37. This analysis allows the comparison of samples containing different numbers of individuals by reducing those samples to equal numbers of individuals. The values for the expected number of species per 500 individuals are plotted in Figure 3.11. The results of the rarefaction analysis are similar to those obtained with the Shannon-Wiener index: the Hurlbert rarefaction values appear to be correlated with sediment texture and reflect the same general pattern as the Shannon-Wiener H′ values. For example, the lowest values, ranging from 23.7 to 29.7, are seen at stations closest to the platform. Although the difference in Hurlbert diversity between the silty Station 4 and the coarse-textured Station 3 is not as great as indicated by the Shannon-Wiener index, values are generally higher at stations with coarser sediments.

3.3.1.10.2 Fall Survey. The values for the Shannon-Wiener diversity index (H′) at Stations 1 through 4 are given in

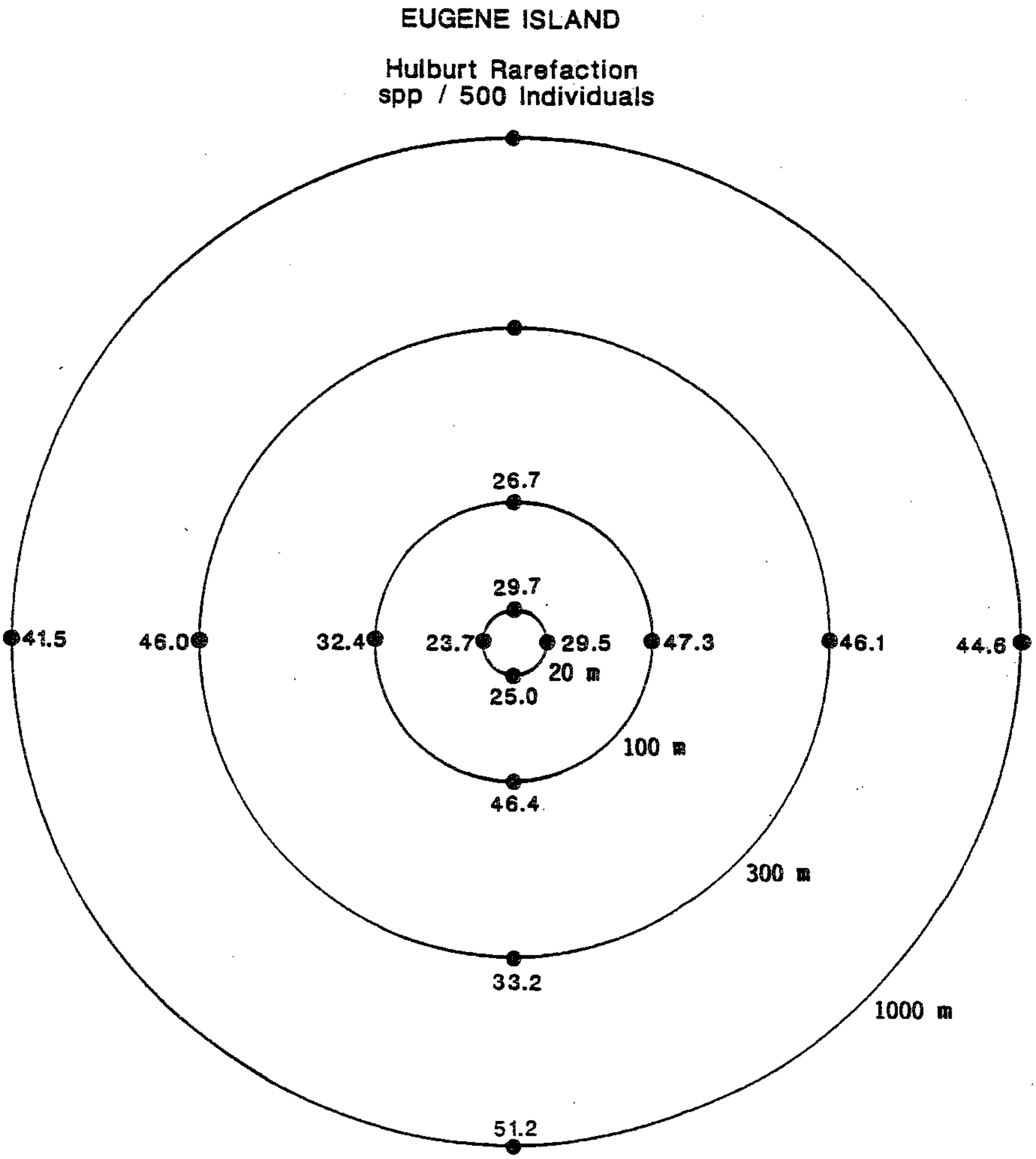


FIGURE 3.11. HURLBERT RAREFACTION VALUES FOR NUMBER OF SPECIES PER 500 INDIVIDUALS IN SEDIMENT SAMPLES COLLECTED AT EUGENE ISLAND DURING THE SPRING SURVEY.

Table 3.38. A more detailed presentation of this index and other diversity parameters is given in Appendix G. The value of H′ is highest at Station 1 and decreases with distance from the platform. In contrast to what was observed in the spring samples, the H′ index does not appear to be correlated with the percent silt/clay in the samples: Station 3 again has the coarsest sediments, but exhibits a much lower diversity than is seen at stations with siltier sediments. At Station 2, the H′ value is nearly the same for both spring and fall samples (1.95 vs. 1.90, respectively) but the sediments are much coarser in the fall than in the spring (54.4 percent silt-plus clay in the spring vs. 32.1 percent in the fall).

Hurlbert rarefaction values show a pattern similar to but not identical to that seen for the Shannon-Wiener index (Table 3.38). The highest values are for samples from Stations 1 and 2; but the number of species in samples from Station 2 is slightly greater than that from Station 1 (even though this is not reflected by the Shannon-Wiener index). Samples from Stations 3 and 4 have lower diversities than samples from the stations near the platform.

3.3.1.11 Dominance

3.3.1.11.1 Spring Survey. Dominance was evaluated in two ways: (1) by calculation of the evenness component of the Shannon-Wiener diversity index, and (2) by calculation of the percent contribution of each species at each station. Evenness is a measure of how the individuals in the sample are distributed among the species in the sample. Values for this parameter can range from 0 to 1: the lower the value, the more the community is dominated by one or a few species. Conversely, high evenness values imply that the individuals in the sample are distributed equitably among the species in the collection. In benthic samples from the spring survey, evenness values at the Eugene Island stations are lowest at

TABLE 3.38. BENTHIC COMMUNITY PARAMETERS FOR SAMPLES COLLECTED AT EUGENE ISLAND IN FALL 1986.

Station	Distance from Platform (m)	Mean Density per 0.01 m^{2a} (± S.D.)	Total Taxa[a]	H'[b,c]	Evenness	Spp/100[b,d]	Spp/500[b,d]	Spp/1000[b,d]
1	20	202.2 ± 101.5	50	2.00	0.36	14.3	30.2	42.7
2	100	295.3 ± 94.2	60	1.90	0.33	14.6	32.8	44.4
3	300	410.5 ± 84.4	62	1.41	0.24	12.3	29.8	40.0
4	1000	392.3 ± 69.5	56	1.38	0.25	10.9	25.7	35.2

[a] These values are based on the total numbers of individuals in the six replicates collected at each station and correspond to density and number of taxa reported in Appendix H.

[b] Diversity measures were calculated after removing "indeterminate" and unidentified juveniles from the total density for each station. The densities and number of taxa on which these values are based are reported in Appendix 6.

[c] Shannon-Wiener diversity index.

[d] Hurlbert rarefaction index (estimated number of species per X individuals).

Stations 6 and 13, with values of 0.23 and 0.29, respectively (Table 3.37). The highest evenness values are for samples from Stations 3 and 11, which have values of 0.58 and 0.57, respectively. (Stations 3 and 11 also have the highest Shannon-Wiener diversity indices and the coarsest sediments of the stations sampled.) Values at the remaining stations range from 0.33 to 0.54.

Table 3.39 is a list of the 15 top dominant species for all spring samples combined. The top dominant is the capitellid polychaete Mediomastus ambiseta, which is an order of magnitude more abundant than any other species. This species is recognized as an early colonizer of disturbed habitats, where it is often present in extremely high densities (e.g., Sanders et al., 1978). An undescribed species of cumacean, Oxyurostylis sp. 1, ranks second in abundance, and Mulinia lateralis, an opportunistic bivalve, ranks third. The majority of the remaining dominant species include five polychaetes, three bivalves, two amphipods, one isopod, and one sipunculan.

Appendix H includes information on the rank and percent contribution of each species at each station. By inspection, it can be seen that M. ambiseta is the top dominant at all of the stations sampled. The percent contribution of this species is mapped in Figure 3.12. Values range from 32.3 percent at Station 11 to 80.0 percent at Station 6. Abundances greater than 68 percent occur at all stations 20 m from the platform and at one station each at 100 and 1000 m. The low evenness values presented in Table 3.37 reflect this high dominance by a single species. The bivalve Mulinia lateralis, another opportunistic species, ranks second at Stations 2, 5, and 15, where it accounts for 19.1, 8.1, and 13.4 percent of the fauna, respectively. This species ranks third or lower at the remaining stations.

3.3.1.11.2 Fall Survey. Evenness values for the fall samples at

TABLE 3.39. FIFTEEN TOP DOMINANT SPECIES AT EUGENE ISLAND STATIONS SPRING 1986.

Rank	Species
1	*Mediomastus ambiseta* (polychaete)
2	*Oxyurostylis* sp. 1 (cumacean)
3	*Mulinia lateralis* (bivalve)
4	*Sabellides* sp. 1 (polychaete)
5	*Spiophanes bombyx* (polychaete)
6	*Scoloplos* sp. 1 (polychaete)
7	*Munna* sp. 1 (isopod)
8	*Paraprionospio pinnata* (polychaete)
9	*Magelona* sp. 1 (polychaete)
10	*Phascolion strombi* (sipunculan)
11	*Microprotopus shoemakeri* (amphipod)
12	*Paramphinome* sp. 1 (polychaete)
13	*Tellina versicolor* (bivalve)
14	*Macoma* sp. 1 (bivalve)
15	*Solen viridis* (bivalve)

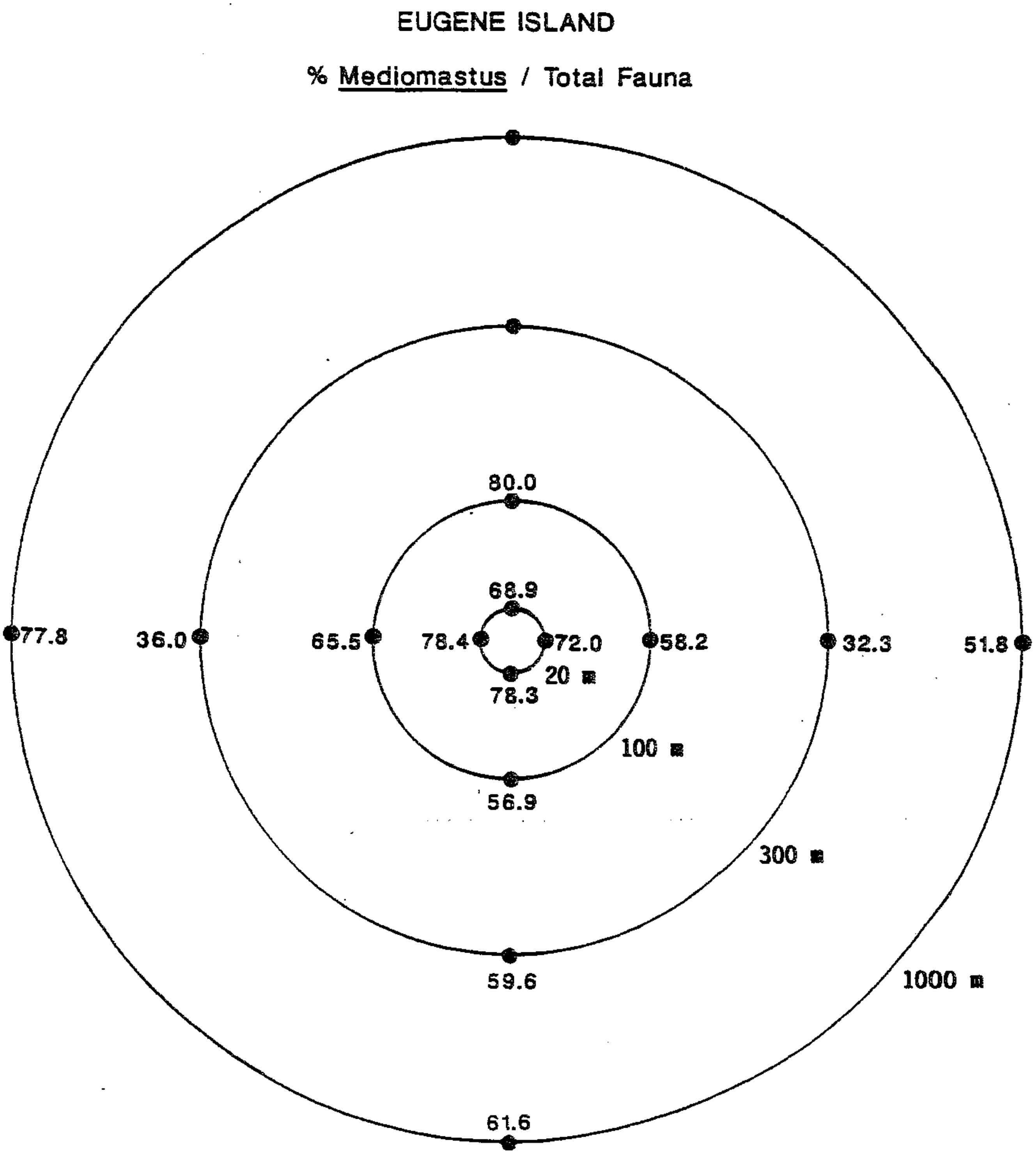


FIGURE 3.12. PERCENT CONTRIBUTION OF THE CAPITELLID POLYCHAETE <u>MEDIOMASTUS AMBISETA</u> TO THE TOTAL FAUNA IN SEDIMENT SAMPLES COLLECTED AT EUGENE ISLAND DURING THE SPRING SURVEY.

Stations 1 through 4 are given in Table 3.38. This parameter is lower at Stations 3 and 4 than at Stations 1 and 2, but all values are low, indicating dominance by one or a few species as seen in the spring samples. Although Station 3 has coarser sediments than those at the other three stations sampled, it has the lowest evenness value. This result is in contrast to the results for the spring samples: at that time, Station 3 had the highest evenness value, as well as the coarsest sediments.

Table 3.40 is a list of the 15 top dominant species for all fall samples combined. Only 6 of the 15 dominant species in the spring samples are also ranked within the top 15 dominants in the fall samples. As in the spring, the top dominant in the fall is the capitellid polychaete Mediomastus ambiseta, which again is present in abundances an order of magnitude higher than the abundance of any other species. The species that ranks second in the spring samples, Oxyurostylis sp. 1, drops to ninth place in the fall samples. The bivalve Mulinia lateralis, which ranks third in the spring, is not among the top 15 species in the fall, but ranks 34th. Several other species that are among the top 15 dominant species in the spring do not rank as highly in the fall. These species include the polychaetes Sabellides sp. 1, Spiophanes bombyx, Scoloplos sp. 1, and Magelona sp. 1; the isopod Munna sp. 1; the bivalves Macoma sp. 1 and Solen viridis; and the amphipod Microprotopus shoemakeri. Three species are more abundant, and rank higher, in the fall than in the spring. These three species are the polychaete Paraprionospio pinnata, which ranks 8th in the spring and 4th in the fall; the sipunculan Phascolion strombi, which ranks 10th in the spring and 7th in the fall; and the bivalve Tellina versicolor, which ranks 13th in the spring and 8th in the fall. The polychaete Paramphinome sp. 1 ranks 12th in both seasons. Of the nine species that are present for the first time among the top 15 dominant species in the fall samples, seven are species of polychaetes, one is a nemertean, and one a small chordate, Branchiostoma caribaeum.

TABLE 3.40. FIFTEEN TOP DOMINANT SPECIES AT EUGENE ISLAND STATIONS IN FALL 1986.

Rank	Species
1	Mediomastus ambiseta (polychaete)
2	Sigambra tentaculata (polychaete)
3	Magelona sp. 1 (polychaete)
4	Paraprionospio pinnata (polychaete)
5	Prionospio perkinsi (polychaete)
6	Nemertea sp. 1 (nemertean)
7	Phascolion strombi (sipunculan)
8	Tellina versicolor (bivalve)
9	Oxyurostylis sp. 1 (cumacean)
10	Neanthes micromma (polychaete)
11	Owenia sp. 1 (polychaete)
12	Paramphinome sp. 1 (polychaete)
13	Scolelepis texana (polychaete)
14	Branchiostoma caribaeum (chordate)
15	Sthenelais sp. 1 (polychaete)

Appendix H includes information on the rank and percent contribution of each species at each station. Mediomastus ambiseta dominates the communities at each station. Values range from 71.5 percent at Station 1 to 82.8 percent at Station 3. Percent dominance by this species is similar to that seen in the spring samples from Stations 1, 2, and 4, but is significantly higher at Station 3 (36.0 percent in the spring vs. 82.8 percent in the fall). Species that rank second or lower at each station account for 5.5 percent or less of the total fauna.

3.3.1.12 Density

3.3.1.12.1 Spring Survey. The mean density of total fauna ranges from 93.5 individuals per 0.01 m^2 at Station 3 to 487.0 individuals per 0.01 m^2 at Station 6. The fauna at all stations is patchy, as is typical of benthic infaunal communities.

Table 3.41 presents the mean and standard deviation of the densities of each of the 15 top dominant species at each Eugene Island station. The high standard deviations reflect the highly patchy distribution of the majority of the species. The dominant species, Mediomastus ambiseta, occurs in the highest densities at Station 6, 100 m to the north of the platform. The second highest mean density of this species is at Station 2, 100 m to the west of the platform. Mean densities of M. ambiseta range from 124.8 to 175.5 individuals per 0.01 m^2 at the four stations closest to the platform. Mean densities at the coarse sediment Stations 3 and 11 are 33.7 and 38.0 individuals per 0.01 m^2, respectively; these mean densities of M. ambiseta are the lowest recorded at any station.

Mean densities of the remaining dominant species are one to three orders of magnitude lower than mean densities of M. ambiseta (Table 3.41). Mean densities of the bivalve Mulinia lateralis are highest at Stations 2, 5, and 15, where it ranks

TABLE 3.41. MEAN DENSITY PER 0.01 M^2 OF FIFTEEN DOMINANT SPECIES AT EUGENE ISLAND STATIONS IN SPRING 1986.

Station	Species Mediomastus ambiseta (P)	Mulinia lateralis (B)	Oxyurostylis sp. 1 (C)	Spiophanes bombyx (P)	Sabellides sp. 1 (P)
1	141.7 ± 57.4	5.3 ± 3.1	2.2 ± 2.0	NP	7.5 ± 3.2
2	187.5 ± 83.2	54.7 ± 2.6	3.5 ± 3.6	1.2 ± 1.0	8.5 ± 2.2
3	33.7 ± 8.6	0.7 ± 0.5	17.5 ± 27.2	13.3 ± 6.0	0.7 ± 0.8
4	86.8 ± 23.0	0.8 ± 0.4	2.0 ± 1.8	1.5 ± 0.8	1.7 ± 0.8
5	129.5 ± 25.5	15.2 ± 4.4	9.7 ± 3.9	0.8 ± 0.8	12.3 ± 3.7
6	389.5 ± 147.9	14.2 ± 4.8	1.5 ± 1.0	2.0 ± 1.2	47.3 ± 27.9
9	124.8 ± 63.5	6.0 ± 4.4	11.8 ± 8.5	1.7 ± 1.2	8.8 ± 7.6
10	72.2 ± 22.0	1.2 ± 0.4	5.0 ± 1.9	14.7 ± 10.6	1.2 ± 1.0
11	38.0 ± 11.4	0.8 ± 0.4	31.0 ± 19.7	15.3 ± 3.4	1.0 + 0.0
12	53.5 ± 21.5	1.2 ± 1.0	11.7 ± 9.7	6.2 ± 2.1	0.8 ± 0.8
13	175.5 ± 37.2	7.2 ± 4.4	3.3 ± 2.5	NP	10.2 ± 2.6
14	90.8 ± 10.8	1.0 ± 0.6	22.7 ± 23.5	8.5 ± 5.8	2.0 ± 1.3
15	124.7 ± 54.4	28.0 ± 6.9	14.7 ± 6.5	1.5 ± 0.8	8.5 ± 7.0
16	71.5 ± 16.3	0.8 ± 0.4	4.2 ± 4.3	9.2 ± 8.3	0.7 ± 0.5

TABLE 3.41. (Continued).

Station	Species *Sigambra tentaculata* (P)	 *Magelona* sp. 1 (P)	 *Paraprionospio pinnata* (P)	 *Scoloplos* sp. 1 (P)	 *Munna* sp. 1 (I)
1	0.7 ± 0.5	2.7 ± 2.2	6.8 ± 2.2	NP	1.2 ± 1.0
2	1.3 ± 0.5	3.8 ± 2.5	1.7 ± 0.8	0.2 ± 0.4	1.5 ± 1.8
3	0.5 ± 0.5	0.2 ± 0.4	NP	4.8 ± 2.4	3.5 ± 6.2
4	0.7 ± 0.5	0.8 ± 0.4	1.5 ± 0.5	0.5 ± 0.8	0.7 ± 0.8
5	0.5 ± 0.5	NP	1.5 ± 0.5	0.2 ± 0.4	0.5 ± 0.5
6	1.2 ± 0.7	0.5 ± 0.5	3.5 ± 2.6	1.2 ± 1.2	1.5 ± 0.8
9	0.5 ± 0.8	1.3 ± 0.8	1.7 ± 0.8	0.7 ± 0.5	1.3 ± 1.4
10	0.3 ± 0.5	1.0 ± 1.3	0.8 ± 0.8	7.3 ± 5.2	3.3 ± 2.3
11	0.3 ± 0.5	NP	NP	5.5 ± 1.4	2.8 ± 3.3
12	0.3 ± 0.5	0.2 ± 0.4	0.2 ± 0.4	5.5 ± 4.3	2.8 ± 2.2
13	0.7 ± 0.5	8.8 ± 1.7	6.2 ± 1.2	NP	0.8 ± 0.4
14	0.5 ± 0.5	0.5 ± 0.5	0.7 ± 0.5	4.3 ± 3.0	4.2 ± 6.0
15	0.7 ± 0.5	0.5 ± 0.5	0.7 ± 0.8	1.0 ± 0.6	8.3 ± 5.1
16	0.3 ± 0.5	2.7 ± 3.1	0.5 ± 0.5	4.8 ± 4.5	0.5 ± 0.5

TABLE 3.41. (Continued).

Station	Species *Paramphinome* sp.1 (P)	 *Scolelpsis texana* (P)	 *Tellina versicolor* (B)	 *Prionospio perkinsi* (P)	 *Phascolion strombi* (S)
1	2.5 ± 1.8	NP	NP	0.2 ± 0.4	0.2 ± 0.4
2	1.7 ± 1.5	NP	0.5 ± 0.6	0.7 ± 1.6	1.7 ± 1.5
3	0.2 ± 0.4	0.5 ± 0.6	0.7 ± 0.5	NP	2.3 ± 1.4
4	0.2 ± 0.4	0.3 ± 0.5	0.8 ± 0.8	0.2 ± 0.4	2.7 ± 2.0
5	3.0 ± 2.6	NP	0.3 ± 0.5	NP	NP
6	0.7 ± 0.8	NP	0.7 ± 0.8	0.2 ± 0.4	0.8 ± 0.8
9	0.8 ± 0.8	NP	0.3 ± 0.5	0.2 ± 0.4	0.5 ± 0.6
10	NP	0.5 ± 0.8	0.7 ± 0.5	0.2 ± 0.4	1.2 ± 0.8
11	0.7 ± 0.4	0.7 ± 0.5	1.5 ± 0.6	0.2 ± 0.4	1.7 ± 2.2
12	0.3 ± 0.5	0.5 ± 0.6	1.5 ± 0.8	NP	2.3 ± 1.4
13	0.8 ± 0.4	NP	0.7 ± 0.4	0.7 ± 0.8	0.2 ± 0.4
14	0.2 ± 0.4	1.0 ± 0.6	1.3 ± 1.0	0.2 ± 0.4	2.5 ± 2.9
15	0.3 ± 0.5	0.3 ± 0.5	0.7 ± 0.5	0.3 ± 0.5	1.8 ± 1.0
16	0.2 ± 0.4	0.3 ± 0.5	1.8 ± 0.8	0.2 ± 0.4	1.7 ± 1.2

P = Polychaete.
B = Bivalve.
C = Cumacean.
I = Isopod.
S = Sipunculan.
NP = Not Present.

second in abundance to M. ambiseta.

3.3.1.12.2 Fall Survey. The mean density of the total fauna ranges from 202.2 individuals per 0.01 m^2 at Station 1 to 410.5 individuals per 0.01 m^2 at Station 3 (Table 3.38). Mean densities at Station 3 are the lowest of any station sampled in the spring, whereas they are the highest of any station sampled in the fall. Mean densities are lower at the two stations (Stations 1 and 2) nearest the platform than at the two stations located 300 and 1000 m away. Densities for each replicate sample are given in Table 3.43.

Table 3.42 summarizes the mean and standard deviation of the densities of the 15 dominant species in the fall samples. Values are presented for each species at each station. The top dominant species, Mediomastus ambiseta, occurs in the highest densities at Station 3. Densities of this species are an order of magnitude higher than they are at this station in the spring samples (33.7 individuals per 0.1 m^2 in the spring vs. 339.8 individuals per 0.1 m^2 in the fall). Mean densities of the other species are one to three orders of magnitude lower than the mean densities of M. ambiseta (Table 3.43). Most species occur in similar abundances at each of the four stations.

Table 3.43 summarizes the results of t-tests comparing the mean densities of 16 species for the spring and fall samples at Stations 1-4. Values of p lower than 0.05 indicate that the mean density differs significantly between the two seasons. Mean densities of M. ambiseta are not significantly different at Station 1 but are significantly different (higher in the fall) at Stations 2, 3, and 4.

3.3.1.13 Percent Juveniles

3.3.1.13.1 Spring Survey. A comparison of the number of juveniles recorded in each replicate sample to the total number

TABLE 3.42. MEAN DENSITY PER 0.01 M^2 OF THE 15 DOMINANT SPECIES (SPRING) AT EUGENE ISLAND STATIONS IN FALL 1986.

Station	Mediomastus ambiseta (P)	Mulinia lateralis (B)	Oxyurostylis sp.1 (C)	Spiophanes bombyx (P)	Sabellides sp.1 (P)
1	144.5 ± 83.6	0.2 ± 0.4	1.8 ± 1.7	NP	NP
2	221.2 ± 70.8	0.3 ± 0.5	0.5 ± 0.5	NP	NP
3	339.8 ± 65.1	0.2 ± 0.4	1.7 ± 2.7	NP	NP
4	318.7 ± 53.9	0.3 ± 0.5	5.0 ± 6.0	NP	NP

Station	Sigambra tentaculata (P)	Magelona sp.1 (P)	Paraprionospio pinnata (P)	Scoloplos sp.1 (P)	Munna sp.1 (I)
1	11.2 ± 4.2	5.2 ± 2.7	8.0 ± 4.0	NP	NP
2	9.5 ± 4.8	9.8 ± 6.2	9.3 ± 3.9	NP	0.2 ± 0.4
3	7.2 ± 2.6	5.8 ± 2.6	3.0 ± 1.7	NP	0.2 ± 0.4
4	17.5 ± 11.2	9.0 ± 4.5	3.2 ± 3.1	NP	0.7 ± 0.8

Station	Paramphinome sp.1 (P)	Scolelepsis texana (P)	Tellina versicolor (B)	Prionospio perkinsi (P)	Phascolion strombi (S)
1	4.3 ± 5.7	0.7 ± 0.8	1.3 ± 1.4	2.5 ± 2.9	0.2 ± 0.4
2	1.2 ± 0.8	3.5 ± 2.6	2.7 ± 3.0	4.5 ± 6.2	3.5 ± 3.5
3	0.2 ± 0.4	2.2 ± 1.6	4.7 ± 6.2	8.2 ± 9.3	3.3 ± 2.9
4	0.8 ± 1.2	0.2 ± 0.4	1.3 ± 1.2	3.5 ± 3.9	3.8 ± 3.1

P = Polychaete.
B = Bivalve.
C = Cumacean.
I = Isopod.
S = Sipunculan.
NP = Not Present.

TABLE 3.43. RESULTS OF t-TESTS COMPARING MEAN DENSITIES OF THE DOMINANT SPECIES AT EUGENE ISLAND STATIONS 1, 2, 3, AN FOR SPRING VS. FALL SAMPLES. VALUES OF $P \leq 0.05$ INDI SIGNIFICANTLY DIFFERENT MEANS.

Species	Stations			
	1	2	3	4
Mediomastus ambiseta (P)	P=0.95	P=0.047	P=0.0001	P=0.0001
Oxyurostylis sp. 1 (C)	P=0.77	P=0.10	P=0.22	P=0.30
Mulinia lateralis (B)	P=0.010	P=0.0013	P=0.096	P=0.19
Sabellides sp. 1 (P)	P=0.0023*	P=0.0003*	P=0.10*	P=0.0041*
Spiophanes bombyx (P)	NP	P=0.034*	P=0.0029*	P=0.0071*
Tellina versicolor (B)	P=0.062*	P=0.14	P=0.18	P=0.42
Paraprionospio pinnata (P)	P=0.55	P=0.0052	P=0.0071*	P=0.25
Paramphinome sp. 1 (P)	P=0.48	P=0.49	P=1.00	P=0.22
Magelona sp. 1 (P)	P=0.11	P=0.071	P=0.0031	P=0.0067
Prionospio perkinsi (P)	P=0.11	P=0.20	P=0.085	P=0.091
Scoloplos sp. 1 (P)	NP	P=0.36*	P=0.0044*	P=0.20*
Scolelepis texana (P)	P=0.10*	P=0.021*	P=0.052	P=0.55
Munna sp. 1 (I)	P=0.034*	P=0.13	P=0.24	P=1.00
Phascolion strombi (S)	P=1.00	P=0.28	P=0.47	P=0.47
Sigambra tentaculata (P)	P=0.0017	P=0.0093	P=0.0016	P=0.015
Nemertea sp. 1 (N)	P=0.20	P=0.0018	P=0.0021	P=0.017

* Species present in either spring or fall only.
P = Polychaete.
C = Cumacean.
B = Bivalve.
I = Isopod.
S = Sipunculan.
N = Nemertean.
NP = Not present.

of individuals in each sample is shown in Table 3.44. The contribution by juveniles to the total population ranges from 19.6 percent at Station 4 to 48.4 percent at Station 12. The average values for this parameter are plotted in Figure 3.13.

The percentages of juveniles of 15 species found at the Eugene Island are presented in Table 3.45. For abundant species such as _Mediomastus ambiseta_, the percentages are based on a large number, perhaps hundreds, of individuals. For those species that are rare in the samples with abundances ranging from two to several tens of individuals, the percentages are often based on only a few specimens. (The total abundances on which the percentages are based can be found in the tables in Appendix H). The dominant species _M. ambiseta_ and particularly _Mulinis lateralis_ are represented by high percentages of juveniles. There is no obvious trend in percent juveniles of these two species with distance from the platform, nor is there any correlation between percent juveniles and sediment texture. However, three of the four stations at which _M. lateralis_ is represented by 83 percent or more juveniles are stations 20 m from the platform. The other station is 100 m from the platform. This implies that turnover of this short-lived, opportunistic species at stations near the platform is high, possibly reflecting continual disturbance near the platform.

3.3.1.13.2 Fall Survey. A comparison of the number of juveniles recorded in each replicate sample to the total number of individuals in each sample is shown in Table 3.46. The contribution by juveniles to the fall samples ranges from 23.3 percent at Station 4 to 32.7 percent at Station 1. Values are similar among Stations 1, 2, and 3, and only slightly lower at Station 4.

Several species that are represented primarily by juveniles in the spring collections are not present at all in the fall collections (Table 3.47). These species include the polychaetes

TABLE 3.44. COMPARISON OF NUMBER OF JUVENILES TO TOTAL NUMBER INDIVIDUALS IN SAMPLES COLLECTED AT EUGENE ISLAND STATIO IN SPRING 1986.

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
1	1	156	65	41.7
	2	134	73	54.4
	3	267	85	31.8
	4	242	53	21.9
	5	149	67	45.0
	6	136	20	14.7
	$\bar{X}$ ± SD			34.9 ± 14.
2	1	437	252	57.7
	2	322	136	42.2
	3	273	58	21.2
	4	232	30	12.9
	5	253	74	29.2
	6	200	37	18.5
	$\bar{X}$ ± SD			30.3 ± 16.
3	1	46	24	52.2
	2	186	36	19.4
	3	98	29	24.5
	4	64	29	45.3
	5	63	23	36.5
	6	104	27	26.0
	$\bar{X}$ ± SD			34.0 ± 12.
4	1	93	14	15.0
	2	143	32	22.4
	3	81	13	16.0
	4	89	15	16.8
	5	111	20	18.0
	6	153	45	29.4
	$\bar{X}$ ± SD			19.6 ± 5.4

TABLE 3.44. (Continued).

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
5	1	238	86	36.1
	2	155	80	51.6
	3	178	52	29.2
	4	214	66	30.8
	5	183	48	26.2
	6	160	48	30.0
	$\bar{X} \pm$ SD			34.0 ± 9.2
6	1	162	52	32.1
	2	529	25	4.7
	3	582	259	44.5
	4	578	130	22.5
	5	410	99	24.2
	6	661	201	30.4
	$\bar{X} \pm$ SD			26.4 ± 13.2
9	1	168	18	10.7
	2	132	53	40.2
	3	138	18	13.0
	4	105	55	52.4
	5	301	160	53.2
	6	196	134	68.4
	$\bar{X} \pm$ SD			39.6 ± 23.3
10	1	142	53	37.3
	2	98	27	27.6
	3	68	23	33.8
	4	115	48	41.7
	5	174	65	37.4
	6	147	41	27.9
	$\bar{X} \pm$ SD			34.3 ± 5.6

TABLE 3.44. (Continued).

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
11	1	88	41	46.6
	2	102	42	41.2
	3	92	35	38.0
	4	112	45	40.2
	5	182	46	25.3
	6	129	45	34.9
	$\bar{X}$ ± SD			37.7 ± 7.2
12	1	117	48	41.0
	2	99	38	38.4
	3	95	34	35.8
	4	177	98	55.4
	5	64	38	59.4
	6	68	41	60.3
	$\bar{X}$ ± SD			48.4 ± 11.
13	1	166	30	18.1
	2	169	29	17.2
	3	247	64	25.9
	4	221	78	35.3
	5	279	87	31.2
	6	262	84	32.1
	$\bar{X}$ ± SD			26.6 ± 7.6
14	1	131	36	27.5
	2	187	63	33.7
	3	162	43	26.5
	4	126	47	37.3
	5	107	27	25.2
	6	244	55	22.5
	$\bar{X}$ ± SD			28.8 ± 5.6

TABLE 3.44. (Continued).

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
15	1	169	61	36.1
	2	186	60	32.3
	3	187	79	42.2
	4	162	55	33.9
	5	341	144	42.2
	6	209	20	9.6
	$\bar{X}$ ± SD			32.7 ± 12.1
16	1	135	33	24.4
	2	130	69	53.1
	3	108	37	34.3
	4	71	11	15.5
	5	111	42	37.8
	6	141	37	26.2
	$\bar{X}$ ± SD			31.9 ± 13.0

TABLE 3.45. PERCENT CONTRIBUTION OF JUVENILES OF THE 15 DOMINANT SPECIES IN THE SPRING 1986 SAMPLES COLLECTED AT EUGENE ISLAND STATIONS.

Species	Station 1	2	3	4	5	6	9	10	11	12	13	14	15	16
Mediomastus ambiseta (P)	30.8	42.3	16.8	13.2	24.6	23.3	41.7	23.3	34.2	54.8	28.0	25.7	36.6	25.9
Mulinia lateralis (B)	93.8	10.1	75.0	60.0	90.1	45.9	83.3	71.4	100	57.1	32.6	83.3	29.2	60.0
Spiophanes bombyx (P)	NP	57.1	76.2	88.9	60.0	8.3	60.0	68.2	78.3	75.7	NP	52.9	77.8	56.4
Sabellides sp. 1 (P)	40.0	19.6	50.0	50.0	48.6	31.3	71.7	14.3	33.3	60.0	29.5	33.3	35.3	75.0
Sigambra tentaculata (P)	100	87.5	66.7	100	100	71.4	100	50.0	100	50.0	100	100	75.0	100
Magelona sp. 1 (P)	0	0	0	60.0	NP	0	0	0	NP	100	3.8	33.3	66.7	18.8
Paraprionospio pinnata (P)	26.8	30.0	NP	55.6	77.8	57.1	70.0	60.0	NP	100	21.6	100	100	33.3
Scoloplos sp. 1 (P)	NP	100	89.7	100	100	71.4	100	93.2	100	97.0	NP	100	100	NP
Paramphinome sp. 1	73.3	20.0	100	100	55.6	100	40.0	NP	100	50.0	80.0	100	50.0	0
Scolelepis texana (P)	NP	NP	0	0	NP	NP	NP	33.3	0	0	NP	33.3	0	0
Tellina versicolor (B)	NP	0	50.0	100	100	100	50.0	75.0	77.8	44.4	100	75.0	100	45.5
Prionospio perkinsi (P)	0	25.0	NP	0	NP	100	0	0	100	NP	0	100	0	100
Neanthes micromma (P)	NP	0	NP	0	0	0	0	NP	NP	NP	0	NP	NP	0
Phoronis architecta (Ph)	50.0	100	100	33.3	100	100	100	100	80.0	66.7	0	50.0	20.0	0
Golfingia sp. 1 (s)	60.0	100	0	100	66.7	100	NP	75.0	66.7	100	100	100	100	100

P = Polychaete.
B = Bivalve.
Ph = Phoronid.
S = Sipunculan.
NP = Not Present.

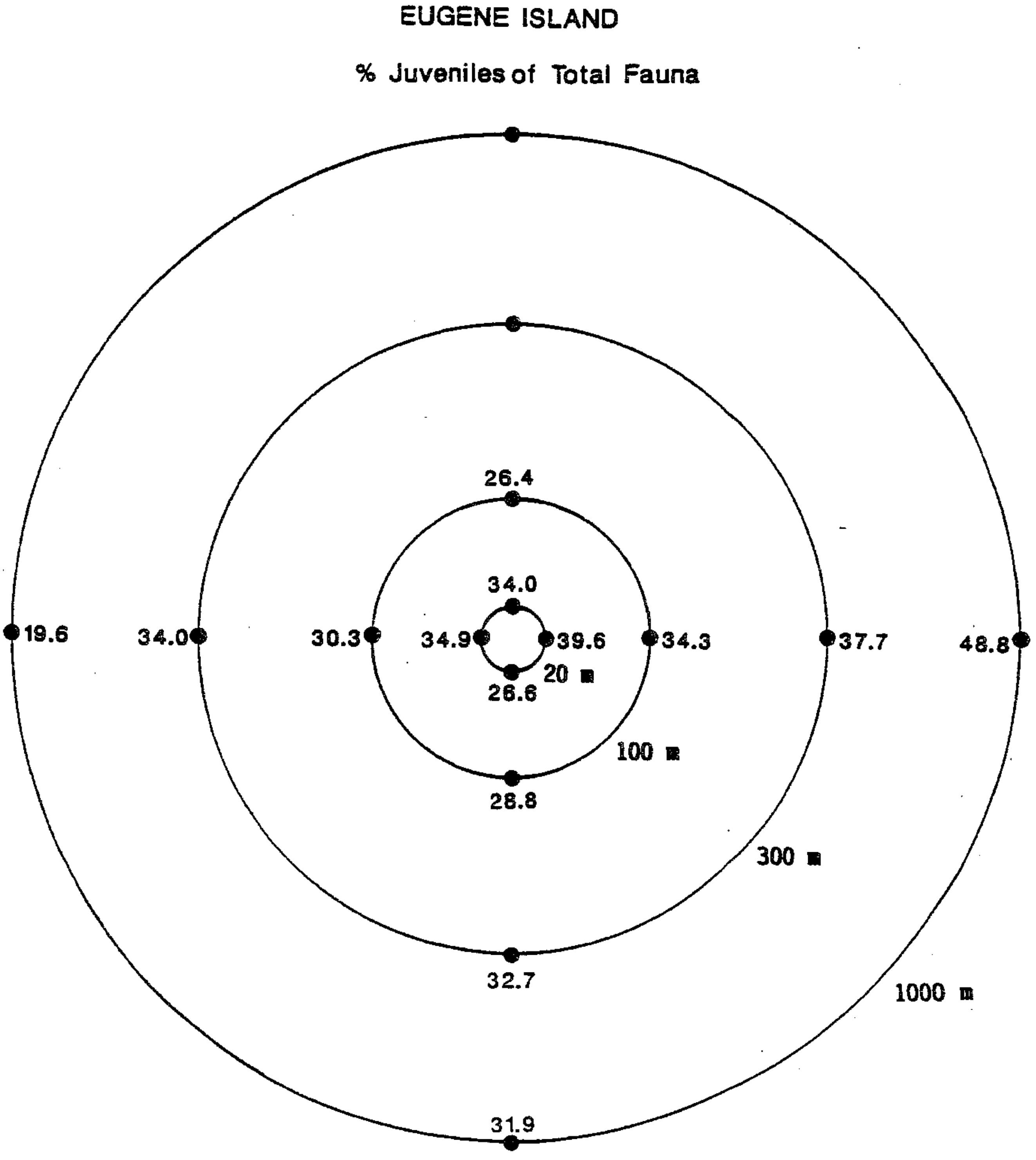
TABLE 3.46. COMPARISON OF NUMBER OF JUVENILES TO TOTAL NUMBER OF INDIVIDUALS IN SAMPLES COLLECTED AT EUGENE ISLAND STATIONS IN FALL 1986.

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
1	1	254	78	30.7
	2	254	70	27.6
	3	354	90	25.4
	4	93	39	41.9
	5	144	60	41.7
	6	114	33	28.9
	$\bar{X}$ ± SD			32.7 ± 7.2
2	1	189	38	20.1
	2	312	111	35.6
	3	257	65	25.3
	4	209	71	34.0
	5	424	168	39.6
	6	381	99	26.0
	$\bar{X}$ ± SD			30.1 ± 7.4
3	1	379	136	35.9
	2	434	122	28.1
	3	294	99	33.7
	4	553	109	19.7
	5	397	142	35.8
	6	406	126	31.0
	$\bar{X}$ ± SD			30.7 ± 6.2
4	1	384	115	29.9
	2	401	101	25.2
	3	495	87	17.6
	4	432	91	21.1
	5	292	74	25.3
	6	350	73	20.8
	$\bar{X}$ ± SD			23.3 ± 4.4

TABLE 3.47. PERCENT CONTRIBUTION OF JUVENILES OF THE 15 DOMINANT SPECIES (SPRING) IN THE FALL 1986 SAMPLES COLLECTED AT EUGENE ISLAND.

Species	Station			
	1	2	3	4
Mediomastus ambiseta (P)	21.4	23.8	23.6	16.
Mulinia lateralis (B)	100	50	100	100
Spiophanes bombyx (P)	NP	NP	NP	NP
Sabellides sp. 1 (P)	NP	NP	NP	NP
Sigambra tentaculata (P)	92.5	86.0	90.7	93.
Magelona sp. 1 (P)	29.0	30.5	54.3	24.
Paraprionospio pinnata (P)	66.7	75.0	94.4	94.
Scoloplos sp.1 (P)	NP	NP	NP	NP
Paramphimome sp. 1 (P)	84.6	100	0	80.
Scolelepis texana (P)	100	90.5	84.6	100
Tellina versicolor (B)	62.5	50.0	92.9	87.
Prionospio perkinsi (B)	80.0	37.0	67.3	81.
Neanthes micromma (P)	38.1	60.0	75.0	100
Phoronis architecta (Ph)	NP	NP	33.3	33.
Golfingia sp. 1 (S)	NP	NP	NP	NP

P = Polychaete.
B = Bivalve.
Ph = Phoronid.
S = Sipunculan.



EUGENE ISLAND

% Juveniles of Total Fauna

FIGURE 3.13. PERCENT CONTRIBUTION OF JUVENILES TO THE TOTAL FAUNA IN SEDIMENT SAMPLES COLLECTED AT EUGENE ISLAND DURING THE SPRING SURVEY.

Spiophanes bombyx, Sabellides sp. 1, Scoloplos sp. 1, and Spiochaetopterus costarum; the gastropod Polynices duplicatus; the bivalve Pandora arenosa; and the sipunculan Golfingia sp. 1. This result implies that the juveniles of some species recruited to the area in the spring did not survive, and no new recruitment of these species took place in the fall. The juveniles may not have survived because the substratum is unsuitable for them, i.e., the sediment texture or associated parameters are not suitable.

Other species are represented by higher percentages of juveniles in the fall as compared to the spring collections. These species include the polychaetes Magelona sp. 1, Scolelepis texana, Neanthes micromma, and Paraprionospio pinnata at Station 3. This result implies that the reproduction and recruitment of these species takes place in the fall rather than in the spring.

The dominant species, Mediomastus ambiseta, is represented by similar percentages of juveniles in both the spring and fall collections. This result implies a continuous recruitment of this opportunistic species.

3.3.1.14 Similarity

3.3.1.14.1 Spring Survey. Because all of the stations are dominated to a very large extent by a single species, similarity measures such as the Bray-Curtis method do not detect any pattern among seasons, stations, or even sites (i.e., Lake Pelto vs. Eugene Island). The similarity measure NESS is less sensitive to the dominant species in the samples, and more sensitive to rare species; therefore, NESS was used to elucidate underlying patterns among stations and between seasons. NESS similarity followed by group average clustering was run on combined replicates for each station sampled at Eugene Island. This analysis included samples from both spring and fall surveys. The dendrogram based on the results of this analysis is presented in Figure 3.14. Stations are indicated on the X-axis of the figure: the values on the Y-axis represent the level of similarity at which two stations are linked. Thus, the higher the value (the lower the height) of the crossbar joining two stations, or groups of stations, the more similar those stations.

Figure 3.14 indicates that the spring and fall collections at the Eugene Island stations are dissimilar: all of the spring samples occur to the left of the figure, and the level of similarity at which they join the fall samples is only 0.58. Within the group of spring samples, two distinct groups of stations, or clusters, can be seen. The first group consists of Stations 1, 5, 9, and 13 (all within 20 m of the platform) and Stations 2 and 6, the stations 100 m to the west and north, respectively, of the platform. Within this first group, Stations 1, 2, and 13 form a highly similar subgroup. The second major group consists of two subgroups. One subgroup includes the highly similar Stations 3, 11, 12, and 14; all at distances of 300 m or greater from the platform. The other subgroup includes Stations 4, 10, 15, and 16.

3.3.1.14.2 Fall Survey. Figure 3.14 includes data on similarity for the fall samples from Eugene Island. The fall samples, while dominated by the same species that dominate the spring samples, differ from the spring samples in the absence of species that are common in the spring and in the presence of species that are not found in the spring. The relationship of the stations presented in Figure 3.14 reflects these results; the fall samples are similar to the spring samples only at a low level of NESS. Stations 3 and 4 are more similar to Stations 1 and 2 for the fall samples than they are for the spring samples. The presence of *Mediomastus ambiseta* at Stations 3 and 4 in much higher abundances in the fall than in the spring accounts for this higher level of similarity.

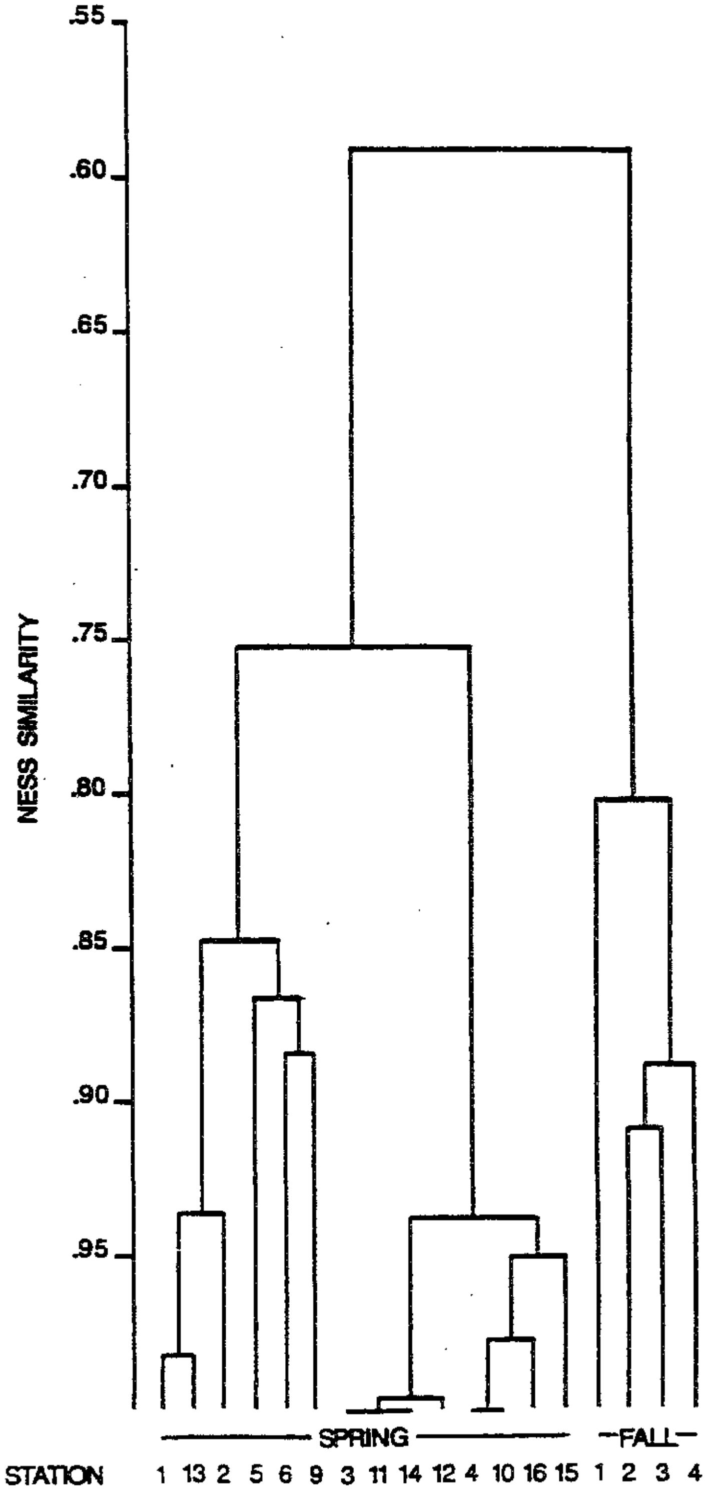


FIGURE 3.14. DENDROGRAM BASED ON CLUSTER ANALYSIS OF INFAUNAL SAMPLES COLLECTED AT EUGENE ISLAND DURING THE SPRING AND FALL SURVEYS.

3.3.2 Lake Pelto, Tank Battery No. 1

3.3.2.1 Sediment Grain Size

3.3.2.1.1 Spring Survey. The percent phi distribution of each sample analyzed is presented in Appendix B (Tables B2 and B3). Mean percent grain-size distribution based on gravel, sand, silt, and clay classes plus total silt plus clay are given in Table 3.48. The distribution of percent silt/clay is presented in a plan view of the study site in Figure 3.15.

Unlike the situation at Eugene Island, the percent silt/clay fraction in sediments at Lake Pelto increases with distance away from the platform. Except for Station 9, the stations closest to the platform have the lowest silt/clay content, ranging from 12 to 28 percent. The percent silt/clay increases to the range of 61 to 91.7 percent in sediments from the 1000-m ring. Distribution of sediment grain size appears to be less patchy at Lake Pelto than at Eugene Island as evidenced by the good agreement between values for the chemistry and biology replicates.

This distribution of fine-grained sediments could indicate that the platform is causing high current shear from wake effects in the arc from the southwest to the northeast immediately adjacent to the platform, sandy material is or has been discharged from the platform, or coarse fill material (sand and shell) was placed at the platform site during construction of the production facility. The southeast quadrant (Station 9) of the platform has a grain-size distribution similar to the rest of the study site and seems to be unaffected by the presence of the platform.

3.3.2.1.2 Fall Survey. The grain size distribution in sediment samples collected on the fall survey from the four stations at Lake Pelto are presented in Table 3.19 (see Appendix B, Table B3

TABLE 3.48. MEAN PERCENT ($\bar{X}$) AND STANDARD DEVIATION (SD) OF MAJOR SEDIMENT SIZE CLASSES IN BIOLOGY (B) AND CHEMISTRY (C) SEDIMENT SAMPLES COLLECTED AT LAKE PELTO STATIONS IN SPRING 1986.

Station		Gravel		Sand		Silt		Clay		Total Silt plus Clay
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$
1	B	6.44	3.44	71.80	5.05	10.91	1.11	10.86	6.60	21.8
	C	22.31	1.18	61.32	3.75	10.91	2.52	5.46	0.91	16.4
2	B	8.94	1.65	67.73	7.26	14.53	5.34	8.80	3.24	23.3
	C	9.10	6.90	67.45	2.75	15.04	3.23	8.42	1.51	23.4
3	B	5.81	3.16	52.22	8.35	25.10	1.86	16.87	9.35	42.0
	C	8.22	5.14	57.92	4.42	23.38	5.85	10.48	3.00	33.9
4	B	0.46	0.43	26.88	3.70	45.26	3.43	27.40	3.31	72.7
	C	0.50	0.33	31.48	4.45	51.19	3.78	16.83	1.31	68.0
5	B	5.56	3.00	69.95	6.60	12.53	2.63	11.96	6.86	24.5
	C	9.06	5.29	78.54	1.74	7.34	2.32	5.06	3.15	12.4
6	B	6.28	2.03	60.67	9.45	10.84	4.66	22.20	12.55	33.0
	C	4.36	1.26	71.31	4.77	13.69	3.01	10.65	3.00	24.3
7	B	2.49	0.46	58.53	8.09	21.53	4.26	17.45	3.82	39.0
	C	1.89	1.23	52.00	6.20	33.20	6.98	12.91	0.64	46.1
8	B	0.27	0.16	26.40	5.50	55.43	5.47	17.91	2.66	73.3
	C	0.43	0.28	24.74	0.81	61.02	2.06	13.82	1.28	74.8
9	B	1.49	0.85	46.60	9.72	30.64	3.60	21.27	7.16	51.9
	C	1.53	0.67	46.44	12.85	34.23	7.52	17.80	4.86	52.0
10	B	1.75	0.92	67.40	3.98	21.41	3.36	9.44	0.96	30.8
	C	1.17	0.82	55.30	4.37	27.78	2.06	15.75	1.96	43.6
11	B	0.71	0.24	39.59	8.06	38.00	2.77	21.70	5.22	59.7
	C	1.11	0.75	42.33	4.36	35.81	2.15	20.75	1.73	56.6
12	B	0.13	0.08	30.60	6.02	43.06	3.29	26.22	6.84	69.3
	C	0.27	0.21	38.75	4.81	38.03	4.25	22.96	2.47	61.0
13	B	5.68	3.49	65.95	5.58	17.22	2.19	11.14	5.50	28.4
	C	4.82	1.42	70.86	4.02	15.85	2.28	8.47	1.21	24.3
14	B	0.17	0.12	46.37	8.49	34.73	4.71	18.74	3.92	53.5
	C	1.68	0.90	48.38	11.26	31.37	5.15	18.58	7.34	50.0
15	B	0.22	0.29	39.93	9.00	41.08	6.35	18.77	3.51	59.8
	C	0.23	0.19	41.43	6.52	38.06	7.15	20.29	2.79	58.4
16	B	0	0	8.37	2.82	62.21	3.82	29.42	2.79	91.6
	C	0.04	0.04	8.24	3.34	58.81	0.96	32.90	3.42	91.7

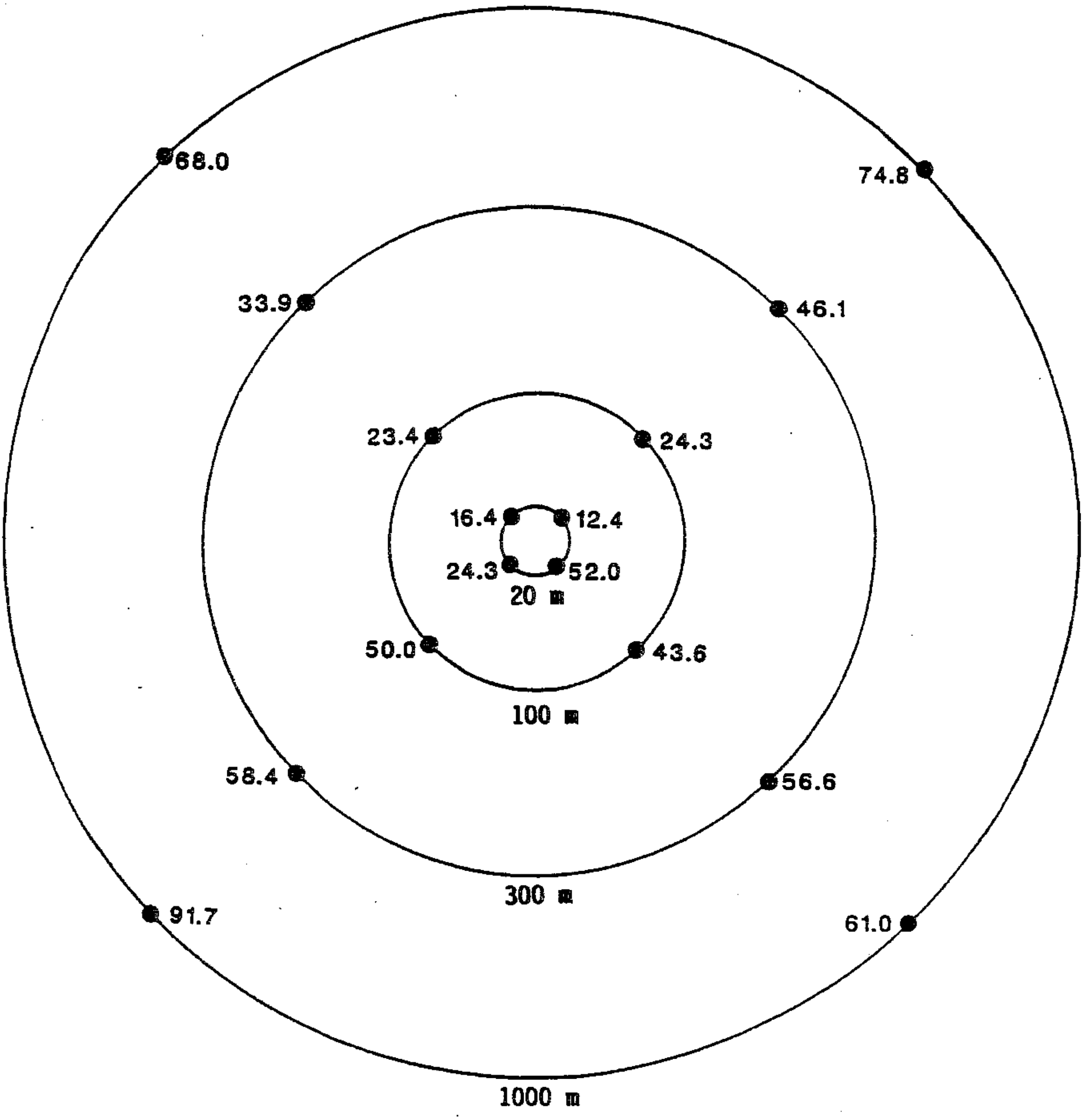


FIGURE 3.15. PERCENT SILT PLUS CLAY IN SEDIMENT SAMPLES COLLECTED FOR CHEMICAL ANALYSIS AT LAKE PELTO, STATIONS 1-16, DURING THE SPRING SURVEY (TABLE 3.48).

for grain size distribution by phi class). The two stations within 20 m of the produced water outfall (Stations 1 and 13) have sediments with low percent silt/clay (approximately 25 percent). Percent silt/clay increases dramatically to 88 percent at the station 100 m from the platform and decreases slightly to 60 percent at the station 300 m from the platform. The grain size distribution near the platform (20 m) in the fall survey is similar to that determined in sediments collected during the spring survey (Table 3.48).

3.3.2.2 Total Hydrocarbons by GC/MS

Total hydrocarbon concentrations were determined in each replicate chemistry sediment sample collected at Lake Pelto during the spring survey. Total hydrocarbon concentration in each replicate plus the mean concentration and standard deviation for each station are presented in Table 3.49. The percent resolved hydrocarbons is also given. The mean total hydrocarbon concentrations in sediments are shown in a plan view of the area (Figure 3.16).

On each transect, the stations closest to the platform (20-m Stations 1, 5, 9, and 13) contain the highest mean total hydrocarbon concentrations and the lowest percent resolvable hydrocarbons (i.e., large unresolved complex mixture envelope). The standard deviations of the mean concentrations are highest at these stations, indicating a patchy distribution of hydrocarbons in the sediments immediately adjacent to the platform. Mean concentrations of total hydrocarbons in sediments at the outer stations are lower by a factor of 2 to 3 than concentrations 20 m from the discharge and there is a tendency for hydrocarbon concentrations to decrease with distance from the platform.

Except at those stations near the platform (<100 m), the hydrocarbon concentrations in sediments at the study site are

TABLE 3.49. TOTAL HYDROCARBON CONCENTRATION (AND PERCENT RESOLVED HYDROCARBONS) IN SEDIMENTS FROM LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

Station	Concentration (µg/g)				
	Replicate				Standard Deviation
	1	2	3	Mean	
1	340 (21%)	280 (13%)	190 (19%)	270 (18%)	75 (4.2%)
2	60 (33)	46 (26)	57 (26)	54 (28)	7.4 (4.0)
3	34 (44)	27 (36)	27 (59)	29 (46)	4.0 (12)
4	28 (46)	34 (59)	27 (41)	30 (49)	3.8 (9.3)
5	39 (24)	60 (27)	89 (42)	63 (31)	25 (9.6)
6	21 (57)	28 (43)	23 (52)	24 (51)	3.6 (7.1)
7	12 (50)	16 (46)	18 (46)	15 (47)	3.0 (2.3)
8	13 (49)	13 (40)	13 (42)	13 (44)	0.0 (4.4)
9	57 (26)	410 (4.0)	41 (27)	170 (19)	210 (13)
10	67 (69)	20 (50)	20 (48)	36 (56)	27 (12)
11	36 (36)	28 (43)	39 (33)	34 (37)	5.7 (5.1)
12	44 (45)	43 (40)	94 (49)	60 (45)	29 (4.5)
13	250 (17)	160 (17)	100 (17)	170 (17)	75 (0.0)
14	48 (38)	71 (55)	110 (60)	76 (51)	31 (12)
15	30 (40)	27 (50)	27 (48)	28 (46)	1.7 (5.3)
16	62 (44)	52 (40)	55 (42)	56 (42)	5.1 (2.0)

BLANKS (Range) 6.6-9.9 µg/g

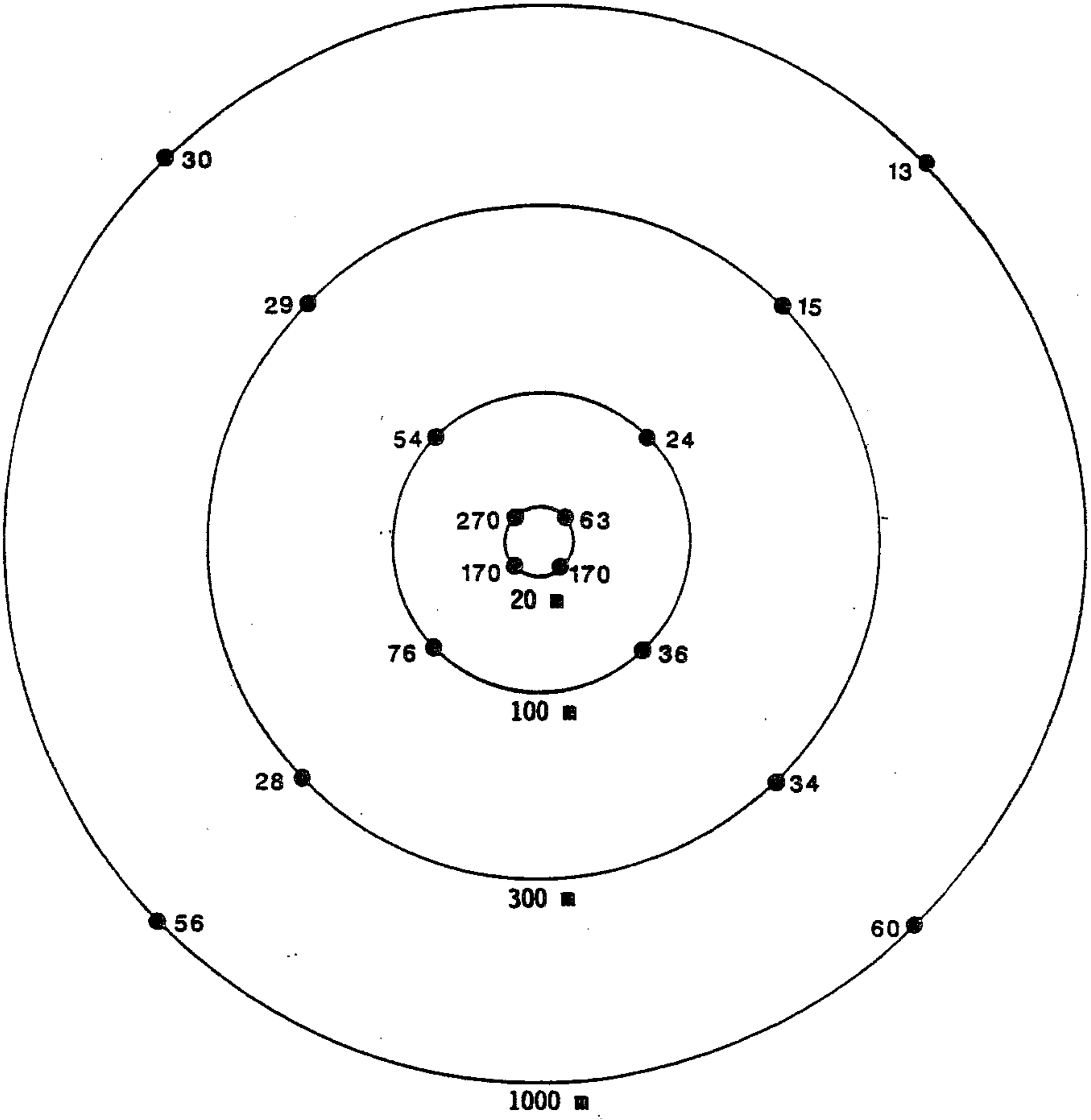


FIGURE 3.16. MEAN TOTAL HYDROCARBON CONCENTRATIONS (μg/g) IN SEDIMENTS COLLECTED AT LAKE PELTO DURING THE SPRING SURVEY (TABLE 3.49).

typical of coastal sediments of the Gulf of Mexico (10 to 50 µg/g). Unlike the situation at Eugene Island (Figure 3.5), there is no relationship between percent silt/clay and total hydrocarbon concentrations in sediments at Lake Pelto (Figure 3.17). The correlation coefficient for the regression of percent silt/clay versus total hydrocarbon concentration in Lake Pelto sediments is -0.40.

3.3.2.3 n-Alkanes

Each replicate sediment chemistry sample collected on the spring survey from the 16 Lake Pelto stations was analyzed for n-alkanes from decane (n-C_{10}) through tetratriacontane (n-C_{34}). Mean concentrations were calculated for each n-alkane, and the results are presented in Tables 3.50 and 3.51 and in Figure 3.18. Results of analysis of each replicate are listed in Appendix C (Tables C17-C32).

Total mean n-alkane concentrations in sediments from the study site range from 0.47 to 3.2 µg/g. Concentrations of n-alkanes at the stations closest to the platform are not significantly higher than those at the other stations further from the platform. There is no correlation between total n-alkane concentrations and percent silt/clay in sediments.

In some of the sediments with higher total n-alkane concentrations (Stations 4, 5, 10, 12, and 14), concentrations of individual compounds increase from n-C_{18} to a maximum at n-C_{25} and then decrease until n-C_{34}. The unresolved complex mixture envelope is centered at the n-C_{25} peak. Concentrations of odd-numbered n-alkanes are higher than those of even-numbered n-alkanes (i.e., odd/even preference index >1.0), indicating a predominantly biogenic origin of the complete n-alkane assemblage.

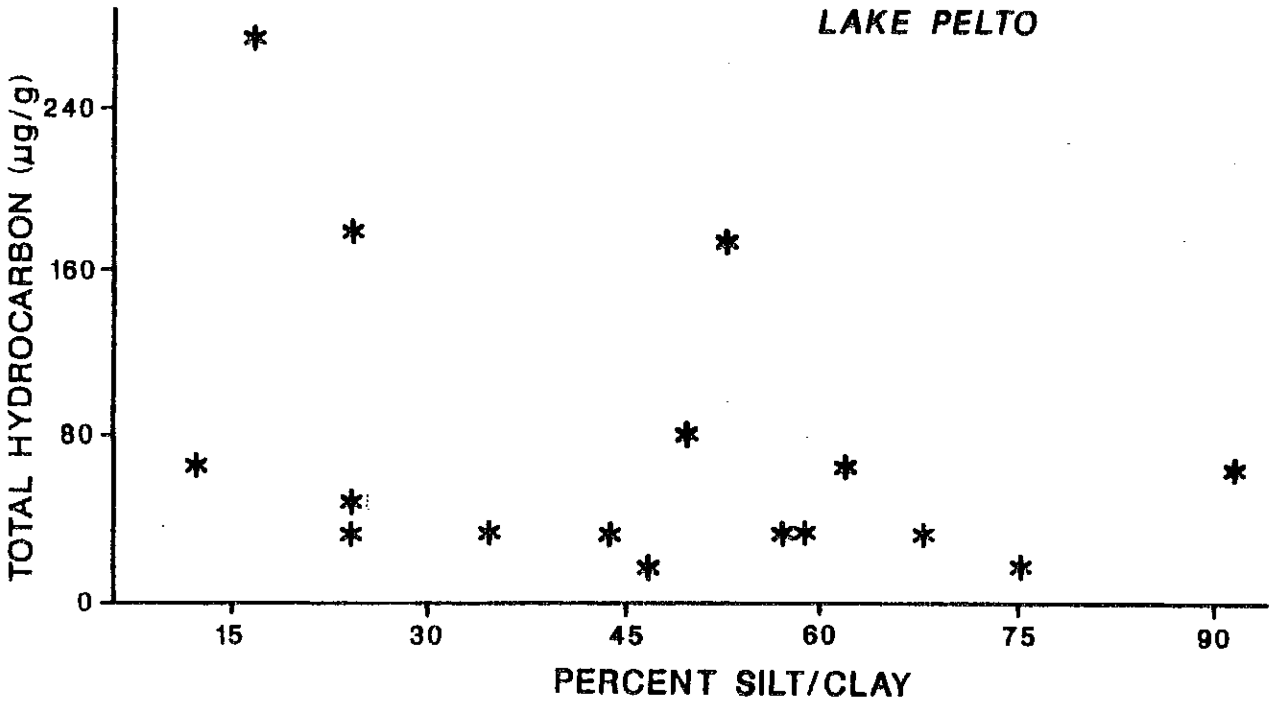


FIGURE 3.17. RELATIONSHIP BETWEEN TOTAL HYDROCARBON CONCENTRATIONS (TABLE 3.49) AND PERCENT SILT PLUS CLAY (TABLE 3.18) IN SEDIMENTS COLLECTED AT LAKE PELTO DURING THE SPRING SURVEY.

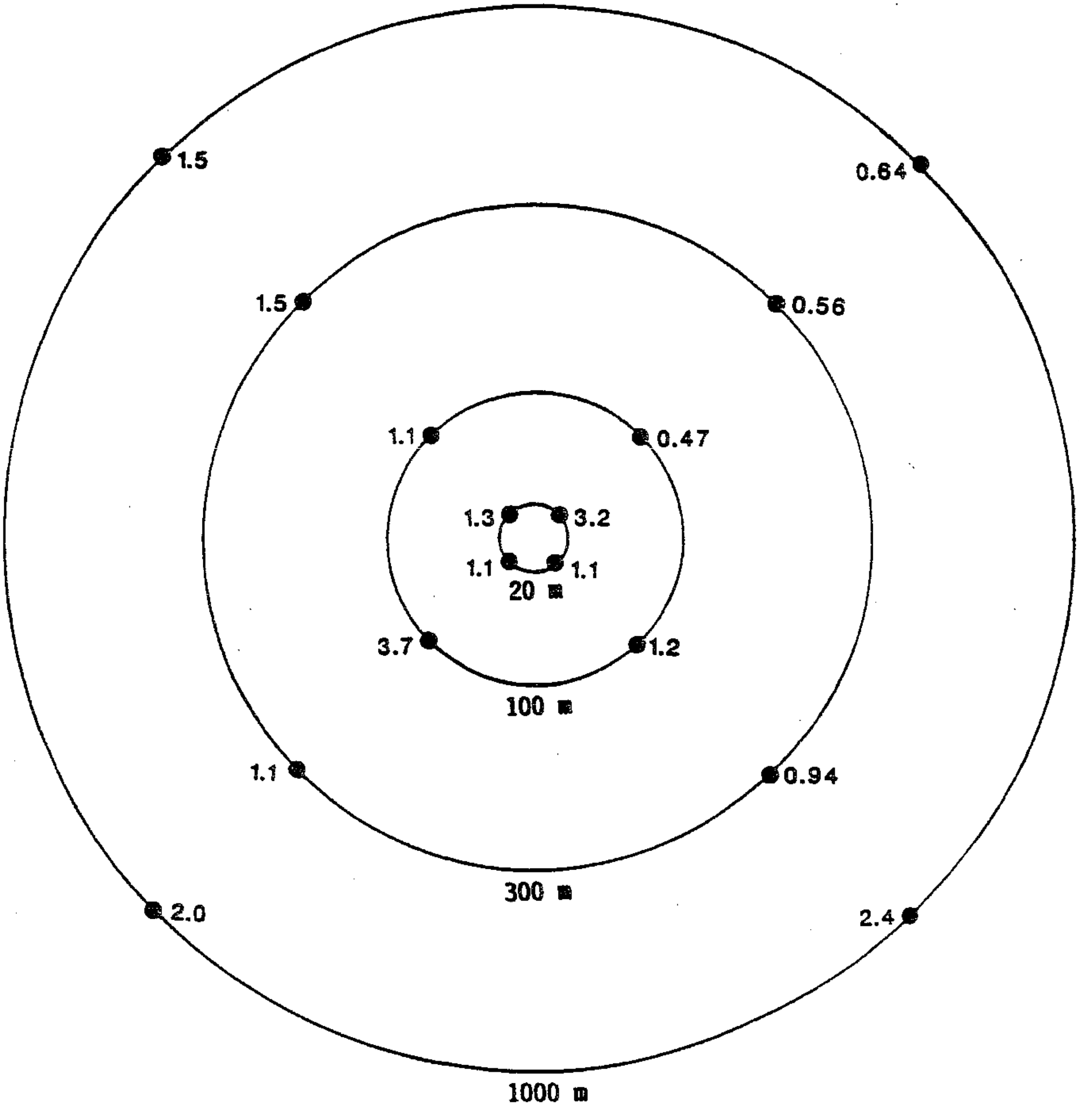


FIGURE 3.18. MEAN TOTAL n-ALKANE CONCENTRATIONS (μg/g) IN SEDIMENTS COLLECTED AT LAKE PELTO, STATIONS 1-16, DURING THE SPRING SURVEY (TABLES 3.50 AND 3.51).

TABLE 3.50. MEAN n-ALKANE CONCENTRATIONS IN SEDIMENTS FROM LAKE PELTO, STATIONS 1 THROUGH 8, COLLECTED DURING THE SPRING SURVEY.

Compound	Concentration (µg/g Dry Weight) Station 1	2	3	4	5	6	7	8
Decane (C_{10})	0.029	0.020	0.014	0.009	0.041	0.004	0.002	0.002
Undecane (C_{11})	0.127	0.234	0.143	0.145	0.067	0.016	0.023	0.018
Dodecane (C_{12})	0.198	0.031	0.017	0.011	0.050	0.009	0.005	0.003
Tridecane (C_{13})	0.004	0.038	0.023	0.014	0.060	0.015	0.003	0.004
Tetradecane (C_{14})	0.032	0.022	0.037	0.011	0.055	0.015	0.002	0.003
Pentadecane (C_{15})	0.028	0.037	0.071	0.024	0.073	0.026	0.012	0.011
Hexadecane (C_{16})	0.002	0.043	0.090	0.021	0.070	0.023	0.012	0.012
Heptadecane (C_{17})	0.480	0.085	0.124	0.039	0.090	0.045	0.028	0.026
Octadecane (C_{18})	0.014	0.022	0.061	0.030	0.059	0.031	0.019	0.020
Nonadecane (C_{19})	0.108	0.020	0.056	0.030	0.073	0.036	0.013	0.015
Eicosane (C_{20})	0.019	0.026	0.043	0.030	0.083	0.027	0.028	0.016
Heneicosane (C_{21})	0.059	0.039	0.060	0.059	0.141	0.033	0.043	0.043
Docosane (C_{22})	0.038	0.028	0.042	0.037	0.256	0.025	0.020	0.019
Tricosane (C_{23})	0.053	0.046	0.077	0.100	0.394	0.031	0.044	0.044
Tetracosane (C_{24})	0.002	0.039	0.062	0.075	0.428	0.022	0.032	0.027
Pentacosane (C_{25})	0.046	0.078	0.126	0.201	0.571	0.035	0.074	0.072
Hexacosane (C_{26})	0.022	0.046	0.060	0.109	0.290	0.015	0.027	0.035
Octacosane (C_{28})	0.0	0.046	0.062	0.110	0.143	0.006	0.027	0.038
Triacontane (C_{30})	0.001	0.039	0.063	0.093	0.078	0.008	0.023	0.036
Hentriacontane (C_{31})	0.026	0.108	0.192	0.343	0.087	0.036	0.114	0.176
Dotriacontane (C_{32})	0.014	0.013	0.027	0.049	0.036	0.006	0.008	0.014
Tetratriacontane (C_{34})	0.020	0.007	0.009	0.004	0.016	0.007	0.004	0.004
TOTAL	**1.322**	**1.067**	**1.459**	**1.544**	**3.161**	**0.471**	**0.563**	**0.638**

TABLE 3.51. MEAN n-ALKANE CONCENTRATIONS IN SEDIMENTS FROM LAKE PELTO, STATIONS 9 THROUGH 16, COLLECTED DURING THE SPRING SURVEY.

Compound	**Concentration (µg/g Dry Weight)**							
	Station							
	9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Decane (C_{10})	0.013	0.011	0.014	0.026	0.019	0.033	0.015	0.022
Undecane (C_{11})	0.065	0.173	0.052	0.071	0.066	0.074	0.050	0.076
Dodecane (C_{12})	0.026	0.011	0.015	0.020	0.076	0.043	0.012	0.025
Tridecane (C_{13})	0.043	0.014	0.017	0.020	0.046	0.038	0.012	0.043
Tetradecane (C_{14})	0.027	0.018	0.015	0.018	0.064	0.037	0.015	0.037
Pentadecane (C_{15})	0.044	0.025	0.025	0.040	0.092	0.063	0.031	0.058
Hexadecane (C_{16})	0.051	0.031	0.024	0.025	0.066	0.065	0.036	0.043
Heptadecane (C_{17})	0.093	0.048	0.064	0.083	0.200	0.133	0.065	0.092
Octadecane (C_{18})	0.058	0.040	0.031	0.042	0.045	0.038	0.023	0.099
Nonadecane (C_{19})	0.065	0.038	0.026	0.037	0.022	0.063	0.038	0.086
Eicosane (C_{20})	0.046	0.038	0.032	0.056	0.045	0.056	0.027	0.063
Heneicosane (C_{21})	0.076	0.051	0.048	0.134	0.036	0.129	0.053	0.112
Docosane (C_{22})	0.035	0.036	0.023	0.215	0.036	0.223	0.022	0.043
Tricosane (C_{23})	0.061	0.085	0.065	0.361	0.051	0.357	0.050	0.100
Tetracosane (C_{24})	0.039	0.061	0.043	0.318	0.038	1.457	0.219	0.076
Pentacosane (C_{25})	0.081	0.134	0.152	0.343	0.061	0.275	0.084	0.190
Hexacosane (C_{26})	0.046	0.064	0.039	0.177	0.006	0.153	0.033	0.080
Octacosane (C_{28})	0.041	0.056	0.052	0.135	0.0	0.117	0.044	0.106
Triacontane (C_{30})	0.037	0.056	0.050	0.086	0.0	0.070	0.035	0.103
Hentriacontane (C_{31})	0.136	0.181	0.122	0.177	0.103	0.188	0.159	0.443
Dotriacontane (C_{32})	0.016	0.031	0.021	0.040	0.009	0.036	0.021	0.048
Tetratriacontane (C_{34})	0.008	0.015	0.011	0.017	0.004	0.010	0.009	0.025
TOTAL	**1.107**	**1.217**	**0.941**	**2.441**	**1.085**	**3.658**	**1.053**	**1.970**

3.3.2.4 PAHs

3.3.2.4.1 Spring Survey. Concentrations of individual parent and alkyl-substituted PAHs were determined in all replicate sediment chemistry samples collected at the 16 Lake Pelto stations during the spring survey. Tables 3.52 and 3.53 present the mean concentration of each PAH and total PAH concentrations for each station. Concentrations of individual PAHs in all replicates are listed in Appendix D (Tables D17-D32). Total PAH concentrations are presented in a plan view of the study site (Figure 3.19).

The sediments in the immediate vicinity of the platform contain PAH concentrations substantially higher than apparent background values for the area. Among the stations at 20 m and 100 m (Stations 1, 2, 5, 6, 9, 10, 13, and 14), mean concentrations of total PAH in sediments range from 1.6 to 12.5 µg/g. At the 300-m and 1000-m stations, mean concentrations decrease to a range of 0.09 to 0.34 µg/g. Concentrations at most of these outer stations are still elevated above apparent background.

Sediments from all the stations at 20 and 100 m from the platform contain assemblages of alkyl-substituted homologues in each homologous series. In most cases, in the lower molecular weight series (naphthalene through fluorene), one or more of the alkyl homologues (usually the C_3 homologue) is more abundant than the parent compound. In the higher molecular weight series (phenanthrene through perylene), the parent compound is usually more abundant than any one of the alkyl homologues. This homologue distribution, as well as the presence of significant concentrations of 4- and 5-ring PAH indicates a mixed petrogenic/pyrogenic origin for the PAH assemblage.

Comparison of the total PAH concentrations and the grain-size distribution in the sediments (Table 3.48) indicates that there is no correlation between PAH concentration and percent

TABLE 3.52. MEAN CONCENTRATIONS OF AROMATIC HYDROCARBONS IN SEDIMENTS FROM LAKE PELTO, STATIONS 1 THROUGH 8, COLLECTED DURING THE SPRING SURVEY.

Compound	Concentration (µg/g Dry Weight) Station 1	2	3	4	5	6	7	8
Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_1-B	0.0	0.010	0.002	0.0	0.0	0.0	0.0	0.0
C_2-B	0.008	0.008	0.003	0.003	0.051	0.0	0.0	0.0
C_3-B	0.013	0.005	0.001	0.001	0.035	0.003	0.0	0.0
C_4-B	0.224	0.0	0.0	0.0	0.023	0.0	0.0	0.0
C_5-B	0.117	0.0	0.0	0.0	0.002	0.0	0.0	0.0
C_6-B	0.260	0.0	0.0	0.0	0.005	0.0	0.0	0.0
Naphthalene	0.033	0.003	0.0	0.0	0.016	0.008	0.0	0.0
C_1-N	0.167	0.006	0.001	0.001	0.004	0.019	0.0	0.0
C_2-N	0.921	0.013	0.0	0.0	0.028	0.018	0.0	0.0
C_3-N	1.387	0.008	0.0	0.0	0.052	0.026	0.0	0.0
C_4-N	0.667	0.003	0.0	0.0	0.027	0.0	0.0	0.0
C_5-N	0.135	0.0	0.0	0.0	0.019	0.0	0.0	0.0
Biphenyl	0.032	0.003	0.0	0.0	0.0	0.003	0.0	0.0
C_1-BL	0.343	0.036	0.0	0.0	0.007	0.0	0.0	0.0
C_2-BL	0.425	0.025	0.0	0.0	0.025	0.040	0.001	0.0
C_3-BL	0.514	0.030	0.0	0.0	0.035	0.042	0.001	0.0
C_4-BL	0.183	0.022	0.0	0.0	0.022	0.011	0.0	0.0
C_5-BL	0.055	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dibenzothiophene	0.043	0.020	0.002	0.0	0.007	0.032	0.001	0.0
C_1-D	0.069	0.010	0.0	0.0	0.009	0.012	0.0	0.0
C_2-D	0.137	0.013	0.0	0.0	0.011	0.019	0.0	0.0
C_3-D	0.111	0.005	0.0	0.0	0.012	0.0	0.0	0.0
C_4-D	0.041	0.0	0.0	0.0	0.001	0.0	0.0	0.0
C_5-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorene	0.179	0.039	0.004	0.0	0.019	0.070	0.003	0.0
C_1-F	0.248	0.012	0.0	0.0	0.012	0.017	0.0	0.0
C_2-F	0.408	0.024	0.0	0.011	0.033	0.019	0.004	0.003
C_3-F	0.304	0.034	0.0	0.0	0.041	0.006	0.0	0.0
C_4-F	0.138	0.006	0.0	0.004	0.011	0.008	0.006	0.0
C_5-F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phenanthrene	0.974	0.334	0.035	0.010	0.153	0.634	0.041	0.0
C_1-P	0.518	0.137	0.019	0.009	0.089	0.217	0.015	0.001
C_2-P	0.461	0.068	0.015	0.018	0.076	0.120	0.011	0.0
C_3-P	0.234	0.032	0.001	0.006	0.064	0.055	0.0	0.0
C_4-P	0.154	0.075	0.003	0.0	0.068	0.141	0.007	0.0
C_5-P	0.044	0.021	0.0	0.0	0.029	0.027	0.0	0.0
Pyrene	1.080	0.506	0.063	0.019	0.264	0.750	0.051	0.016
C_1-PY	0.492	0.194	0.023	0.006	0.161	0.329	0.017	0.001
C_2-PY	0.236	0.053	0.0	0.0	0.065	0.103	0.004	0.0
C_3-PY	0.063	0.026	0.001	0.0	0.014	0.040	0.0	0.0
C_4-PY	0.012	0.011	0.0	0.0	0.024	0.012	0.0	0.0
C_5-PY	0.0	0.0	0.0	0.0	0.006	0.0	0.0	0.0
Chrysene	0.398	0.176	0.030	0.008	0.096	0.223	0.023	0.0
C_1-C	0.226	0.078	0.013	0.002	0.061	0.088	0.004	0.0
C_2-C	0.108	0.022	0.0	0.0	0.052	0.143	0.0	0.0
C_3-C	0.018	0.009	0.0	0.0	0.022	0.002	0.0	0.0
C_4-C	0.0	0.005	0.0	0.0	0.0	0.003	0.0	0.0
C_5-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Perylene	0.163	0.105	0.056	0.077	0.035	0.066	0.043	0.069
C_1-PL	0.167	0.091	0.013	0.001	0.029	0.095	0.0	0.0
C_2-PL	0.029	0.019	0.0	0.0	0.010	0.015	0.0	0.0
C_3-PL	0.003	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_4-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_5-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	12.542	2.297	0.285	0.176	1.825	3.416	0.232	0.090

TABLE 3.53. MEAN CONCENTRATIONS OF AROMATIC HYDROCARBONS IN SEDIMENTS FROM LAKE PELTO, STATIONS 9 THROUGH 16, COLLECTED DURING THE SPRING SURVEY.

	Concentration (µg/g Dry Weight)							
	Station							
Compound	9	10	11	12	13	14	15	16
Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_1-B	0.002	0.0	0.0	0.043	0.0	0.0	0.0	0.0
C_2-B	0.011	0.002	0.021	0.048	0.010	0.052	0.023	0.0
C_3-B	0.007	0.001	0.012	0.039	0.006	0.035	0.011	0.0
C_4-B	0.0	0.0	0.003	0.013	0.021	0.021	0.0	0.0
C_5-B	0.0	0.0	0.0	0.0	0.003	0.001	0.0	0.0
C_6-B	0.0	0.0	0.0	0.0	0.066	0.0	0.0	0.0
Naphthalene	0.008	0.013	0.0	0.024	0.012	0.037	0.0	0.0
C_1-N	0.008	0.012	0.005	0.007	0.028	0.027	0.003	0.0
C_2-N	0.0	0.018	0.002	0.0	0.102	0.036	0.0	0.0
C_3-N	0.0	0.019	0.0	0.0	0.230	0.053	0.0	0.0
C_4-N	0.0	0.0	0.0	0.0	0.154	0.021	0.0	0.0
C_5-N	0.0	0.0	0.0	0.0	0.040	0.0	0.0	0.0
Biphenyl	0.0	0.006	0.0	0.0	0.009	0.005	0.0	0.0
C_1-BL	0.007	0.125	0.0	0.0	0.056	0.069	0.0	0.0
C_2-BL	0.018	0.086	0.001	0.002	0.088	0.067	0.0	0.0
C_3-BL	0.026	0.058	0.002	0.0	0.125	0.076	0.0	0.0
C_4-BL	0.015	0.009	0.0	0.0	0.097	0.048	0.0	0.0
C_5-BL	0.0	0.0	0.0	0.0	0.007	0.0	0.0	0.0
Dibenzothiophene	0.012	0.079	0.0	0.0	0.027	0.044	0.0	0.0
C_1-D	0.008	0.020	0.0	0.004	0.033	0.033	0.001	0.0
C_2-D	0.016	0.012	0.0	0.005	0.064	0.032	0.0	0.0
C_3-D	0.012	0.0	0.0	0.007	0.054	0.012	0.0	0.[illegible]
C_4-D	0.0	0.0	0.0	0.001	0.014	0.001	0.0	0[illegible]
C_5-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.[illegible]
Fluorene	0.025	0.171	0.002	0.002	0.049	0.087	0.002	0.0
C_1-F	0.016	0.043	0.0	0.003	0.075	0.040	0.0	0.0
C_2-F	0.021	0.038	0.011	0.023	0.145	0.033	0.0	0.0
C_3-F	0.036	0.034	0.008	0.039	0.167	0.057	0.005	0.01
C_4-F	0.032	0.011	0.009	0.0	0.107	0.030	0.016	0.0
C_5-F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phenanthrene	0.185	1.597	0.014	0.015	0.283	0.828	0.019	0.01
C_1-P	0.069	0.256	0.010	0.022	0.174	0.197	0.0	0.0
C_2-P	0.062	0.087	0.024	0.039	0.204	0.115	0.019	0.02
C_3-P	0.039	0.029	0.007	0.031	0.113	0.040	0.004	0.0
C_4-P	0.029	0.131	0.0	0.001	0.094	0.136	0.002	0.0
C_5-P	0.002	0.020	0.0	0.0	0.016	0.024	0.0	0.0
Pyrene	0.287	1.348	0.021	0.024	0.492	1.167	0.028	0.02
C_1-PY	0.142	0.399	0.012	0.010	0.213	0.385	0.016	0.01
C_2-PY	0.075	0.103	0.0	0.010	0.098	0.107	0.0	0.0
C_3-PY	0.034	0.030	0.0	0.0	0.061	0.051	0.0	0.0
C_4-PY	0.008	0.010	0.0	0.0	0.035	0.021	0.0	0.00
C_5-PY	0.0	0.0	0.0	0.0	0.005	0.004	0.0	0.0
Chrysene	0.118	0.476	0.012	0.013	0.162	0.500	0.026	0.01
C_1-C	0.068	0.137	0.002	0.011	0.109	0.211	0.004	0.0
C_2-C	0.024	0.024	0.0	0.002	0.058	0.079	0.0	0.00
C_3-C	0.007	0.002	0.0	0.0	0.019	0.032	0.0	0.0
C_4-C	0.0	0.012	0.0	0.0	0.0	0.022	0.0	0.0
C_5-C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Perylene	0.094	0.373	0.086	0.184	0.130	0.249	0.071	0.20
C_1-PL	0.062	0.140	0.0	0.005	0.092	0.215	0.0	0.0
C_2-PL	0.013	0.019	0.0	0.0	0.029	0.063	0.0	0.0
C_3-PL	0.0	0.002	0.0	0.0	0.0	0.024	0.0	0[illegible]
C_4-PL	0.0	0.0	0.0	0.0	0.0	0.001	0.0	0.[illegible]
C_5-PL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	1.598	5.952	0.264	0.627	4.176	5.388	0.250	0.33

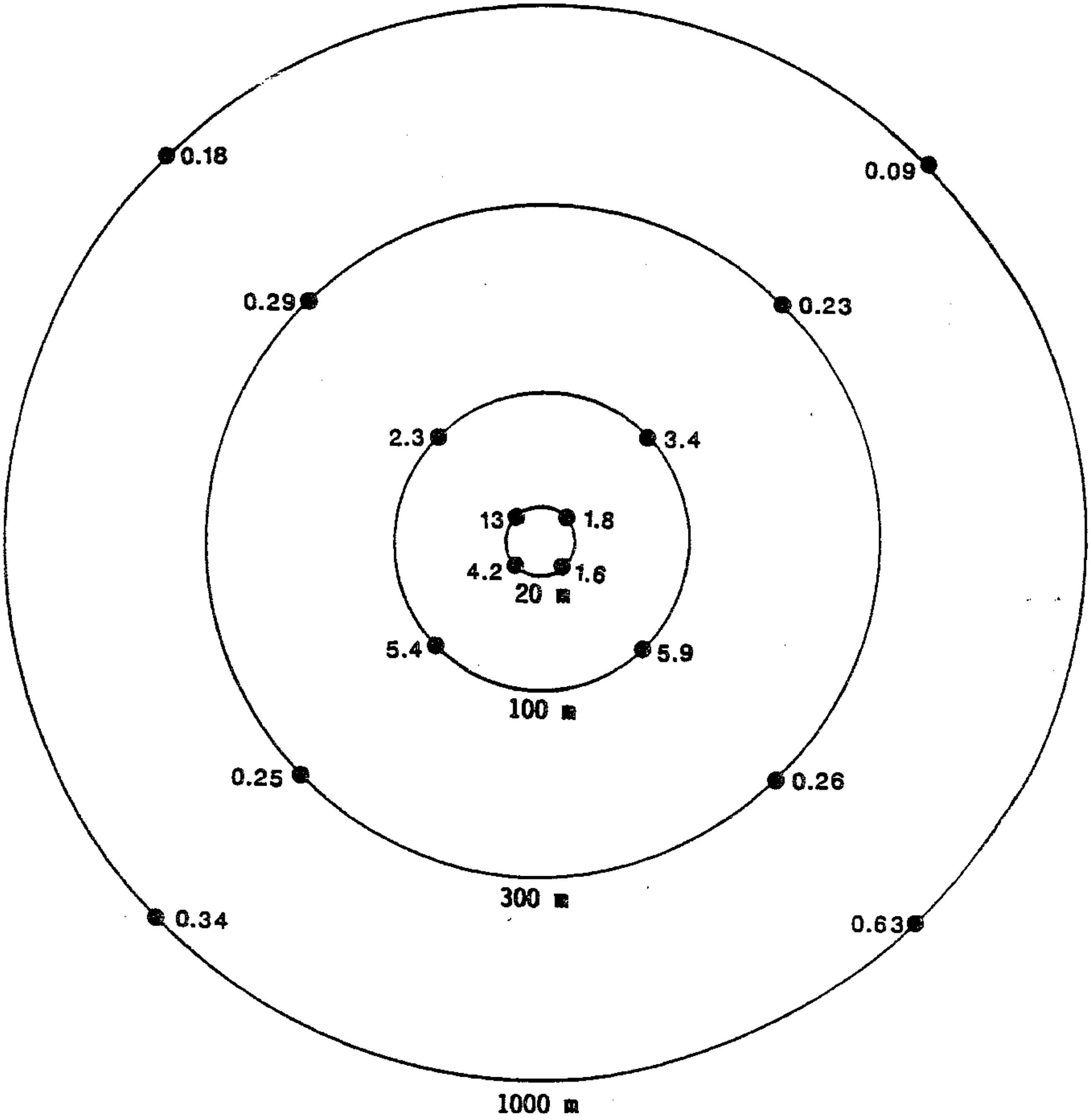


FIGURE 3.19. MEAN TOTAL PAH CONCENTRATIONS (µg/g) IN SEDIMENTS COLLECTED AT LAKE PELTO, STATIONS 1-16, DURING THE SPRING SURVEY (TABLES 3.52 AND 3.53).

silt/clay in sediments, in contrast to the situation at Eugene Island where there was a significant correlation between sediment grain size and PAH concentrations. In fact, at Lake Pelto, PAH concentrations are highest in sediments that have the lowest silt/clay content and are located near the platform (Table 3.48). The total PAH concentration is particularly high at Station 1 where replicate values range from 7 to 20 μg/g (mean, 13 μg/g). The grain-size distribution at this station is very low in silt/clay content (16 percent); the sediment is sandy.

As stated before, the high sand content of sediments near the platform could be the result of high-current shears around the platform due to wake effects, discharges of material from the oil and gas operations on the platform, or materials placed at the site during platform construction. The high PAH concentrations in these sandy sediments near the platform suggest that some crude petroleum input, perhaps from produced water discharges, is contaminating the sediments in the immediate vicinity of the outfall. Produced water from Lake Pelto Tank Battery No. 1 contains about 5.8 μg/l total 4- and 5-ring PAHs (Table 3.4). This topic is discussed further in Section 4.5.1.

3.3.2.4.2 Fall Survey. Individual and total PAH concentrations in sediments at Stations 1, 13, 14, and 15 are presented in Tables 3.54 and 3.55. As was observed in sediment samples from the spring survey (Tables 3.52 and 3.53), PAH concentrations are highest (4 to 9 μg/g) at the stations close to the platform (Stations 1 and 13) and decrease with distance from the platform. Total PAH concentrations at Station 1 are, however, not as high in the fall survey (4.4 μg/g) as they were in the spring survey (12.5 μg/g), but are still well above background for the area. Homologous series for each PAH are similar in sediments from both surveys, suggesting that the source of these PAH has remained the same during the six months between surveys.

TABLE 3.54. CONCENTRATIONS OF AROMATIC HYDROCARBONS IN REPLICATE SEDIMENT SAMPLES FROM LAKE PELTO, STATION 1, COLLECTED DURING THE FALL SURVEY.

Compound	Concentration (µg/g Dry Weight)				
	Replicate				
	1	2	3	Mean	Standard Deviation
Benzene	0.0	0.0	0.0	0.0	0.0
C_1-B	0.0	0.0	0.0	0.0	0.0
C_2-B	0.009	0.004	0.004	0.006	0.003
C_3-B	0.003	0.0	0.001	0.001	0.002
C_4-B	0.0	0.0	0.0	0.0	0.0
C_5-B	0.0	0.0	0.0	0.0	0.0
C_6-B	0.0	0.0	0.0	0.0	0.0
Naphthalene	0.021	0.015	0.006	0.014	0.008
C_1-N	0.054	0.043	0.028	0.042	0.013
C_2-N	0.102	0.044	0.030	0.059	0.038
C_3-N	0.194	0.060	0.051	0.102	0.080
C_4-N	0.094	0.025	0.043	0.054	0.036
C_5-N	0.066	0.029	0.0	0.032	0.033
Biphenyl	0.010	0.008	0.005	0.008	0.002
C_1-BL	0.0	0.0	0.0	0.0	0.0
C_2-BL	0.0	0.0	0.0	0.0	0.0
C_3-BL	0.0	0.0	0.0	0.0	0.0
C_4-BL	0.0	0.0	0.0	0.0	0.0
C_5-BL	0.0	0.0	0.0	0.0	0.0
Dibenzothiophene	0.040	0.047	0.014	0.034	0.017
C_1-D	0.034	0.024	0.011	0.023	0.012
C_2-D	0.057	0.035	0.021	0.038	0.018
C_3-D	0.083	0.031	0.026	0.047	0.032
C_4-D	0.0	0.0	0.0	0.0	0.0
C_5-D	0.0	0.0	0.0	0.0	0.0
Fluorene	0.102	0.106	0.031	0.080	0.042
C_1-F	0.069	0.053	0.018	0.047	0.026
C_2-F	0.007	0.0	0.0	0.002	0.004
C_3-F	0.0	0.001	0.0	0.0	0.0
C_4-F	0.0	0.0	0.0	0.0	0.0
C_5-F	0.0	0.0	0.020	0.007	0.012
Phenanthrene	0.621	0.769	0.213	0.534	0.288
C_1-P	0.271	0.271	0.096	0.213	0.101
C_2-P	0.213	0.198	0.090	0.167	0.067
C_3-P	0.116	0.156	0.070	0.114	0.043
C_4-P	0.0	0.012	0.028	0.013	0.014
C_5-P	0.0	0.022	0.025	0.016	0.014
Pyrene	0.919	1.234	0.336	0.830	0.456
C_1-PY	0.475	0.630	0.185	0.430	0.226
C_2-PY	0.178	0.211	0.077	0.155	0.070
C_3-PY	0.034	0.055	0.039	0.043	0.011
C_4-PY	0.0	0.0	0.0	0.0	0.0
C_5-PY	0.0	0.0	0.0	0.0	0.0
Chrysene	0.496	0.727	0.227	0.483	0.250
C_1-C	0.182	0.346	0.113	0.214	0.020
C_2-C	0.075	0.049	0.037	0.054	0.019
C_3-C	0.0	0.0	0.0	0.0	0.0
C_4-C	0.0	0.0	0.0	0.0	0.0
C_5-C	0.0	0.0	0.0	0.0	0.0
Perylene	0.260	0.315	0.133	0.236	0.093
C_1-PL	0.234	0.454	0.129	0.272	0.166
C_2-PL	0.0	0.054	0.0	0.018	0.031
C_3-PL	0.0	0.0	0.0	0.0	0.0
C_4-PL	0.0	0.0	0.0	0.0	0.0
C_5-PL	0.0	0.0	0.0	0.0	0.0
TOTAL AROMATICS	5.019	6.028	2.107	4.388	-

TABLE 3.55. CONCENTRATIONS OF AROMATIC HYDROCARBONS IN SEDIMENTS FROM LAKE PELTO, STATIONS 13, 14, AND 15, ONE REPLICATE FROM EACH STATION COLLECTED DURING THE FALL SURVEY.

Compound	Concentration (μg/g Dry Weight) Station 13	14	15
Benzene	0.0	0.0	0.0
C_1-B	0.0	0.0	0.0
C_2-B	0.0	0.010	0.004
C_3-B	0.0	0.003	0.0
C_4-B	0.004	0.0	0.0
C_5-B	0.0	0.0	0.0
C_6-B	0.0	0.0	0.0
Naphthalene	0.008	0.0	0.0
C_1-N	0.019	0.003	0.0
C_2-N	0.083	0.007	0.0
C_3-N	0.455	0.010	0.0
C_4-N	0.669	0.0	0.0
C_5-N	0.315	0.0	0.0
Biphenyl	0.007	0.0	0.0
C_1-BL	0.0	0.0	0.0
C_2-BL	0.0	0.0	0.0
C_3-BL	0.0	0.0	0.0
C_4-BL	0.0	0.0	0.0
C_5-BL	0.0	0.0	0.0
Dibenzothiophene	0.028	0.004	0.0
C_1-D	0.024	0.003	0.0
C_2-D	0.168	0.005	0.0
C_3-D	0.044	0.0	0.0
C_4-D	0.069	0.0	0.0
C_5-D	0.0	0.0	0.0
Fluorene	0.044	0.005	0.0
C_1-F	0.104	0.0	0.0
C_2-F	0.422	0.0	0.0
C_3-F	0.605	0.0	0.0
C_4-F	0.406	0.0	0.0
C_5-F	0.034	0.0	0.0
Phenanthrene	0.283	0.052	0.010
C_1-P	0.155	0.069	0.017
C_2-P	0.429	0.049	0.0
C_3-P	0.499	0.0	0.0
C_4-P	0.269	0.0	0.0
C_5-P	0.104	0.0	0.0
Pyrene	0.530	0.109	0.020
C_1-PY	0.515	0.035	0.0
C_2-PY	0.344	0.0	0.0
C_3-PY	0.222	0.0	0.0
C_4-PY	0.121	0.0	0.0
C_5-PY	0.047	0.0	0.0
Chrysene	0.318	0.044	0.0
C_1-C	0.376	0.010	0.0
C_2-C	0.306	0.0	0.0
C_3-C	0.037	0.0	0.0
C_4-C	0.0	0.0	0.0
C_5-C	0.0	0.0	0.0
Perylene	0.303	0.160	0.141
C_1-PL	0.423	0.0	0.0
C_2-PL	0.019	0.0	0.0
C_3-PL	0.0	0.0	0.0
C_4-PL	0.0	0.0	0.0
C_5-PL	0.0	0.0	0.0
TOTAL AROMATICS	8.808	0.578	0.192

From the spring to the fall survey, concentrations of total PAH in sediments appear to decrease at Stations 1, 14, and 15, and increase at Station 13. However, the pattern of PAH distribution at these stations remains essentially unchanged.

3.3.2.5 Steranes and Triterpanes

The biomarkers, C_{27} through C_{29} steranes and triterpanes, were determined in selected sediment samples collected during the spring survey from the northwest transect (Stations 1 through 4) of the Lake Pelto study site. Figures 3.20 and 3.21 show representative mass ion chromatograms of steranes (m/e-217) and triterpanes (m/e-191), respectively. Total concentration estimates of steranes and triterpanes in Lake Pelto sediments are given in Table 3.56. Ratios of selected steranes and triterpanes are presented in Table 3.9.

Unlike the situation at Eugene Island, at Lake Pelto the distribution and relative concentrations of the different steranes is similar in sediments (Figure 3.20) and produced water. However, there are significant differences in the source-indicator ratio of the 24-ethyl 14α(H), 17α(H)-cholestane (20S) and the (20R) isomer (peaks 17 and 19, respectively) between the produced water and the sediments (see Table 3.9). In addition, the relative abundance of $C_{27}\alpha\alpha$(R) cholestane (peak 10) is much different in produced water than in sediments. In fact, the $C_{27}\alpha\alpha$(R) cholestane was not even detected in sediments at Station 1, 20 m from the outfall. These differences are sufficient to indicate that produced water is not the sole source of the steranes in the Lake Pelto sediments.

The distribution of the triterpanes in the sediments is slightly different in the 20-m sediment sample (Figure 3.21) closest to the platform than in the other sediment samples further away (Figure 3.22). The relative peak heights of the identified (numbered) peaks are different, and more peaks are evident in

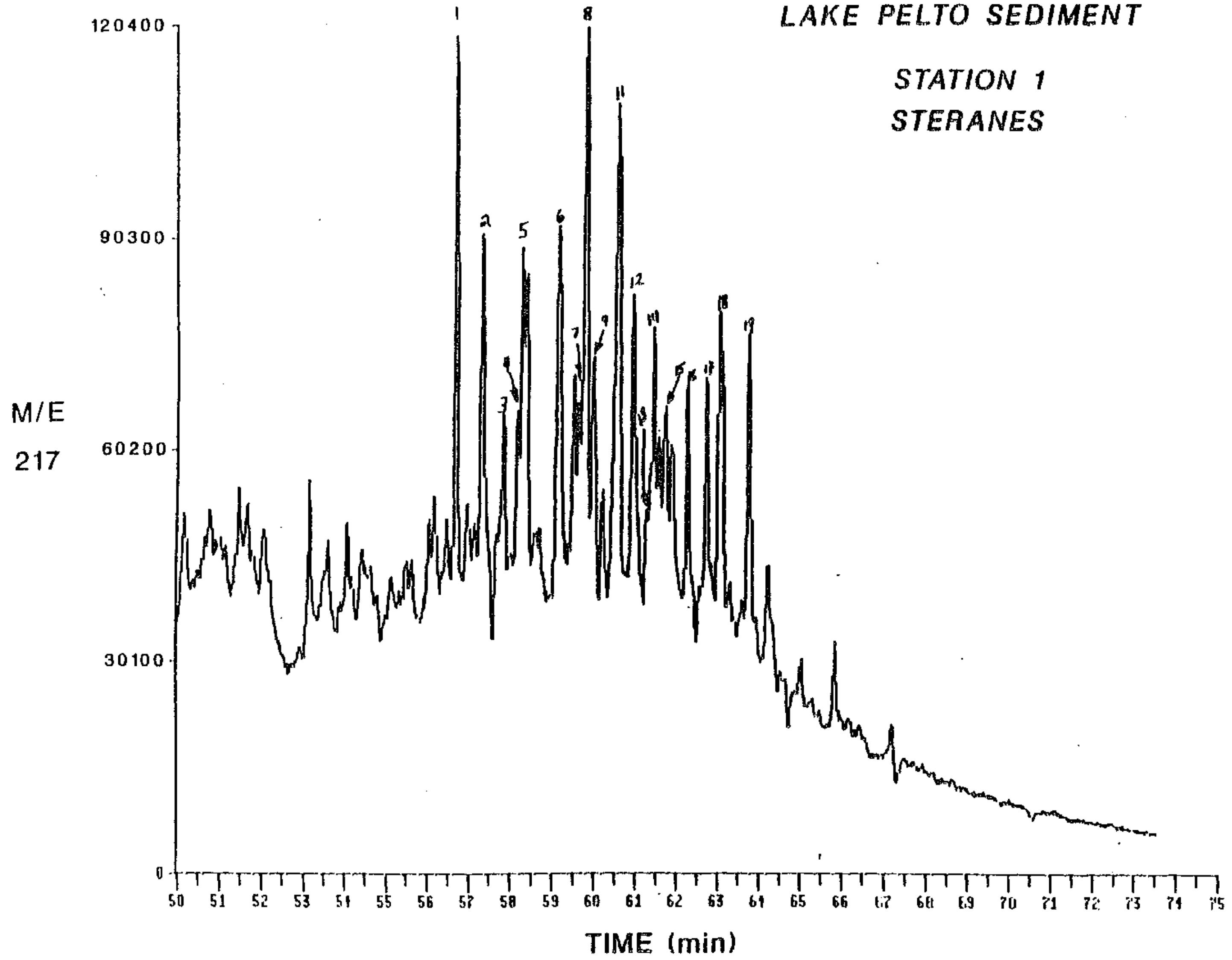


FIGURE 3.20. MASS ION CHROMATOGRAM OF STERANES (m/e – 217) IN SEDIMENT FROM STATION 1, REPLICATE 1, COLLECTED AT LAKE PELTO DURING THE SPRING SURVEY.

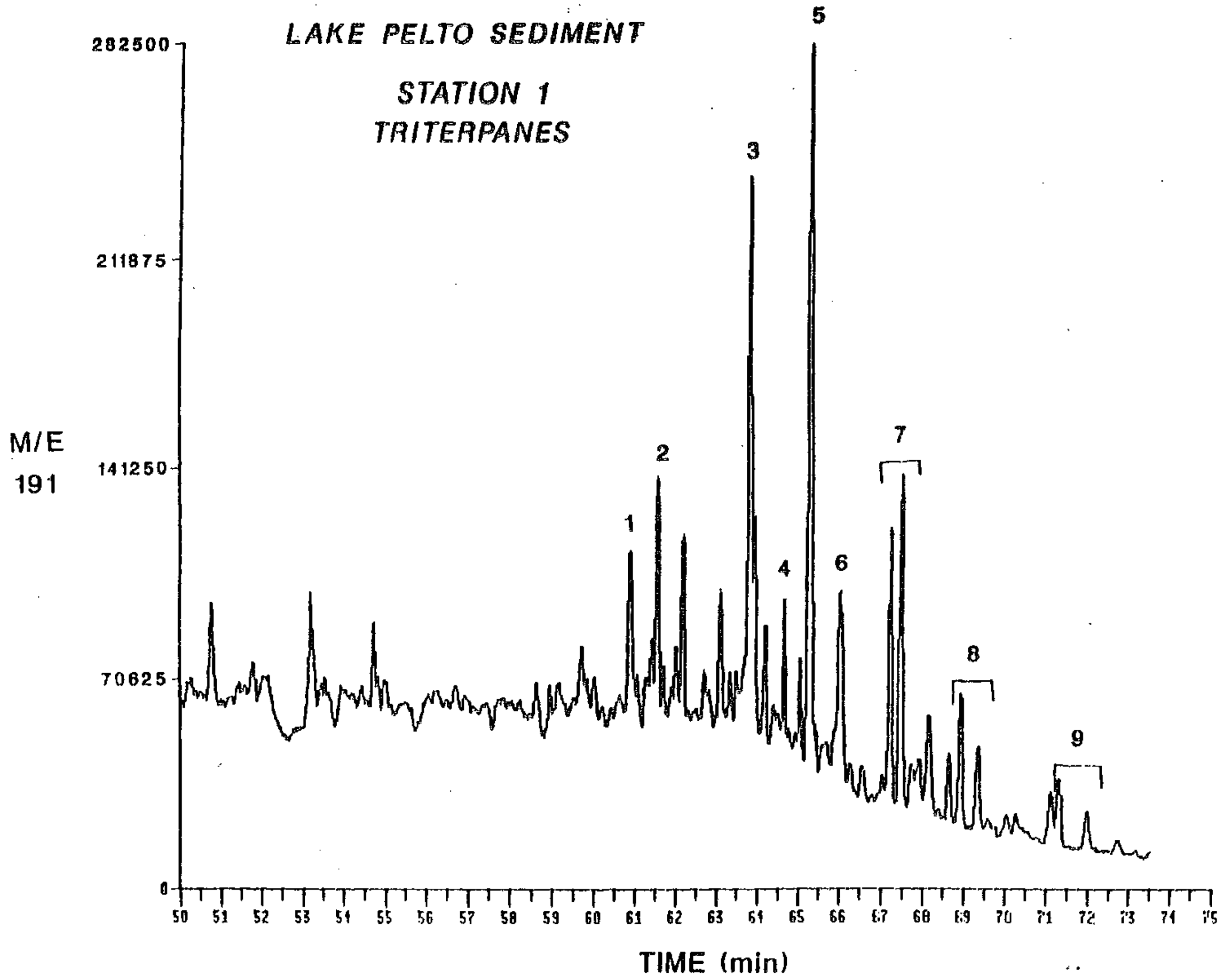


FIGURE 3.21. MASS ION CHROMATOGRAM OF TRITERPANES (m/e - 191) IN SEDIMENT FROM STATION 1, REPLICATE 1, COLLECTED AT LAKE PELTO DURING THE SPRING SURVEY.

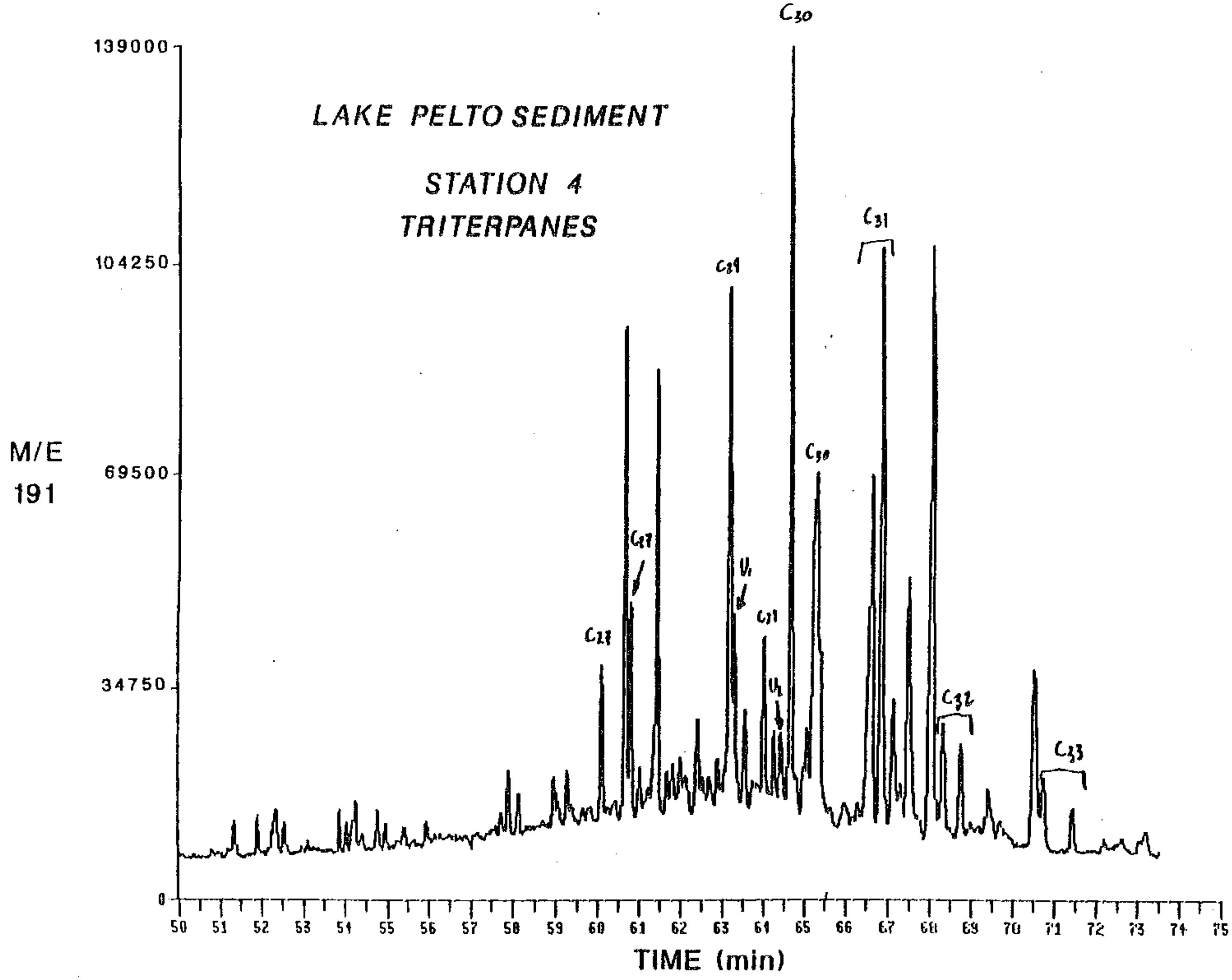


FIGURE 3.22. **MASS ION CHROMATOGRAM OF TRITERPANES (m/e - 191) IN SEDIMENT FROM STATION 4, REPLICATE 4, COLLECTED AT LAKE PELTO DURING THE SPRING SURVEY.**

TABLE 3.56. ESTIMATED CONCENTRATIONS OF STERANES AND TRITERPANES IN COMPOSITE SAMPLES OF SEDIMENTS AND PRODUCED WATER FROM LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

Sample	Steranes	Triterpanes
Produced Water	92 µg/l	80 µg/l
Sediment		
Station 1	1.5 µg/g Dry Wt.	1.8 µg/g Dry Wt.
Station 2	0.45	1.1
Station 3	0.30	1.1
Station 4	0.41	1.4

the sediment samples from the outer stations than in the sample from 20 m from the platform. The distribution of the identified triterpanes in the sediment sample taken 20 m from the platform is, however, not completely similar to that of produced water. Although there are more compounds in the sediment samples outside a 20-m radius, the total triterpane concentration in the 20-m sample is slightly higher than that in the other samples. The ratio of $C_{22}S$ to $C_{22}R$ isomers of the C_{31} hopanes indicates an "immature" fossil source for the sediment triterpanes. Although the ratio is slightly higher in the Station 1 sample (0.80) than in the other sediment samples, the value is significantly lower than the ratio observed in the produced water (1.2) as shown in Table 3.9. The difference in ratio values in the produced water and sediments indicates that the triterpanes in the Lake Pelto sediments cannot be attributed to produced water.

3.3.2.6 Total Organic Carbon

All replicate sediment samples from the 16 stations at Lake Pelto were analyzed for total organic carbon. Concentrations in each replicate are given in Appendix E (Table E2) and mean TOC concentrations are summarized in Table 3.57.

Unlike the specific organic constituents (i.e., PAH, alkanes) discussed earlier, the TOC concentrations do not show the trend of decreasing concentration with distance from the platform; there is either no change or a slight increase with distance. Also, TOC concentrations in sediments do not correlate with the percent silt/clay in the sediments. In the Eugene Island sediments, increases in TOC concentration did correlate with increases in percent silt/clay.

3.3.2.7 Phenol and Alkyl Phenols

The replicate samples collected during the spring survey closest

TABLE 3.57. PERCENT TOTAL ORGANIC CARBON IN SEDIMENTS FROM LAKE PELTO COLLECTED DURING THE SPRING SURVEY ($\bar{X}$ - MEAN, S.D. - STANDARD DEVIATION).

Station	Mean Percent ($\bar{X}$)	Standard Deviation (S.D.)
1 (NW, 20 m)	0.52	0.15
2 (NW, 100 m)	0.46	0.03
3 (NW, 300 m)	0.46	0.02
4 (NW, 1000 m)	0.49	0.05
5 (NE, 20 m)	0.37	0.03
6 (NE, 100 m)	0.39	0.04
7 (NE, 300 m)	0.38	0.04
8 (NE, 1000 m)	0.37	0.06
9 (SE, 20 m)	0.64	0.20
10 (SE, 100 m)	0.42	0.02
11 (SE, 300 m)	0.65	0.11
12 (SE, 1000 m)	0.83	0.17
13 (SW, 20 m)	0.45	0.06
14 (SW, 100 m)	0.58	0.11
15 (SW, 300 m)	0.47	0.06
16 (SW, 1000 m)	0.78	0.13

to the Lake Pelto platform (Stations 1, 5, 9, and 13) were analyzed for phenol and its alkyl homologues (C_1 through C_4-phenols). Phenol concentrations in individual replicates from the four stations are presented in Tables 3.58 through 3.61.

Except for one replicate at Station 1 that contains C_2-phenol, the sediment samples do not contain o-cresol, m,p-cresol, C_2-phenol, or C_4-phenol. Phenol and C_3-phenols are the only phenols represented in the Lake Pelto sediments and these compounds are contained in all replicates. Phenol is the homologue present at highest concentration in all sediment samples; one replicate sample from Station 9 contains 35 ppm phenol. As discussed before, the phenol concentrations are probably overestimated because phenol was found in laboratory blanks.

The phenol homologue distribution in the sediments is not similar to the distribution in the Lake Pelto produced water. Lake Pelto produced water has the full complement of phenolic compounds (Table 3.11), whereas the sediments contain only phenol (perhaps) and C_3-phenols. As is the case for the Eugene Island sediments, it is uncertain whether the phenol homologue distribution in Lake Pelto sediments reflects selective degradation of different phenols, or a source other than produced water for the sediment phenols.

Because C_3-phenols are present in every sediment sample and do not seem to originate from produced water, these compounds may be of biogenic origin or from another anthropogenic source, such as hindered phenol antioxidants that have become ubiquitous in the environment (Gusten et al., 1973). The presence of C_3-phenols in Eugene Island sediments suggests that a biogenic origin of these phenols is the more plausible hypothesis.

TABLE 3.58. PHENOL CONCENTRATIONS IN SEDIMENTS COLLECTED AT LAKE PELTO, STATION 1, DURING THE SPRING SURVEY.

Compound	Concentration (μg/kg)				
	Replicate				Standard Deviation
	1	2	3	Mean	
Phenol	490[a]	633[a]	4500[a]	1870[a]	2275
o-Cresol	ND	ND	ND	--	--
m,p-Cresol	ND	ND	ND	--	--
C_2-Phenol	11.2	ND	ND	3.73	6.47
C_3-Phenol	20.2	3.0	213	78.7	117
C_4-Phenol	ND	ND	ND	--	--
		TOTAL PHENOLS		1956	

ND = Not Detected.

[a] Concentrations of phenol listed here probably are substantially higher than the true concentrations in sediments as indicated by the excessively high recovery of phenol from the spiked blanks (220%) and the presence of phenol in the laboratory blanks.

TABLE 3.59. PHENOL CONCENTRATIONS IN SEDIMENTS COLLECTED AT LAKE PELTO, STATION 5, DURING THE SPRING SURVEY.

Compound	Concentration (µg/kg) Replicate 1	2	3	Mean	Standard Deviation
Phenol	4730[a]	9820[a]	2740[a]	5760[a]	3651
o-Cresol	ND	ND	ND	--	--
m,p-Cresol	ND	ND	ND	--	--
C_2-Phenol	ND	ND	ND	--	--
C_3-Phenol	294	488	66.9	283	211
C_4-Phenol	ND	ND	ND	--	--
		TOTAL PHENOLS		**6046**	

ND = Not Detected.

[a] Concentrations of phenol listed here probably are substantially higher than the true concentrations in sediments as indicated by the excessively high recovery of phenol from the spiked blanks (220%) and the presence of phenol in the laboratory blanks.

TABLE 3.60. PHENOL CONCENTRATIONS IN SEDIMENTS COLLECTED AT LAKE PELTO, STATION 9, DURING THE SPRING SURVEY.

Compound	Concentration (μg/kg) Replicate 1	2	3	Mean	Standard Deviation
Phenol	1600[a]	34,500[a]	1030[a]	12,376	19,161
o-Cresol	ND	ND	ND	--	--
m,p-Cresol	ND	ND	ND	--	--
C_2-Phenol	ND	ND	ND	--	--
C_3-Phenol	58.7	880	41.4	327	480
C_4-Phenol	ND	ND	ND	--	--
		TOTAL PHENOLS		12,703	

ND = Not Detected.

[a] Concentrations of phenol listed here probably are substantially higher than the true concentrations in sediments as indicated by the excessively high recovery of phenol from the spiked blanks (220%) and the presence of phenol in the laboratory blanks.

TABLE 3.61. PHENOL CONCENTRATIONS IN SEDIMENTS COLLECTED AT LAKE PELTO, STATION 13, DURING THE SPRING SURVEY.

	Concentration (μg/kg)				
	Replicate				
Compound	1	2	3	Mean	Standard Deviation
Phenol	322[a]	312[a]	600[a]	411	163
o-Cresol	ND	ND	ND	--	--
m,p-Cresol	ND	ND	ND	--	--
C_2-Phenol	ND	ND	ND	--	--
C_3-Phenol	51.3	24.0	35.0	36.8	13.7
C_4-Phenol	ND	ND	ND	--	--
		TOTAL PHENOLS		448	

ND = Not Detected.

[a] Concentrations of phenol listed here probably are substantially higher than the true concentrations in sediments as indicated by the excessively high recovery of phenol from the spiked blanks (220%) and the presence of phenol in the laboratory blanks.

One interesting observation from the analysis of phenols in Lake Pelto sediments is the discovery of a compound that has a mass spectrum similar to that of the C_3-phenols. The mass spectrum of this unknown compound is shown in Figure 3.23. In processing the mass spectra data, this compound was originally included as a C_3-phenol. However, after determining that this compound did not elute at the same time as the C_3-phenols (Figure 3.24), the unknown compound was removed from the quantification calculations for the C_3-phenols. This unknown was found only in Lake Pelto sediment samples, but not in produced water from either platform or Eugene Island sediment samples. A tentative identification of this unknown is a single-ring aromatic ether.

3.3.2.8 Metals

3.3.2.8.1 Spring Survey. Each sediment chemistry replicate from all 16 stations was analyzed for barium, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. The concentrations of these nine metals are presented in Appendix F (Tables F10 through F18). Mean concentrations of metals at each station are given in Table 3.62.

Metal concentrations as a whole do not follow any particular trend in Lake Pelto sediments. Each metal has its own particular distribution. Barium appears to have elevated concentrations throughout the study site, whereas other metals such as chromium, copper, and silver are not elevated above background concentrations anywhere in the study area.

Barium concentrations in sediments of the Lake Pelto area range from 1000 to 3000 mg/kg, considerably higher than the typical coastal concentrations of 500 to 700 mg/kg. There is no relation between concentration and distance from the platform; the distribution is patchy. Because Ba concentrations are high in the produced water, produced water barium may be a source of the elevated concentrations in the sediment. Ba that is not in

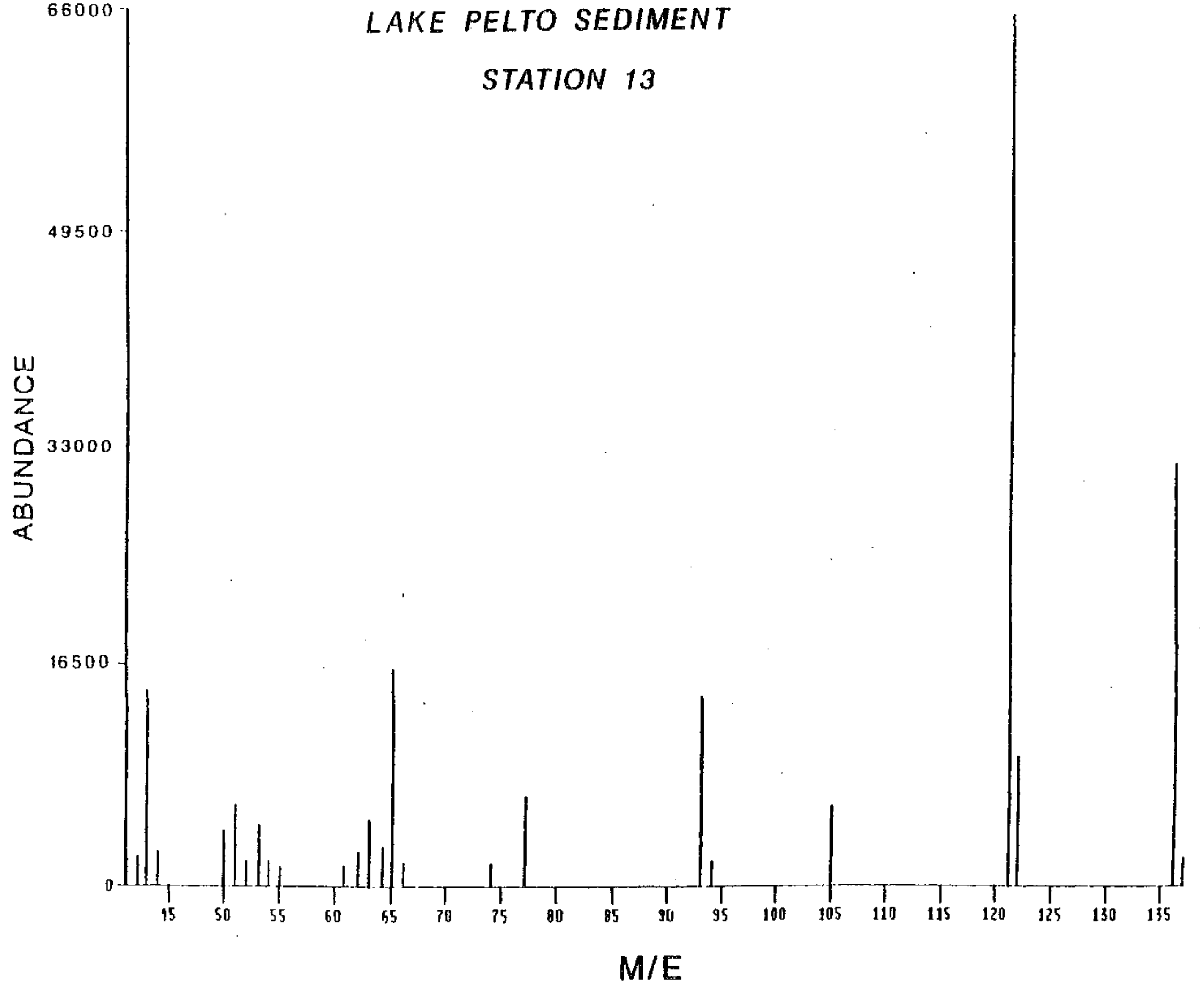


FIGURE 3.23. MASS SPECTRUM (#558) OF AN UNKNOWN COMPOUND, TENTATIVELY IDENTIFIED AS A SINGLE-RING AROMATIC ETHER, FROM THE PHENOLS EXTRACT OF SEDIMENT FROM

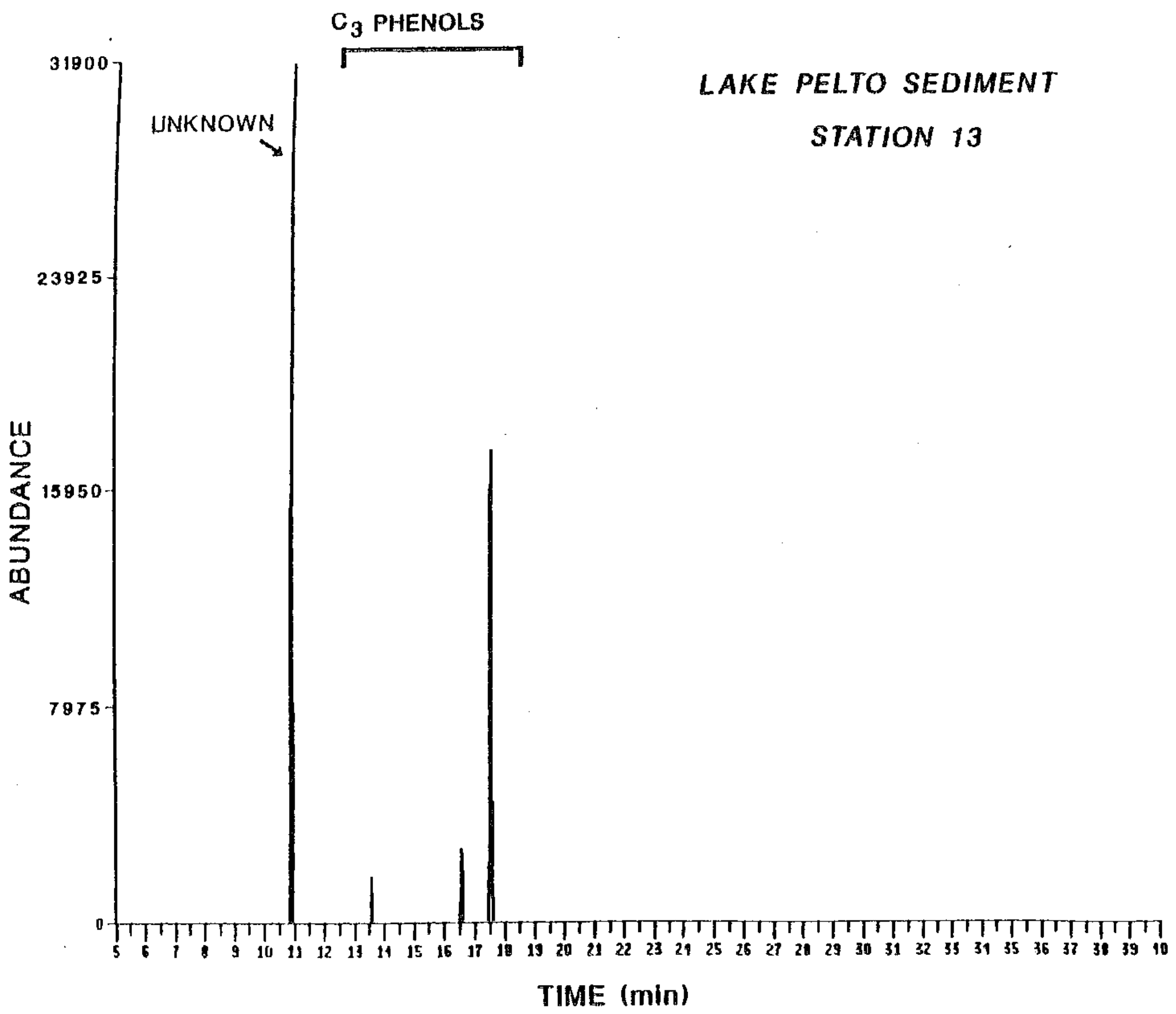


FIGURE 3.24. MASS ION CHROMATOGRAM OF C_3-PHENOLS (m/e - 136) IN SEDIMENTS COLLECTED AT LAKE PELTO, STATION 13, DURING THE SPRING SURVEY.

TABLE 3.62. MEAN CONCENTRATIONS OF TRACE METALS IN SEDIMENTS FROM LAKE PELTO COLLECTED DURING THE SPRING SURVEY (MEAN OF THREE REPLICATES ± STANDARD DEVIATION).

Station Distance (M)	Direction From Platform NW	 NE	 SE	 SW
	(Concentrations in mg/kg Dry Weight)			
	Barium			
20	1300 ± 304	1003 ± 81	2557 ± 519	2100 ± 332
100	1743 ± 612	3047 ± 365	2437 ± 1182	2447 ± 314
300	1990 ± 735	1483 ± 586	1903 ± 240	2673 ± 443
1000	2577 ± 885	1379 ± 508	1403 ± 497	1423 ± 474
	Cadmium			
20	0.334 ± 0.130	0.199 ± 0.039	0.091 ± 0.003	0.161 ± 0.034
100	0.095 ± 0.002	0.107 ± 0.018	0.107 ± 0.012	0.107 ± 0.022
300	0.120 ± 0.014	0.077 ± 0.004	0.112 ± 0.017	0.104 ± 0.010
1000	0.125 ± 0.010	0.075 ± 0.006	0.100 ± 0.010	0.098 ± 0.024
	Chromium			
20	7.78 ± 1.44	6.62 ± 1.50	6.29 ± 1.38	8.48 ± 3.89
100	6.22 ± 0.80	7.17 ± 1.05	9.46 ± 0.27	10.12 ± 2.10
300	6.34 ± 1.31	7.58 ± 0.91	9.58 ± 0.65	8.77 ± 3.04
1000	12.90 ± 0.60	8.25 ± 1.72	11.50 ± 0.90	9.38 ± 0.72
	Copper			
20	6.93 ± 1.13	6.10 ± 1.16	6.07 ± 0.78	11.24 ± 3.65
100	5.77 ± 1.96	6.69 ± 1.87	6.41 ± 0.65	8.03 ± 3.16
300	6.64 ± 1.62	5.36 ± 0.33	7.30 ± 1.14	5.76 ± 1.11
1000	7.61 ± 0.78	4.78 ± 0.50	8.54 ± 0.81	9.17 ± 2.50
	Lead			
20	10.80 ± 2.14	13.58 ± 7.20	7.77 ± 0.75	11.40 ± 1.40
100	7.05 ± 0.84	15.70 ± 9.45	8.51 ± 0.73	10.40 ± 0.70
300	9.14 ± 2.01	6.23 ± 0.86	11.80 ± 4.57	7.82 ± 1.28
1000	8.80 ± 1.13	6.07 ± 0.62	9.25 ± 0.96	9.31 ± 2.60
	Mercury			
20	0.375 ± 0.159	0.310 ± 0.176	0.069 ± 0.019	0.161 ± 0.043
100	0.390 ± 0.410	0.763 ± 0.287	0.050 ± 0.023	0.114 ± 0.134
300	0.022 ± 0.011	0.049 ± 0.052	0.038 ± 0.005	0.023 ± 0.008
1000	0.007 ± 0.052	0.014 ± 0.004	0.017 ± 0.002	0.017 ± 0.004
	Nickel			
20	7.67 ± 0.81	6.12 ± 0.50	9.15 ± 0.21	8.38 ± 1.06
100	7.16 ± 0.84	8.29 ± 0.87	11.40 ± 0.30	10.28 ± 1.64
300	8.48 ± 0.03	9.47 ± 0.80	11.09 ± 1.03	9.82 ± 1.32
1000	10.65 ± 0.82	8.84 ± 0.75	13.30 ± 0.60	12.50 ± 2.30
	Silver			
20	0.024 ± 0.008	0.019 ± 0.001	0.025 ± 0.001	0.033 ± 0.002
100	0.025 ± 0.002	0.021 ± 0.004	0.068 ± 0.063	0.033 ± 0.005
300	0.015 ± 0.002	0.024 ± 0.005	0.045 ± 0.005	0.032 ± 0.003
1000	0.021 ± 0.016	0.021 ± 0.002	0.039 ± 0.003	0.042 ± 0.009
	Zinc			
20	103.8 ± 9.60	88.1 ± 11.2	43.2 ± 3.40	83.6 ± 20.3
100	43.1 ± 5.30	61.9 ± 11.6	46.4 ± 1.50	51.9 ± 14.1
300	41.5 ± 3.40	36.2 ± 2.60	56.1 ± 16.6	46.5 ± 5.20
1000	48.7 ± 3.50	35.0 ± 2.90	48.9 ± 1.50	45.3 ± 6.70

the form of $BaSO_4$ in the produced water would react with the excess sulfate in the receiving waters and precipitate as barite. The barium in the sediment may also be from deposition of barite-containing drilling fluids discharged to waters of the study area during the drilling of production wells. Over the years, the barium may have been redistributed throughout the area.

Cadmium, lead, mercury, and zinc are the only trace metals that are present in sediments at slightly elevated concentrations near the platform, that decrease away from the platform. In most cases, the Cd, Pb, and Zn concentrations are only slightly higher (20 percent to 40 percent) at the stations near the platform (20 m and 100 m) than at the stations further away.

Mercury concentrations, however, are substantially higher (0.05 to 0.8 mg/kg) at stations near the platform than at stations further away (0.007 through 0.05 mg/kg). A plan view of mean mercury concentrations in sediments of the study site is presented in Figure 3.25. At several stations close to the platform, mercury concentrations in sediments are an order of magnitude higher than at the outer stations. Mercury concentration decreases with distance from the platform. The source of these elevated metals concentrations in sediments near the platform is not clear. Unless there is some preferential removal of these metals in the water column, discharges of produced water do not seem to be the source because of the low concentrations of these metals in Lake Pelto produced water.

Copper, chromium, and silver do not show any trend within the study site and are at concentrations typical of background coastal sediments. Chromium, however, shows some correlation with the silt/clay fraction.

3.3.2.8.2 Fall Survey. The results of analysis of barium, nickel, and mercury in sediments from the four stations are

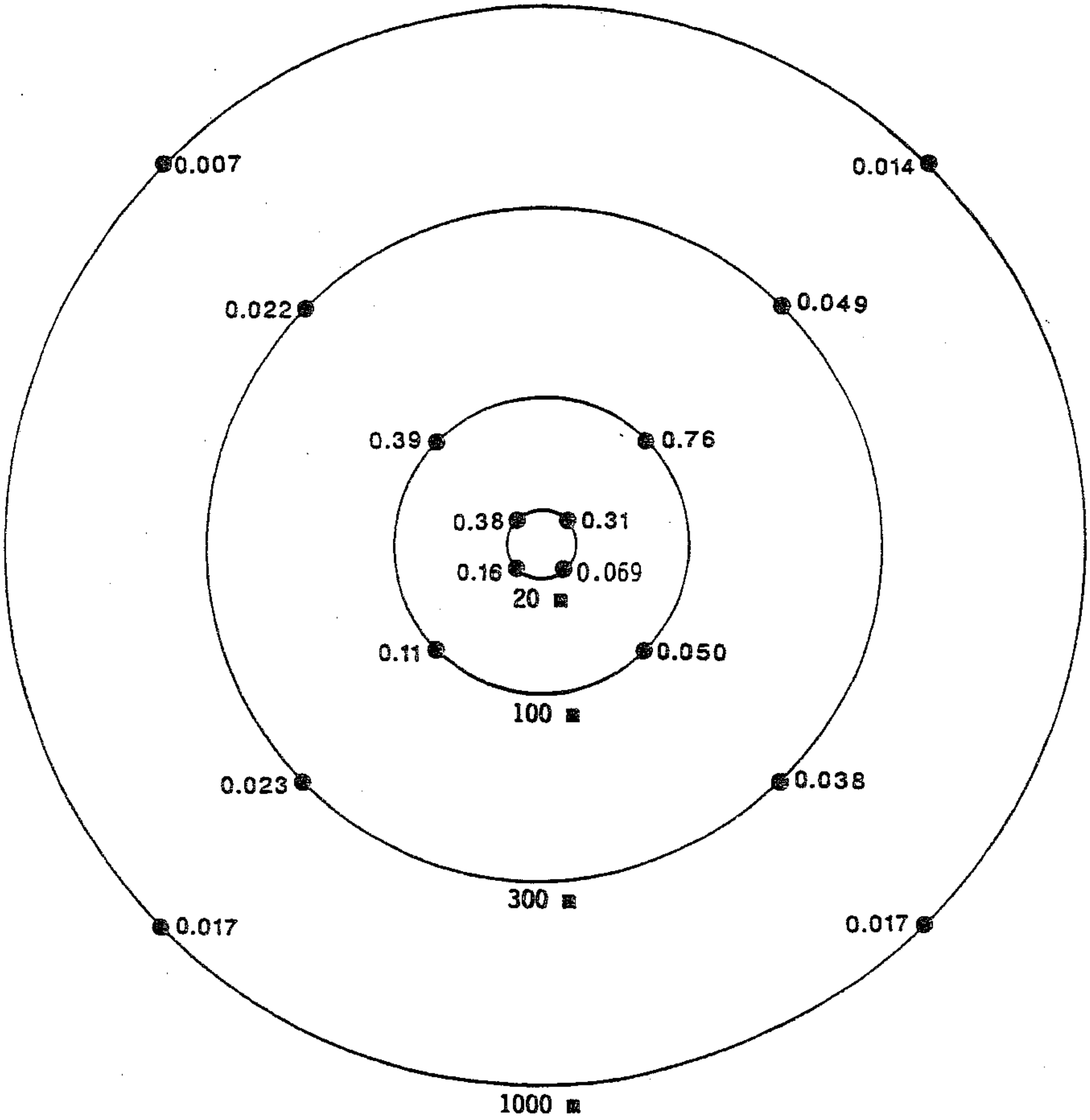


FIGURE 3.25. MEAN CONCENTRATIONS OF MERCURY IN SEDIMENTS COLLECTED AT LAKE PELTO, STATIONS 1-16, DURING THE SPRING SURVEY (TABLE 3.62).

presented in Table 3.63.

The concentration ranges and the distributions of the three trace metals in sediments at the four stations were similar in the spring (Table 3.62) and fall (within a factor of about 2). Barium concentrations in sediments range from 1460 mg/kg at Station 14 to 5040 mg/kg at Station 13 in the fall, compared to concentrations of 1300 to 2673 mg/kg at the same stations in the spring. Nickel concentrations in sediments from the four stations are slightly higher in the fall than they were in the spring, ranging from 12 to 15 mg/kg. Mercury concentrations in sediments at the four stations are the same in the fall as in the spring at Stations 1 and 15 and higher at Stations 13 and 14. As in the spring, there is a decreasing concentration of Hg in sediments with distance from the platform. These results agree with those for PAH and sediment grain size in indicating that conditions in sediments around Lake Pelto Tank Battery No. 1 did not change very much in the six months between the spring and fall surveys.

3.3.2.9 Species Composition

3.3.2.9.1 Spring Survey. A total of 208 taxa of benthic fauna are recorded from the Lake Pelto samples (Table 3.64). This total includes taxa from both the spring and fall samples. Table 3.65 shows the number of taxa present only in the spring samples, only in the fall samples, or in samples from both seasons. The major phyla represented are the Annelida, Mollusca, and Arthropoda, with 83, 43, and 40 taxa, respectively. Three species of sipunculans, eight species of nemerteans, and three species of echinoderms also are present. Seven species of bryozoans and eight species of hydrozoans are present in the samples; as with the Eugene Island samples, these colonial taxa are not included in the statistical analyses.

TABLE 3.63. CONCENTRATIONS OF TRACE METALS IN SEDIMENTS FROM LAKE PELTO COLLECTED DURING THE FALL SURVEY.

Station	Replicate	Concentration in mg/kg Dry Weight		
		Ni	Hg	Ba
1	1 (NW, 20 m)	14.0	0.298	1350
	2	13.0	0.609	1670
	3	14.8	0.055	1910
	$\bar{x}$ ± S.D.	13.9 ± 0.90	0.321 ± 0.278	1643 ± 281
13	1 (SW, 20 m)	12.6	0.501	5040
14	1 (SW, 100 m)	12.3	0.597	1460
15	1 (SW, 300 m)	14.4	0.072	1810
Blank		<0.5	<0.025	NA

TABLE 3.64. SPECIES RECORDED FROM INFAUNAL SAMPLES COLLECTED AT LAKE PELTO STATIONS. SPECIES MARKED WITH AN ASTERISK (*) WERE NOT INCLUDED IN STATISTICAL ANALYSES.

PORIFERA
- *_Cliona_ sp. 1

CNIDARIA
- Hydrozoa
    - *_Alcyonidium_ sp. 1
    - *Atractylidae sp. 1
    - *_Bimeria_ cf. _humilis_
    - *_Clytia coronata_
    - *_Eudendrium_ sp. 1
    - *_Obelia geniculata_
    - *_Obelia hyalina_
    - *_Opercularella_ cf. _lacerata_
- Anthozoa
    - _Bunctactis texaensis_
    - Cerianthidae sp. 1
    - Anthozoa sp. 1, 3

PLATYHELMINTHES
- *Turbellaria

NEMERTEA
- _Cerebratulus_ sp. 1
- _Micrura_ sp. 1
- Nemertea sp. 1, 2, 3, 5, 6, 7

ANNELIDA
- Polychaeta
    - Ampharetidae
        - _Melinna maculata_
        - _Sabellides_ sp. 1
    - Amphinomidae
        - _Paramphinome_ sp. 1
    - Capitellidae
        - _Heteromastus filiformis_
        - _Mediomastus ambiseta_
        - _Notomastus latericeus_
        - _Notomastus daueri_
    - Chaetopteridae
        - _Spiochaetopterus costarum_
    - Cirratulidae
        - _Cirriformia_ sp. 1
        - _Tharyx acutus_
        - _Tharyx_ sp. 1
    - Cossuridae
        - _Cossura delta_
    - Ctenodrilidae
        - _Ctenodrilus_ sp. 1
    - Dorvilleidae
        - _Schistomeringos_ sp. 1
    - Flabelligeridae
        - _Piromis roberta_
    - Glyceridae
        - _Glycera americana_
        - _Glycera_ sp. 1
    - Goniadidae
        - _Glycinde solitaria_
    - Hesionidae
        - _Gyptis brevipalpa_
        - _Gyptis vittata_
        - _Podarke obscura_
    - Lumbrineridae
        - _Lumbrineris verrilli_
    - Magelonidae
        - _Magelona_ sp. 1, 2
    - Maldanidae
        - _Asychis elongata_
        - _Clymenella torquata_
        - _Macroclymene_ sp. 1
        - _Maldane sarsi_
        - _Maldane_ sp. 1
        - Maldanidae sp. 1
    - Nereididae
        - _Ceratocephale oculata_
        - _Neanthes micromma_
        - _Neanthes succinea_
        - _Nereis falsa_
        - _Nereis_ sp. 1
    - Onuphidae
        - _Diopatra_ sp. 1
        - _Kinbergonuphis virgata_
    - Orbiniidae
        - _Leitoscoloplos_ nr. _foliosus_
        - _Leitoscoloplos fragilis_
        - _Scoloplos_ sp. 1
    - Oweniidae
        - _Galathowenia_ sp. 1
        - _Owenia_ sp. 1

TABLE 3.64. (Continued)

- Paraonidae
  - *Aricidea* nr. *fragilis*
  - *Aricidea* nr. *taylori*
  - *Aricidea philbinae*
  - *Aricidea* sp. 2, 3, 4, 5
  - *Cirrophorus* sp. 1
  - *Paradoneis* sp. 1, 2
- Pectinariidae
  - *Pectinaria* sp. 1
- Phyllodocidae
  - *Eteone lactea*
  - *Eumida sanguinea*
  - *Paranaitus speciosa*
  - *Phyllodoce arenae*
- Pilargidae
  - *Ancistrosyllis jonesi*
  - *Ancistrosyllis papillosa*
  - *Sigambra tentaculata*
  - *Sigambra* sp. 2
- Polynoidae
  - *Malmgreniella* sp. 1, 2
- Sabellidae
  - *Chone* sp. 2
  - *Megalomma pigmentum*
  - *Megalomma* sp. 1
- Serpulidae
  - Serpulidae spp. juvenile
- Sigalionidae
  - *Sthenelais* sp. 1, 2
- Spionidae
  - *Boccardia hamata*
  - *Carazziella hobsonae*
  - *Paraprionospio pinnata*
  - *Polydora ligni*
  - *Polydora socialis*
  - *Prionospio perkinsi*
  - *Spiophanes bombyx*
  - *Streblospio benedicti*
- Syllidae
  - *Exogone* sp. 1
  - *Sphaerosyllis taylori*
  - Syllidae sp. 1, 2
- Terebellidae
  - *Hauchiella* sp. 2
  - *Polycirrus* sp. 1
- Oligochaeta
  - Oligochaeta spp.

ECHIURA

- *Echiura spp. indeterminate

SIPUNCULA

- *Golfingia* cf. *trichocephala*
- *Golfingia* sp. 1
- *Phascolion strombi*

MOLLUSCA

- Bivalvia
  - *Aligena texasensis*
  - *Anadara transversa*
  - *Asthenothaerus hemphilli*
  - *Chione* sp. 1
  - *Crassostrea virginica*
  - *Cuspidaria* spp. juvenile
  - *Diplodanta semiaspera*
  - *Dosinia discus*
  - *Dosinia elegans*
  - *Linga amiantus*
  - *Lucina* sp. 1
  - *Lyonsia hyalina*
  - *Macoma tenata*
  - *Macoma* sp. 1
  - *Mulinia lateralis*
  - *Mysella planulata*
  - *Nuculana carpenteri*
  - *Nuculana verrilliana*
  - Nuculanidae sp. 1
  - *Pandora arenosa*
  - *Pandora trilineata*
  - *Parvilucina mattilineata*
  - *Solen vividis*
  - *Tellina vesicolor*
- Gastropoda
  - *Acteocina canaliculata*
  - *Acteocina candei*
  - *Acteon schuctostriatus*
  - *Anachis obesa*
  - *Caecum* (*Fartulum*) sp. 1
  - *Crepidula fornicata*
  - *Crepidula plana*
  - *Cyclostremella humilis*
  - *Dorridum* sp. 1
  - *Epitonium albidum*
  - Mellanellidae sp. 1
  - *Nassarius acutus*
  - *Nassarius vibex*
  - *Natica pusilla*
  - *Polynices duplicatus*
  - *Stiliger vossi*
  - *Turbonilla* sp. 1, 3, 4

TABLE 3.64. (Continued)

ARTHROPODA
- Arachnida
  - *Acarina
- Crustacea
  - Cirripedia
    - Cirripedia sp. 1
      - _Mysidopsis bigelowi_
    - Decapoda
      - _Brachyura_ sp. 2
      - _Callinectes similis_
      - _Clibanarius vittatus_
      - _Hepatus pudibundus_
      - _Ogryides alphaerostris_
      - _Ogryides_ sp. 2
      - _Pagurus_ sp. 1, 3
      - Penaeidea sp. 1
      - _Pinnixa sayana_
    - Cumacea
      - _Cyclaspis pustulata_
      - _Cyclaspis varians_
      - _Eudorella monodon_
      - _Eudorella_ sp. 1
      - _Oxyurostylis_ sp. 1
    - Isopoda
      - _Edotea_ spp. juvenile
      - _Munna_ sp. 1
      - _Xenanthura brevitelson_
    - Amphipoda
      - _Ampelisca verilli_
      - _Ampelisca_ sp. 2
      - _Batea catharinensis_
      - _Callianassa_ sp. 1
      - *Caprellidea spp. juvenile
      - _Corophium acherusium_
      - Gammaridea sp. 4, 5, 6, 7, 8, 9, 10
      - _Listriella barnardi_
      - _Microprotopus shoemakeri_
      - _Monoculodes nyei_
      - _Paracaprella pusilla_
      - Stenothoidae sp. 1
      - _Synchelidium americanum_
      - _Tiron tricellatus_

PHORONIDA
- _Phoronis architecta_

BRYOZOA
- *_Aeverrilla armata_
- *_Anguinella palmata_
- *_Bowerbankia gracilis_
- *_Electra hastingsae_
- *_Hippoporina_ sp. 1
- *_Membranipora tenuis_
- *_Membranipora tuberculata_

ECHINODERMATA
- Ophiuroidea
  - _Hemipholis elongata_
  - _Micropholis atra_
- Holothuroidea
  - _Thyone_ sp. 1

HEMICHORDATA
- Enteropneusta sp. 1

CHORDATA
- *Ascidiacea spp. juvenile
- _Myrophis punctata_

3.3.2.9.2 Fall Survey. As indicated in Table 3.65, there are several species present in the fall collections from Lake Pelto Stations 1, 13, 14, and 15 that are not present in the spring. At least one species that dominates the spring samples, the polychaete *Streblospio benedicti*, is not present at any of the stations sampled in the fall.

3.3.2.10 Diversity

3.3.2.10.1 Spring Survey. The values for the Shannon-Wiener diversity index (H′) at each station are summarized in Table 3.66 and plotted in Figure 3.26. Appendix G includes tables in which more detailed information is presented for each station. The value of H′ for infaunal samples from stations at Lake Pelto ranges from 1.84 to 3.08. In general, diversity is higher at stations near the platform (20 m) than at stations farther away (Figure 3.26). At stations near the platform, H′ ranges from 2.01 at Station 9 to 2.75 at Station 13. The two stations with the lowest H′ value are Stations 12 and 16, both 1000 m from the platform. These two stations also have the finest grained sediments containing 69 and 92 percent silt/clay, respectively (see Table 3.48). As observed in the spring samples at Eugene Island, there is a good correlation between Shannon-Wiener diversity and sediment texture.

Hurlbert rarefaction values are given in Table 3.66 and the expected number of species per 500 individuals is plotted in Figure 3.27. Values for this parameter are fairly uniform over all stations, with two exceptions. The lowest value (26.7 species/500 individuals) is for Station 9, one of the stations closest to the platform. The next lowest value (29.2 species/500 individuals) is for Station 16, located 1000 m from the platform. Sediments at Station 16 have the highest percent silt/clay of the stations at Lake Pelto. Station 6, which has the highest Shannon-Wiener diversity, also has the highest diversity as measured by the Hurlbert rarefaction method. This

TABLE 3.65. NUMBER OF TAXA (INCLUDING JUVENILES AND INDETERMINATES) PRESENT IN SPRING, FALL, OR BOTH SEASONS AT LAKE PELTO.

	Station			
	1	13	14	15
Spring Only	49	36	26	34
Fall Only	41	60	55	36
Both Seasons	24	35	34	50
Total Taxa	114	131	115	120

TABLE 3.66. BENTHIC COMMUNITY PARAMETERS FOR SAMPLES COLLECTED AT LAKE PELTO IN SPRING 1986. VALUES ARE FOR SIX REPLICATES COMBINED.

Station	Distance from Platform (m)	Mean Density per 0.01 m^2[a] (± S.D.)	Total Taxa[a]	H'[b,c]	Evenness	Spp/100[b,d]	Spp/500[b,d]	Spp/1000[b,d]
1	20	371.2 ± 72.3	72	2.68	0.46	14.6	32.4	44.2
2	100	352.5 ± 127.7	80	2.34	0.38	16.0	35.7	49.8
3	300	362.3 ± 72.7	79	2.51	0.42	17.9	38.9	50.5
5	20	370.7 ± 174.9	70	2.51	0.43	16.2	32.0	41.7
6	100	286.8 ± 80.0	80	3.08	0.50	21.2	44.0	58.6
7	300	334.3 ± 68.5	67	2.58	0.44	18.4	37.0	46.3
9	20	567.2 ± 176.5	71	2.01	0.34	12.6	26.7	36.5
10	100	360.8 ± 91.2	72	2.47	0.42	17.3	35.3	46.2
11	300	344.0 ± 146.3	73	2.09	0.35	15.8	35.6	47.0
12	1000	344.7 ± 96.7	69	1.84	0.31	15.2	35.8	47.9
13	20	311.7 ± 40.6	70	2.75	0.47	16.2	34.3	46.0
14	100	403.8 ± 93.8	57	2.19	0.39	15.8	31.8	40.0
15	300	394.3 ± 131.9	81	2.24	0.37	17.6	37.1	48.7
16	1000	702.7 ± 854.6	54	1.95	0.35	13.5	29.2	39.3

[a] These values are based on the total numbers of individuals in the six replicates collected at each station and correspond to density and number of taxa reported in Appendix H.

[b] Diversity measures were calculated after removing "indeterminate" and unidentified juveniles from the total density for each station. The densities and number of taxa on which these values are based are reported in Appendix 6.

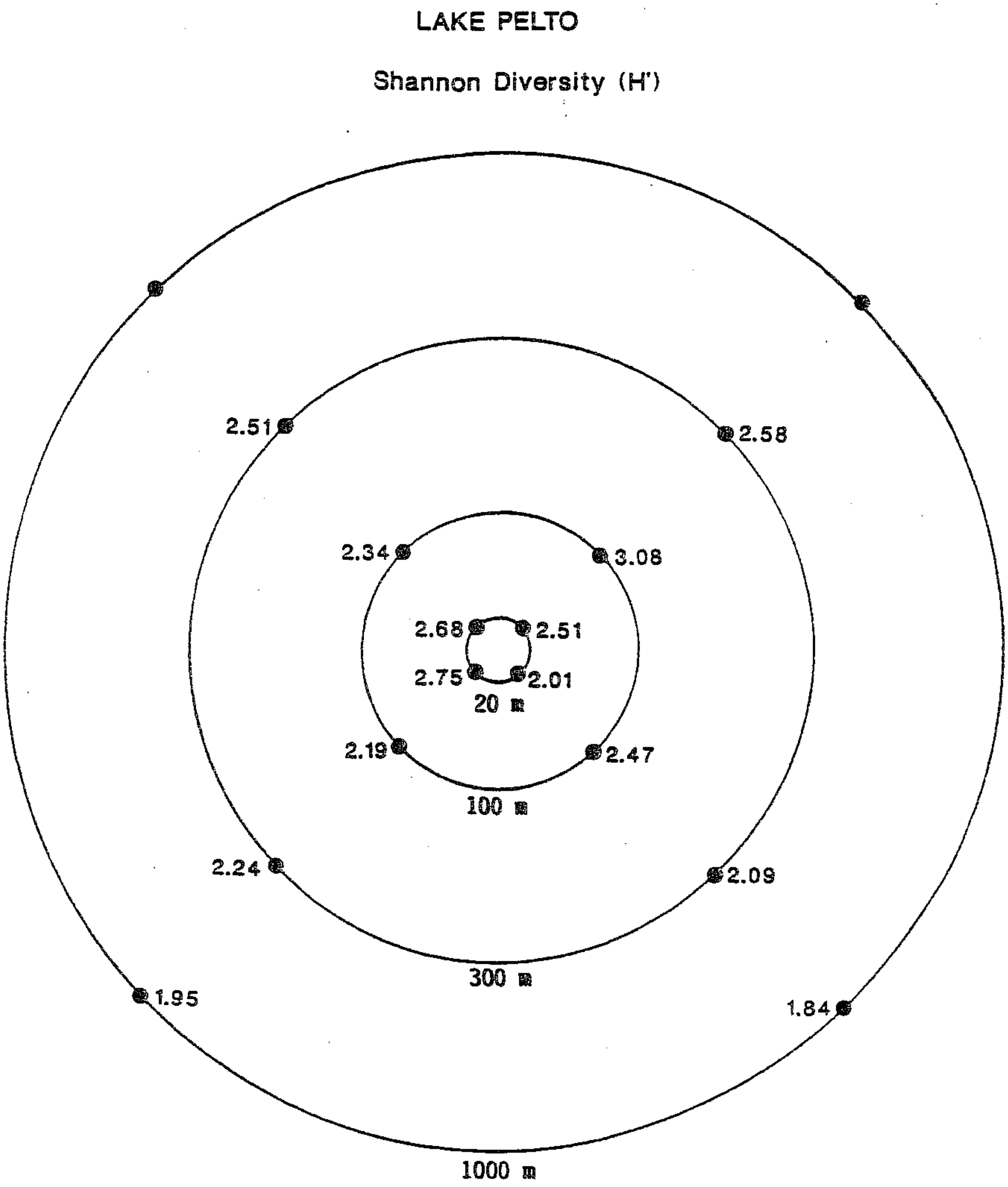


FIGURE 3.26. SHANNON-WIENER DIVERSITY INDEX (H') FOR BENTHIC FAUNA IN SEDIMENT SAMPLES COLLECTED AT LAKE PELTO, STATIONS 1-3, 5-7, AND 9-16, DURING THE SPRING SURVEY.

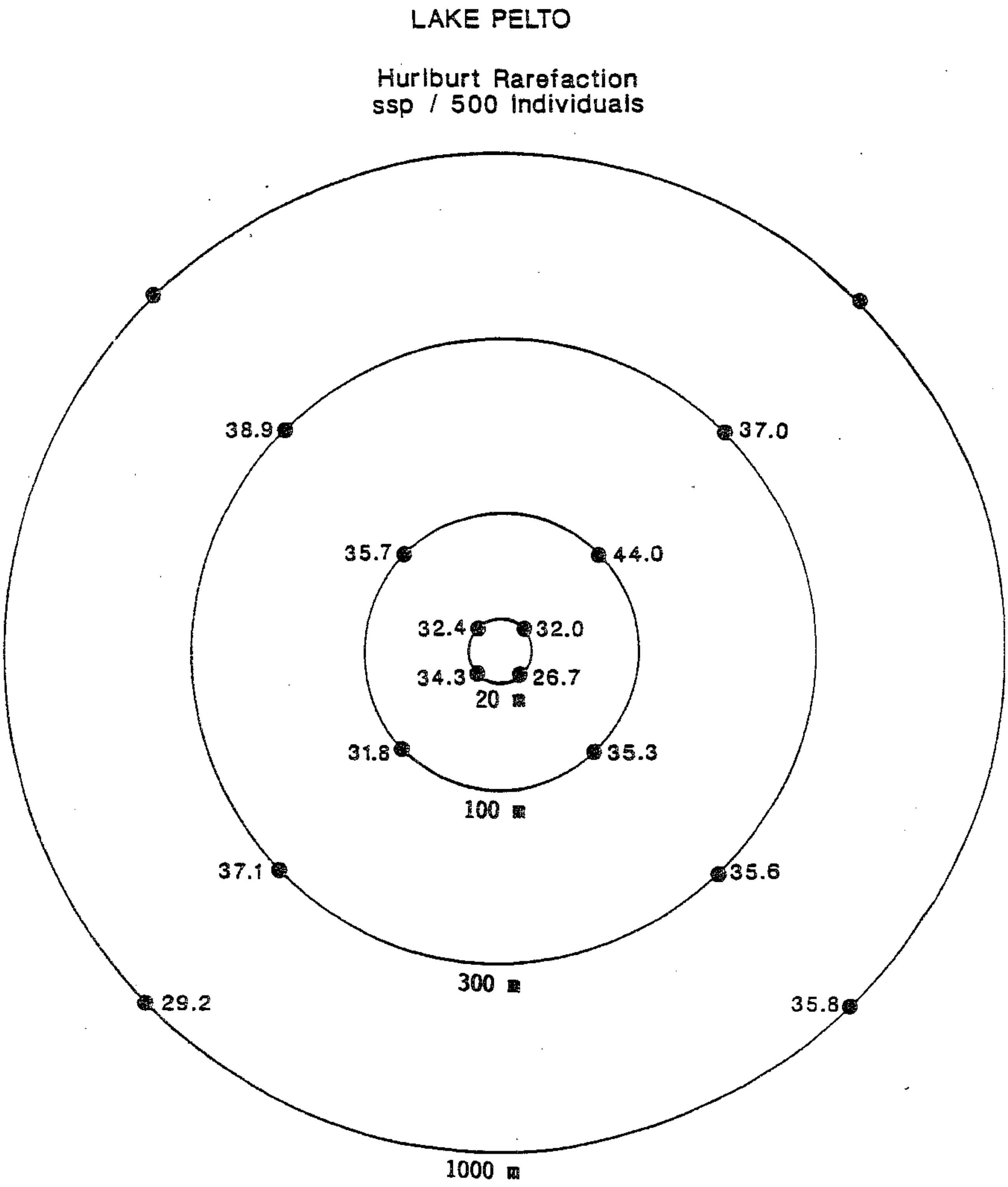


FIGURE 3.27. HURLBERT RAREFACTION VALUES FOR NUMBER OF SPECIES PER 500 INDIVIDUALS IN SEDIMENT SAMPLES COLLECTED AT LAKE PELTO DURING THE SPRING SURVEY.

station has 33.0 percent silt/clay, a value intermediate among the percentages seen at other stations.

3.3.2.10.2 Fall Survey. The values for the Shannon-Wiener diversity index (H′) for the fall samples are given in Table 3.67. A more detailed presentation of this information is contained in Appendix G. Values for Stations 1 and 13, both 20 m from the platform, are slightly lower than measured in the spring; whereas values for Stations 14 and 15, located at distances of 100 and 300 m, respectively, are slightly higher than the spring values. As noted for Eugene Island, the correlation between diversity and sediment texture is not as clear in the fall as in the spring. Sediments at Station 14 contain more than three times the percent silt/clay as sediments from Stations 1 and 13, but diversity at Station 14 is only slightly, not significantly, lower than at the other two stations.

Hurlbert rarefaction values for expected number of species per 500 individuals indicate that Station 15 is the most diverse, followed by Stations 13, 14, and 1, in that order.

3.3.2.11 Dominance

3.3.2.11.1 Spring Survey. Evenness values for the spring samples from Lake Pelto range from 0.31 at Station 12 to 0.50 at Station 6 (Table 3.66). Evenness values at the stations nearest the platform are moderate, ranging from a low of 0.34 at Station 9 to 0.46 and 0.47 at Stations 1 and 13, respectively.

Table 3.68 is a rank order listing of the 15 top dominant species for all spring samples combined from Lake Pelto. The top dominant species is the capitellid polychaete, *Mediomastus ambiseta*, which is an order of magnitude more abundant than any other species. Another opportunistic species, the spionid polychaete *Streblospio benedicti*, ranks second, and the

TABLE 3.67. **BENTHIC COMMUNITY PARAMETERS FOR SAMPLES COLLECTED AT LAKE PELTO IN FALL 1986.**

Station	Distance from Platform (m)	Mean Density per 0.01 m^{2a} (± S.D.)	Total Taxa[a]	$H'^{b,c}$	Evenness	Spp/100[b,d]	Spp/500[b,d]	Spp/1000[b,d]
1	20	186.3 ± 36.9	58	2.64	0.49	13.9	29.2	39.6
13	20	348.0 ± 94.4	87	2.61	0.43	17.3	39.7	52.5
14	100	598.7 ± 130.8	80	2.24	0.37	14.9	33.1	44.0
15	300	347.3 ± 69.8	81	2.80	0.46	18.8	40.0	51.9

[a] These values are based on the total numbers of individuals in the six replicates collected at each station and correspond to density and number of taxa reported in Appendix H.

[b] Diversity measures were calculated after removing "indeterminate" and unidentified juveniles from the total density for each station. The densities and number of taxa on which these values are based are reported in Appendix 6.

[c] Shannon-Wiener diversity index.

[d] Hurlbert rarefaction index (estimated number of species per X individuals).

TABLE 3.68. FIFTEEN TOP DOMINANT SPECIES AT LAKE PELTO STATIONS IN SPRIN
1986.

Rank	Species
1	*Mediomastus ambiseta* (polychaete)
2	*Streblospio benedicti* (polychaete)
3	*Mulinia lateralis* (bivalve)
4	Nemertea sp. 1 (nemertean)
5	Oligochaeta
6	*Glycinde solitaria* (polychaete)
7	*Sabellides* sp. 1 (polychaete)
8	*Sphaerosyllis taylori* (polychaete)
9	*Cyclaspis varians* (cumacean)
10	*Polydora socialis* (polychaete)
11	*Paraprionospio pinnata* (polychaete)
12	*Sigambra tentaculata* (polychaete)
13	*Aligena texasiana* (bivalve)
14	*Clymenella torquata* (polychaete)
15	*Notomastus daueri* (polychaete)

opportunistic bivalve Mulinia lateralis ranks third. The remaining dominant species include eight polychaetes, one bivalve, one nemertean, one cumacean and the taxon Oligochaeta.

Appendix H includes information on the rank and percent contribution of each species at each station. Mediomastus ambiseta is the top dominant at each station. The percent contribution of this species to the benthic community of each station in the spring is mapped in Figure 3.28. Values range from 43.1 percent at Station 1 to 77.1 percent at Station 12 and tend to increase with distance from the platform. The low to moderate evenness values presented in Table 3.66 reflect this high degree of dominance by a single species. Streblospio benedicti ranks second at seven stations (Stations 1, 2, 5, 6, 9, 11, and 13) where it accounts for 3.5 to 27.7 percent of the fauna. At Stations 3 and 14, S. benedicti ranks third, and Mulinia lateralis ranks second.

3.3.2.11.2 Fall Survey. Evenness values for the fall samples at Lake Pelto are given in Table 3.67. These values are similar to the spring values at Stations 1, 13, and 14, and slightly higher at Station 15.

Table 3.69 is a list of the 15 top dominant species for all fall samples combined. Seven of the species that are among the top dominants in the spring samples also rank among the top 15 species in the fall samples. As in the spring, the top dominant in the fall is the capitellid polychaete Mediomastus ambiseta, which again is an order of magnitude more abundant than any other species in the samples. The species that ranks second in the spring, S. benedicti, does not occur at any of the four stations sampled in the fall. Mulinia lateralis, which ranks third in the spring, ranks 10th in the fall samples. The other five taxa dominant in both the spring and fall are Oligochaeta, Nemertea sp. 1, Sphaerosyllis taylori, Paraprionospio pinnata, and Sigambra tentaculata. All of these taxa rank higher in the

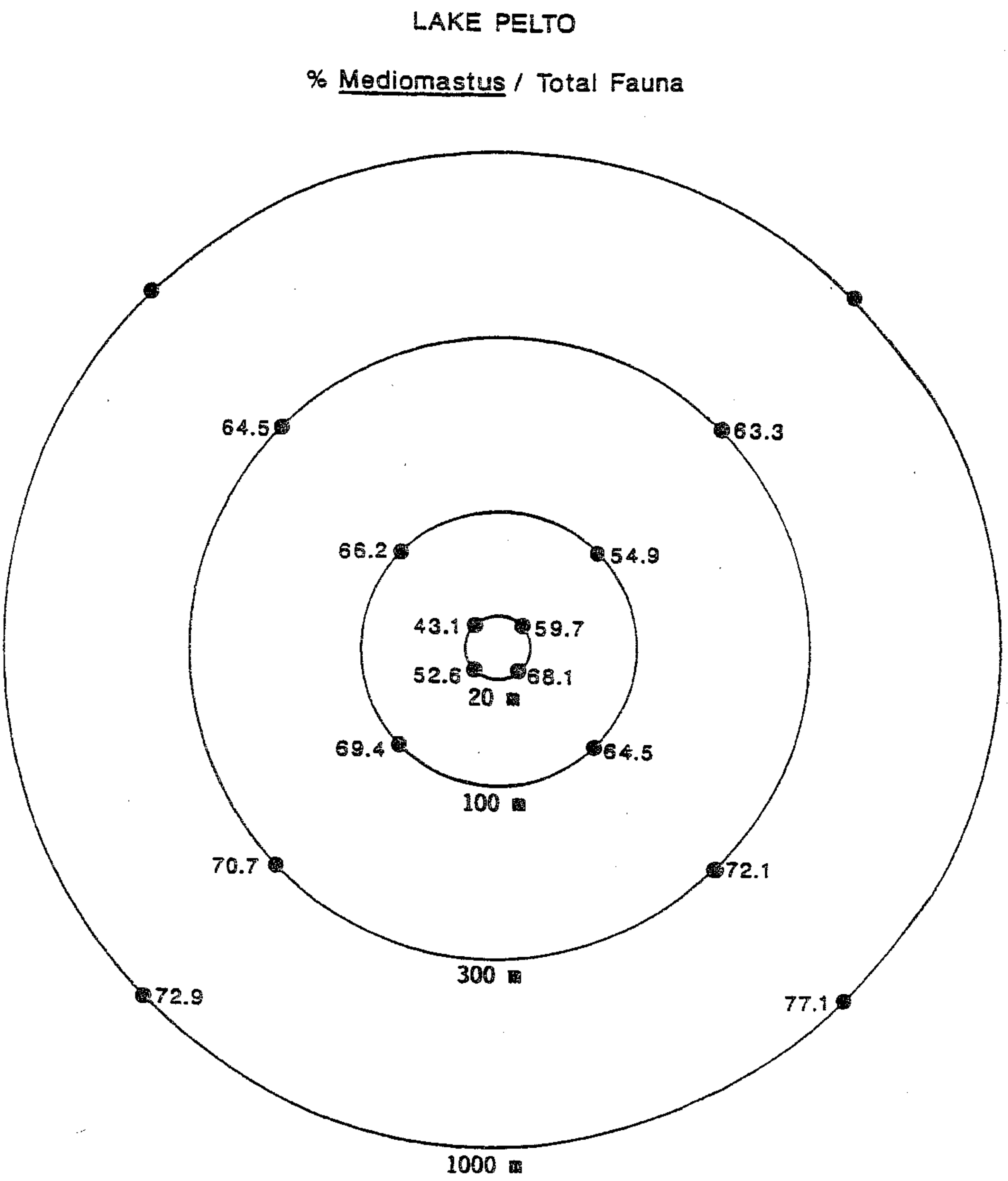


FIGURE 3.28. PERCENT CONTRIBUTION OF THE CAPITELLID POLYCHAETE *MEDIOMASTUS AMBISETA* TO THE TOTAL FAUNA IN SEDIMENT SAMPLES COLLECTED AT LAKE PELTO DURING THE SPRING SURVEY.

TABLE 3.69. FIFTEEN TOP DOMINANT SPECIES AT LAKE PELTO STATIONS IN F
1986.

Rank	Species
1	*Mediomastus ambiseta* (polychaete)
2	Oligochaeta
3	Nemertea sp. 1 (nemertean)
4	*Sphaerosyllis taylori* (polychaete)
5	*Paraprionospio pinnata* (polychaete)
6	*Cirriformia* sp. 1 (polychaete)
7	*Acteocina candei* (gastropod)
8	*Phascolion strombi* (sipunculan)
9	*Sigambra tentaculata* (polychaete)
10	*Mulinia lateralis* (bivalve)
11	*Tharyx* sp. 1 (polychaete)
12	*Mysella planulata* (bivalve)
13	*Lumbrineris verrilli* (polychaete)
14	*Chione* sp. 1 (bivalve)
15	*Nassarius acutus* (gastropod)

fall than in the spring (Tables 3.68 and 3.69). The eight species that are present among the top 15 dominant species for the first time in the fall include three polychaetes, two gastropods, two bivalves, and one sipunculan (Table 3.69).

Appendix H includes information on the rank and percent contribution of each species at each station. Mediomastus ambiseta dominates the communities at Stations 13, 14, and 15, and ranks second to Oligochaeta at Station 1. Values range from 66.1 percent at Station 14 to 31.7 percent at Station 1. The percent dominance by M. ambiseta in the fall is similar to but slightly lower than in the spring samples from Stations 1, 14, and 15, and slightly higher in the samples from Station 13. At Stations 13, 14, and 15, species that rank second or lower account for 11 percent or less of the total fauna. At Station 1, Oligochaeta account for 38.3 percent and M. ambiseta account for 31.7 percent of the fauna.

3.3.2.12 Density

3.3.2.12.1 Spring Survey. The mean density of total fauna ranges from 286.8 individuals per 0.01 m^2 at Station 6 to 702.7 individuals per 0.01 m^2 at Station 16 (Table 3.66). Table 3.70 summarizes the mean and standard deviation of the densities of the 15 top dominant species at the Lake Pelto stations. Values for each species are presented separately for each station. The dominant species, M. ambiseta, occurs in the highest mean densities at Station 16, 1000 m to the southwest of the platform. However, the distribution of this species is very patchy, as evidenced by the high standard deviation for mean density values for the six replicates from this station (Table 3.71). The next highest mean density of M. ambiseta is at Station 9, located 20 m from the platform. Mean abundances at the four stations nearest the platform range from 159.8 to 386.2 individuals per 0.01 m^2.

TABLE 3.70. MEAN DENSITY PER 0.01 M^2 OF FIFTEEN DOMINANT SPECIES AT LAKE PELTO STATIONS IN SPRING 1986.

Station	*Mediomastus ambiseta* (P)	*Mulina lateralis* (B)	*Oxyurostylis* sp.1 (C)	*Sigambra tentaculata* (P)	*Streblospio benedicti* (P)
1	159.8 ± 64.8	16.2 ± 3.1	1.8 ± 1.5	1.3 ± 0.8	102.7 ± 21.8
2	233.5 ± 92.1	9.0 ± 7.5	1.7 ± 1.5	2.7 ± 2.2	27.5 ± 9.4
3	233.7 ± 65.2	19.3 ± 13.7	1.5 ± 2.3	3.0 ± 2.4	13.7 ± 2.0
5	221.2 ± 105.9	4.3 ± 4.0	NP	1.0 ± 0.9	46.7 ± 27.1
6	157.3 ± 65.5	7.2 ± 4.3	0.3 ± 0.5	1.0 ± 1.1	19.2 ± 5.3
7	211.5 ± 46.8	7.8 ± 4.0	1.3 ± 1.9	1.7 ± 1.5	5.3 ± 4.4
9	386.2 ± 165.8	22.7 ± 15.7	0.7 ± 0.5	3.3 ± 1.6	65.7 ± 23.4
10	232.7 ± 73.2	24.5 ± 7.2	1.0 ± 0.6	2.2 ± 1.6	7.0 ± 1.4
11	248.2 ± 115.2	11.2 ± 5.7	0.7 ± 0.8	2.0 ± 0.9	12.2 ± 6.6
12	265.8 ± 86.0	2.3 ± 2.1	0.8 ± 0.8	4.3 ± 2.9	7.2 ± 2.6
13	163.8 ± 39.7	13.8 ± 2.9	1.2 ± 0.8	1.8 ± 1.6	37.7 ± 9.6
14	280.2 ± 88.7	24.0 ± 12.3	0.7 ± 0.8	0.7 ± 1.6	15.0 ± 9.5
15	278.7 ± 116.5	9.2 ± 4.1	0.8 ± 0.8	4.9 ± 3.1	8.0 ± 4.2
16	768.0 ± 736.8	10.0 ± 4.4	0.3 ± 0.6	17.0 ± 10.5	23.7 ± 35.9

TABLE 3.70. (Continued).

Station	Nemertea sp.1 (N)	*Sphaerosyllis taylori* (P)	*Glycinde solitaria* (P)	*Sabellides* sp.1 (P)	*Cyclaspis varians* (C)
1	2.0 ± 1.3	6.5 ± 2.4	2.8 ± 1.5	1.8 ± 1.0	6.8 ± 3.2
2	8.5 ± 5.9	8.7 ± 6.9	6.7 ± 2.4	8.0 ± 2.7	11.3 ± 7.1
3	11.3 ± 6.8	9.8 ± 4.5	10.7 ± 2.2	9.2 ± 3.7	6.3 ± 6.5
5	4.5 ± 1.2	9.5 ± 6.1	5.3 ± 3.5	4.2 ± 2.2	4.3 ± 4.9
6	11.5 ± 4.2	8.7 ± 4.7	5.3 ± 1.4	6.3 ± 2.7	6.2 ± 2.8
7	21.3 ± 2.7	10.7 ± 4.2	9.2 ± 3.7	7.8 ± 4.9	6.0 ± 7.0
9	13.0 ± 7.0	6.2 ± 4.3	8.0 ± 5.7	8.5 ± 2.7	5.8 ± 3.6
10	11.5 ± 6.1	10.0 ± 2.4	11.7 ± 4.6	6.7 ± 4.6	6.5 ± 3.9
11	7.3 ± 3.0	5.7 ± 4.4	9.2 ± 6.0	10.0 ± 3.5	1.2 ± 1.5
12	10.2 ± 5.7	1.5 ± 1.4	6.2 ± 3.4	7.8 ± 7.1	1.7 ± 1.9
13	4.2 ± 2.2	6.3 ± 2.4	9.3 ± 3.5	4.3 ± 2.6	6.2 ± 2.6
14	4.2 ± 3.7	5.7 ± 3.9	12.5 ± 4.9	6.0 ± 5.5	2.2 ± 1.3
15	13.7 ± 6.2	4.8 ± 1.7	10.2 ± 5.8	5.8 ± 4.0	6.8 ± 3.3
16	29.3 ± 22.8	1.7 ± 2.9	3.0 ± 4.4	17.7 ± 21.1	NP

TABLE 3.70. (Continued).

Station	*Paraprionospio pinnata* (P)	*Sigambra tentaculata* (P)	*Phascolion strombi* (S)	*Polydora socalis* (P)	*Aligena texasiana* (B)
1	0.7 ± 0.5	1.3 ± 0.8	0.3 ± 0.5	8.7 ± 4.0	NP
2	1.0 ± 0.6	2.7 ± 2.2	4.0 ± 4.5	1.0 ± 1.3	1.0 ± 1.1
3	2.8 ± 1.0	3.0 ± 2.4	2.7 ± 1.9	1.0 ± 0.9	2.0 ± 2.0
5	0.8 ± 1.3	1.0 ± 0.9	6.2 ± 4.6	3.1 ± 1.3	7.2 ± 3.5
6	0.2 ± 0.4	1.0 ± 1.1	2.0 ± 2.6	13.8 ± 7.2	4.0 ± 3.9
7	1.0 ± 0.6	1.7 ± 1.5	5.0 ± 1.4	3.8 ± 3.0	4.3 ± 2.5
9	2.7 ± 1.2	3.3 ± 1.6	1.3 ± 1.5	2.0 ± 1.9	1.7 ± 1.4
10	2.5 ± 1.9	2.2 ± 1.6	2.0 ± 1.9	2.5 ± 2.2	3.2 ± 2.4
11	1.7 ± 0.8	2.0 ± 0.9	2.3 ± 2.1	0.8 ± 1.0	1.3 ± 1.2
12	3.8 ± 3.3	4.3 ± 2.9	0.5 ± 0.8	0.7 ± 1.2	NP
13	2.2 ± 2.2	1.8 ± 1.6	0.5 ± 0.5	5.0 ± 2.8	0.5 ± 0.6
14	4.5 ± 2.8	0.7 ± 1.6	0.8 ± 1.2	2.5 ± 3.7	8.2 ± 5.5
15	4.0 ± 2.3	4.8 ± 3.1	2.3 ± 1.8	1.8 ± 3.5	4.2 ± 2.9
16	24.3 ± 16.2	17.0 ± 10.5	1.0 ± 1.7	1.0 ± 1.0	NP

P = Polychaete.
B = Bivalve.
C = Cumacean.
N = Nemertean.
S = Si

Mean densities of Streblospio benedicti and Mulinia lateralis, the second- and third-ranked species, respectively, are one to two orders of magnitude lower than the mean densities of M. ambiseta (Table 3.71). Mean densities of the remaining species are one to three orders of magnitude lower than that of M. ambiseta.

3.3.2.12.2 Fall Survey. Mean densities of the total fauna in the fall samples are lowest at Station 1 and highest at Station 14. Mean densities are similar between spring and fall at Stations 13 and 15, significantly lower at Station 1, and higher at Station 14 (Table 3.67).

Table 3.71 summarizes the mean and standard deviation of the densities of 15 species in the fall samples. Values are presented for each species at each station. At Station 1, mean densities of Mediomastus ambiseta are an order of magnitude lower in the fall compared to the spring. Mean densities of M. ambiseta are significantly lower at Station 1 than at Stations 13, 14, and 15, but mean densities of Oligochaeta are significantly higher at Station 1 than at the other three stations. Mean densities of M. ambiseta in the fall are highest at Station 14, followed by Stations 13 and 15. Several species are more abundant at Station 14 than at the other three stations; these species include Nemertea sp. 1, Sphaerosyllis taylori, and Paraprionospio pinnata. Table 3.72 presents the results of the t-tests comparing the mean densities of 15 species in the spring and fall samples at the Lake Pelto stations. Values of p lower than 0.5 indicate that the mean density differs significantly between the two seasons. With the exception of the polychaete Notomastus daueri, the mean densities of every species tested differ between seasons at one or more stations.

TABLE 3.71. MEAN DENSITY PER 0.01 M2 OF FIFTEEN DOMINANT SPECIES (SPRING) AT LAKE PELTO STATIONS IN FALL 1986.

Station	Mediomastus ambiseta (P)	Mulinia lateralis (B)	Oxyurostylis sp. 1 (C)	Sigambra tentaculata (P)	Streblospio benedicti (P)
1	59.0 ± 27.0	0.2 ± 0.4	NP	7.3 ± 2.4	NP
13	203.7 ± 63.0	0.3 ± 0.5	NP	2.3 ± 2.5	NP
14	395.7 ± 115.6	7.0 ± 3.1	0.5 ± 1.2	4.0 ± 2.1	NP
15	195.7 ± 76.7	7.9 ± 3.9	1.0 ± 0.6	2.0 ± 1.4	NP

Station	Nemertea sp. 1 (N)	Sphaerosyllis taylori (P)	Glycinde solitaria (P)	Sabellides sp. 1 (P)	Cyclaspis varians (C)
1	11.0 ± 3.5	1.7 ± 2.4	NP	NP	0.2 ± 0.4
13	22.0 ± 8.6	11.3 ± 6.2	NP	NP	NP
14	41.3 ± 14.7	44.7 ± 19.4	0.5 ± 0.5	NP	1.3 ± 1.2
15	28.7 ± 8.4	33.3 ± 15.5	0.2 ± 0.4	NP	0.4 ± 0.5

Station	Paraprionospio pinnata (P)	Sigambra tentaculata (P)	Phascolion strombi (S)	Polydora socalis (P)	Aligena texasensis (B)
1	0.5 ± 0.5	7.3 ± 2.4	0.7 ± 1.0	NP	0.5 ± 0.5
13	1.3 ± 0.8	2.3 ± 2.5	3.0 ± 2.1	NP	1.5 ± 3.2
14	17.3 ± 11.7	4.0 ± 2.1	7.2 ± 6.2	NP	NP
15	7.5 ± 2.7	2.0 ± 1.4	7.0 ± 3.2	NP	0.6 ± 1.3

P = Polychaete.
B = Bivalve.
C = Cumacean.
N = Nemertean.
NP = Not present.

TABLE 3.72. RESULTS OF t-TESTS COMPARING MEAN DENSITIES OF THE 15 DOMINAN SPECIES AT LAKE PELTO STATIONS 1, 3, 14, AND 15 FOR SPRING VS. FALL SAMPLES. VALUES OF P $\leq$ 0.05 INDICATE SIGNIFICANTL DIFFERENT MEANS.

Species	Stations			
	1	13	14	15
Mediomastus ambiseta (P)	P=0.0063	P=0.83	P=0.10	P=0.18
Streblospio benedicti (P)	P=0.0001*	P=0.0002*	P=0.012	P=0.0057*
Nemertea sp. 1 (N)	P=0.0010	P=0.0044	P=0.0018	P=0.0064
Mulinia lateralis (B)	P=0.0001	P=0.0001	P=0.022	P=0.58
Sphaerosyllis taylori (P)	P=0.0073	P=0.12	P=0.0047	P=0.0065
Glycinde solitaria (P)	P=0.0053*	P=0.0013*	P=0.0020	P=0.0082
Sabellides sp. 1(P)	P=0.0060*	P=0.0093*	P=0.045*	P=0.016*
Cyclaspis varians (C)	P=0.0038	P=0.0020*	P=0.29	P=0.0054
Paraprionospio pinnata (P)	P=0.60	P=0.42	P=0.048	P=0.040
Sigambra tentaculata (P)	P=0.0012	P=0.69	P=0.013	P=0.079
Phascolion strombi (S)	P=0.50	P=0.037	P=0.057	P=0.016
Polydora socialis (P)	P=0.0031*	P=0.0067*	P=0.16*	P=0.26*
Aligena texasiana (B)	P=0.076*	P=0.49	P=0.014*	P=0.030
Clymenella torquata (P)	P=0.010*	P=0.095	P=0.032*	P=0.032
Notomastus daueri (P)	P=0.36*	P=0.77	P=0.12	P=0.093

* Species present in either spring or fall only.
P = Polychaete.
B = Bivalve.
C = Cumacean.
S = Sipunculan.
N = Nemertean.

3.3.2.13 Percent Juveniles

3.3.2.13.1 Spring Survey. A comparison of the number of juveniles recorded in each replicate sample to the total number of individuals in each sample is shown in Table 3.73. The contribution by juveniles to the total fauna ranges from 25.2 percent at Station 11 to 52.9 percent at Station 13. The average values for this parameter are plotted in Figure 3.29.

The percentages of juveniles of 16 species common in sediments from stations at Lake Pelto are presented in Table 3.74. The top dominant species, *Mediomastus ambiseta*, is represented by 5.7 to 47.3 percent juveniles. The species ranked second and third, *Streblospio benedicti* and *Mulinia lateralis*, are represented primarily by juveniles -- up to 88.1 percent for *S. benedicti* and up to 100 percent for *M. lateralis*. The percentages of juveniles of the other common species are also very high at all Lake Pelto stations.

3.3.2.13.2 Fall Survey. A comparison of the number of juveniles recorded in each replicate sample to the total number of individuals in each sample is shown in Table 3.75. The contribution by juveniles to the total fauna in the fall samples ranges from 24.2 percent at Station 14 to 35.8 percent at Station 15. Values are similar at all four stations.

Table 3.76 shows the percent contribution of juveniles to the populations of 16 species. Juveniles of *Mediomastus ambiseta* account for 9.0 to 35.6 percent of the individuals of this species in the fall samples. *Mulinia lateralis* is represented almost entirely by juveniles, as are a majority of the other species listed. The polychaete *Sphaerosyllis taylori* is represented by only 1.1 to 10.0 percent juveniles and the bivalve *Aligena texasiana* is represented by 33.3 to 55.6 percent juveniles.

TABLE 3.73. COMPARISON OF NUMBER OF JUVENILES TO TOTAL NUMBER OF INDIVIDUALS IN SAMPLES COLLECTED AT LAKE PELTO STATIONS IN SPRING 1986.

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
1	1	267	158	59.2
	2	350	172	49.1
	3	454	135	29.7
	4	393	171	43.5
	5	321	140	43.6
	6	442	142	32.1
	$\bar{X}$ ± SD			42.9 ± 10.9
2	1	238	119	50.0
	2	497	265	53.3
	3	508	248	48.8
	4	266	106	39.8
	5	377	126	33.4
	6	229	64	28.0
	$\bar{X}$ ± SD			42.2 ± 10.1
3	1	328	128	39.0
	2	435	130	29.9
	3	291	121	41.6
	4	421	117	27.8
	5	275	81	29.4
	6	424	135	31.8
	$\bar{x}$ ± SD			33.2 ± 5.7
5	1	332	68	20.5
	2	603	123	20.4
	3	277	135	48.7
	4	116	44	37.9
	5	525	218	41.5
	6	371	195	52.6
	$\bar{x}$ ± SD			36.9 ± 13.8

TABLE 3.73. (Continued).

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
6	1	248	105	42.3
	2	223	116	52.0
	3	436	190	43.6
	4	249	85	34.1
	5	246	101	41.1
	6	319	115	36.0
	$\bar{X}$ ± SD			41.5 ± 6.
7	1	335	114	34.0
	2	377	105	27.8
	3	272	69	25.4
	4	284	90	31.7
	5	449	131	29.2
	6	289	68	23.5
	$\bar{X}$ ± SD			28.6 ± 3.
9	1	759	144	19.0
	2	451	170	37.7
	3	430	216	50.2
	4	490	164	33.5
	5	448	183	40.8
	6	825	289	35.0
	$\bar{X}$ ± SD			36.0 ± 1
10	1	360	135	37.5
	2	412	183	44.4
	3	409	130	31.8
	4	179	72	40.2
	5	394	128	32.5
	6	411	116	28.2
	$\bar{X}$ ± SD			35.8 ± 6.

TABLE 3.73. (Continued).

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
11	1	466	117	25.1
	2	298	88	29.5
	3	425	78	18.4
	4	244	70	28.7
	5	126	35	27.8
	6	505	108	21.4
	$\bar{X}$ ± SD			25.2 ± 4.4
12	1	295	71	24.1
	2	307	63	20.5
	3	252	78	31.0
	4	394	161	40.9
	5	518	128	24.7
	6	302	65	21.5
	$\bar{X}$ ± SD			27.1 ± 7.7
13	1	305	159	52.1
	2	305	157	51.5
	3	382	234	61.3
	4	330	151	45.8
	5	277	156	56.3
	6	271	137	50.6
	$\bar{X}$ ± SD			52.9 ± 5.3
14	1	388	128	33.0
	2	480	147	30.6
	3	231	84	36.4
	4	492	223	45.3
	5	418	121	29.0
	6	414	314	75.8
	$\bar{X}$ ± SD			41.7 ± 17.7

TABLE 3.73. (Continued).

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
15	1	447	107	23.9
	2	588	163	27.7
	3	326	85	26.1
	4	451	155	34.4
	5	352	226	64.2
	6	202	78	38.6
	$\bar{X}$ ± SD			35.8 ± 14.
16	1	108	60	55.6
	2	318	25	7.9
	3	1682	550	32.7
	$\bar{X}$ ± SD			32.1 ± 23.

TABLE 3.74. PERCENT CONTRIBUTION OF JUVENILES OF THE 16 DOMINANT SPECIES IN THE SPRING 1986 SAMPLES COLLECTED AT LAKE PELTO STATIONS.

Species	Station													
	1	2	3	5	6	7	9	10	11	12	13	14	15	16
Mediomastus ambiseta (P)	5.7	41.0	22.6	26.8	37.1	21.4	25.3	26.1	17.9	23.7	47.3	33.6	29.3	26.7
Streblospio benedicti (P)	86.4	87.9	73.2	84.3	69.6	59.4	65.0	88.1	53.4	67.4	76.5	77.8	72.9	36.6
Mulinia lateralis (B)	100	94.4	93.1	92.3	93.0	80.8	99.3	95.9	53.7	71.4	100	96.5	92.7	80.0
Glycinde solitaria (P)	94.1	97.5	95.3	100	100	100	97.9	91.4	74.5	94.6	100	93.3	91.8	88.9
Sabellides sp. 1 (P)	72.7	75.0	67.3	52.0	63.2	72.3	66.7	80.0	56.7	57.4	96.2	66.7	85.7	54.7
Sphaerosyllis taylori (P)	56.4	28.8	18.6	47.4	36.5	40.6	16.2	11.7	20.6	11.1	65.8	52.9	41.4	0
Paraprionospio pinnata (P)	100	100	88.2	80.0	100	100	87.5	86.7	60.0	73.9	92.3	74.1	95.8	90.4
Sigambra tentaculata (P)	75.0	43.8	66.7	0	16.7	40.0	60.0	61.5	41.7	80.8	63.6	0	51.7	82.4
Acteocina candei (G)	0	66.7	40.0	83.3	50.0	100	0	80.0	66.7	50.0	66.7	87.5	57.1	50.0
Tellina versicolor (B)	66.7	50.0	12.5	0	0	20.0	0	14.3	20.0	0	0	11.8	20.0	00
Chione sp. 1 (B)	NP	0	0	8.0	9.1	0	0	20.0	0	NP	33.3	0	NP	NP
Mysella planulata (B)	81.8	80.0	75.0	NP	53.8	35.7	100	100	66.7	36.4	0	NP	0	50.0
Aligena texasiana (B)	NP	66.7	83.3	53.5	58.3	53.8	50.0	47.4	37.5	NP	66.7	53.1	52.0	NP
Lumbrineris verrilli (P)	NP	50.0	25.0	0	NP	60	0	83.3	50.0	00	NP	50.0	16.7	25.0
Polydora socialis (P)	84.6	83.3	66.7	84.2	61.4	73.9	58.3	60.0	40.0	50.0	86.7	73.3	90.9	100
Tharyx sp. 1 (P)	NP	NP	NP	0	NP	NP	NP	0	NP	0	NP	NP	0	NP

NP = Not present.
P = Polychaete.
B = Bivalve.
G = Gastropod.

TABLE 3.75. COMPARISON OF NUMBER OF JUVENILES TO TOTAL NUMBER INDIVIDUALS IN SAMPLES COLLECTED AT LAKE PELTO STATI IN FALL 1986.

Station	Rep.	Total Fauna	Total Juveniles	Percent Juveniles
1	1	194	76	39.2
	2	178	52	29.2
	3	178	57	32.0
	4	238	69	29.0
	5	204	47	23.0
	6	126	35	27.8
	$\bar{X}$ ± SD			30.0 ± 5.
13	1	255	76	29.8
	2	336	132	39.3
	3	242	89	36.8
	4	338	104	30.8
	5	458	95	20.7
	6	459	141	30.7
	$\bar{X}$ ± SD			31.4 ± 6.
14	1	556	109	19.6
	2	605	122	20.2
	3	817	195	23.9
	4	430	119	27.7
	5	531	135	25.4
	6	653	186	28.5
	$\bar{X}$ ± SD			24.2 ± 3.
15	1	421	109	25.9
	2	248	154	62.1
	3	394	99	25.1
	4	296	107	36.1
	5	319	103	32.3
	6	406	135	33.2
	$\bar{X}$ ± SD			35.8 ± 13

TABLE 3.76. PERCENT CONTRIBUTION OF JUVENILES OF THE 16 DOMINANT SPECIES IN THE FALL 1986 SAMPLES COLLECTED AT LAKE PELTO.

Species	Station 1	 13	 14	 15
Mediomastus ambiseta (P)	35.6	26.4	9.0	21.7
Streblospio benedicti (P)	NP	NP	NP	NP
Mulinia lateralis (B)	100	100	95.2	100
Glycinde solitaria (P)	NP	NP	100	100
Sabellides sp. 1 (P)	NP	NP	NP	NP
Sphaerosyllis taylori (P)	10.0	1.5	1.1	NP
Paraprionospio pinnata (P)	100	100	79.8	86.7
Sigambra tentaculata (P)	75.0	78.6	66.7	91.7
Acteocia candei (G)	NP	78.6	98.8	80.5
Tellina versicolor (B)	100	100	75.0	91.7
Chione sp. 1 (B)	NP	92.0	100	93.3
Mysella planulata (B)	92.3	100	100	100
Aligena texasiana (B)	33.3	55.6	NP	33.3
Lumbrineris verrilli (P)	0	75.0	92.9	70.3
Polydora socialis (P)	NP	NP	NP	NP
Tharyx sp. 1 (P)	89.4	89.7	66.7	50.0

NP = Not present.
P = Polychaete.
B = Bivalve.
G = Gastropod.

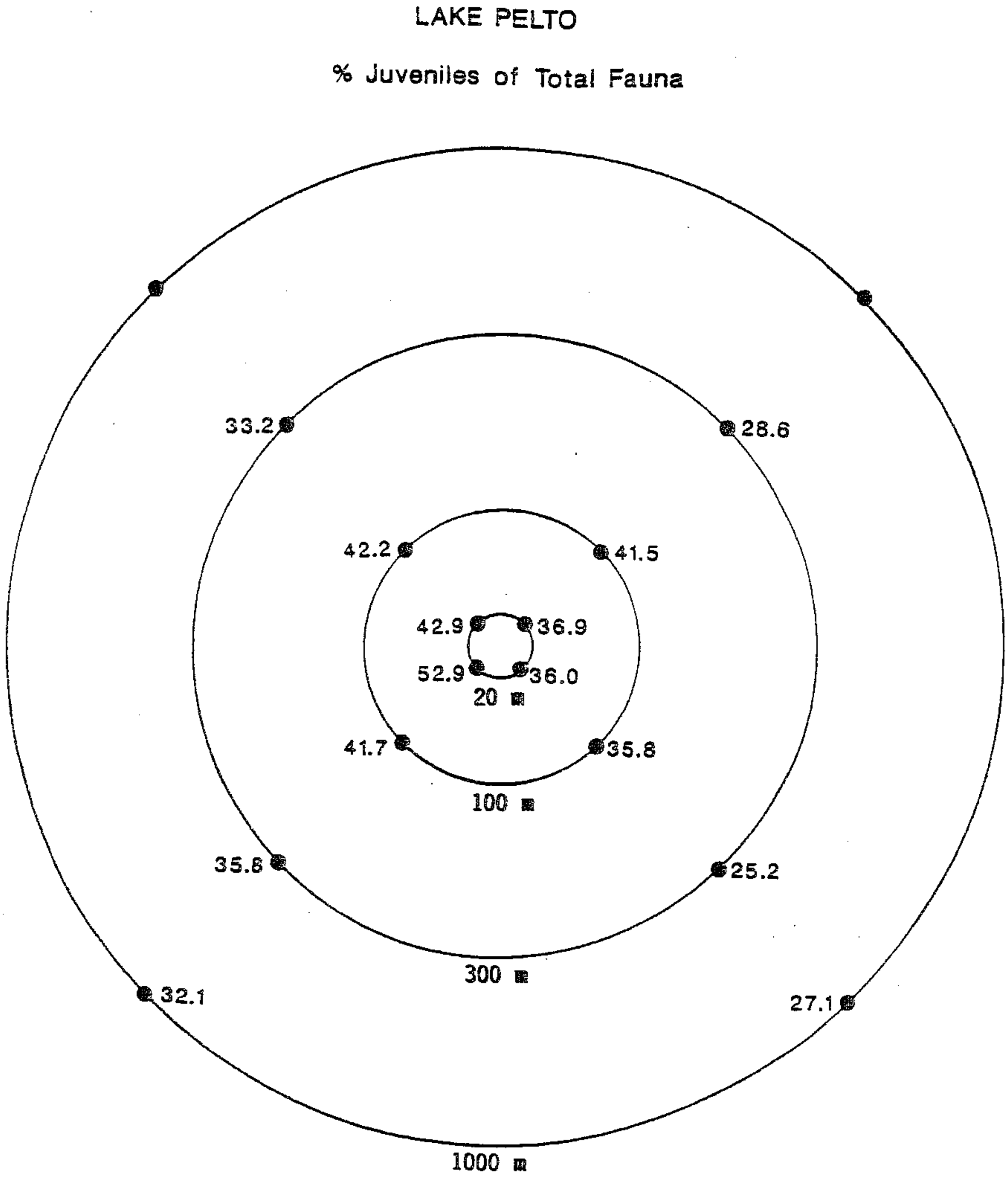


FIGURE 3.29. PERCENT CONTRIBUTION OF JUVENILES TO THE TOTAL FAUNA IN SEDIMENT SAMPLES COLLECTED AT LAKE PELTO DURING THE SPRING SURVEY.

Several species that are represented primarily by juveniles in the spring samples are not present at all in the fall samples. These species include the polychaetes Streblospio benedicti, Polydora socialis, and Sabellides sp. 1. Other species are represented by higher percentages of juveniles in the fall than in the spring. These species include the bivalves Tellina versicolor, Chione sp. 1, and Mysella planulata, and the polychaete Thayrx sp. 1.

3.3.2.14 Similarity

3.3.2.14.1 Spring Survey. NESS similarity followed by group average clustering was performed on combined replicates from each station sampled at Lake Pelto. This analysis included samples from both spring and fall surveys. The dendrogram based on the results of this analysis is presented in Figure 3.30. As with the Eugene Island samples, the spring and fall collections at Lake Pelto are highly dissimilar. Within the group of spring samples, several distinct subgroups can be noted. Stations 12 and 16, both 1000 m from the platform, form a unit that is similar to the remaining stations at the 0.77 level. Stations 5 and 6, 20 m and 100 m, respectively, to the northeast of the platform, also form a distinct unit. The other three stations located 20 m from the platform, Stations 1, 9, and 13, are highly similar to one another and to Station 2, located 100 m to the northwest of the platform. The remaining six stations, including the four stations located 300 m from the platform and Stations 10 and 14, form a highly similar unit.

3.3.2.14.2 Fall Survey. Figure 3.30 presented above includes the fall samples from Lake Pelto. Stations 1 and 13 are most similar to one another, and Stations 14 and 15 also form a unit at an even higher NESS level of similarity. These four stations exhibit the same relationship to each other in the fall as they do in the spring. Seasonal differences can be seen in Figure 3.30, because the spring samples and the fall samples are similar to each other only at a NESS level of 0.58.

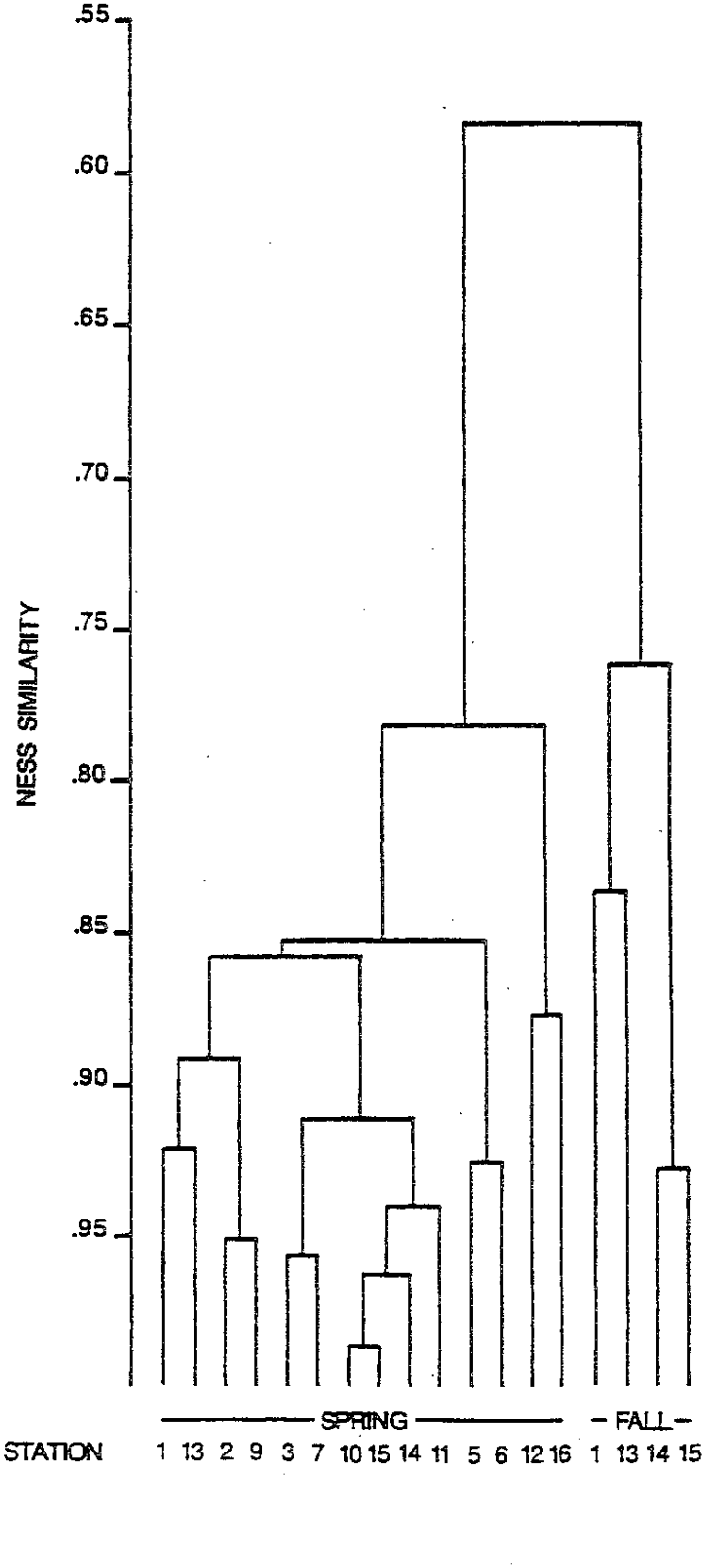


FIGURE 3.30. DENDROGRAM BASED ON CLUSTER ANALYSIS OF INFAUNAL SAMPLES COLLECTED AT LAKE PELTO DURING THE SPRING AND FALL SURVEYS.

4.0 DISCUSSION

4.1 PRODUCED WATER COMPOSITION

4.1.1 Hydrocarbons and Total Organic Carbon

Produced water from Eugene Island, Block 105, platform A, and Lake Pelto, Tank Battery No. 1 has a chemical composition similar to that reported for produced water from other sources (see review by Neff et al., 1987). Total organic carbon (TOC) concentrations in several produced water samples from the Gulf of Mexico and Cook Inlet, Alaska, analyzed by Lysyj (1982) ranged from 68,000 to 661,000 µg/l (parts per billion). Produced water samples from North Sea platforms contained 430,000 to 673,000 ppb TOC (Somerville et al., 1987). Produced water samples from wells in the Palo Duro Basin, Texas contained 700 to 223,000 ppb TOC (Means and Hubbard, 1987). By comparison, produced water from Eugene Island and Lake Pelto, collected on the spring survey, contained 222,000 and 298,000 ppb TOC, respectively (Table 4.1). TOC concentrations in produced water samples collected from four platforms on the preliminary field survey ranged from 195,000 ppb (Ship Shoal, Block 114) to 334,000 µg/l (Eugene Island, Block 120).

Lysyj (1982) reported that suspended and soluble petroleum hydrocarbons accounted for 25 to 65 percent of the TOC in samples from Cook Inlet and 3 to 28 percent of the TOC in samples from six platforms in the Gulf of Mexico. Total hydrocarbons, determined by IR, accounted for 16 percent of the TOC in produced water from Eugene Island and 8.5 percent of the TOC in produced water from Lake Pelto.

The chemical composition of the remainder of the TOC is poorly understood. Lysyj (1982) reported that the concentration of dissolved nonvolatile organic material increased during the initial stages of treatment of produced water. He suggested that

TABLE 4.1. SUMMARY OF CONCENTRATIONS OF SEVERAL CLASSES OF ORGANIC COMPOUNDS IN PRODUCED WATER COLLECTED AT EUGENE ISLAND AND LAKE PELTO DURING THE SPRING SURVEY (VALUES ARE IN μg/l).

Compound Class	Eugene Island	Lake Pelto
Total Organic Carbon	222,000	298,000
Total Hydrocarbons (IR)	36,300	25,500
Total Saturates (GC)	28,400	17,100
Total Aromatics (GC)	2,500	3,300
Total Hydrocarbons (GC)	30,900	20,400
Total Targeted n-Alkanes (C_{10}-C_{34})	2,677	606
Total Targeted PAH (Naph-Peryl)	80	142
Targeted Volatile Hydrocarbons (Methane-C_3 - Benzenes)	11,308	5,515
Steranes	63	92
Triterpanes	76	80
Priority Pollutants (Ketones)	2,230	1,320
Phenols (C_0-C_4)	2,720	675
TOTAL TARGETED ORGANICS	**19,154**	**8,430**

this organic matter might be derived from treatment chemicals added to the produced water or from the production of oxygenated by-products of hydrocarbons during treatment of the produced water at elevated temperatures. Recent reports by Somerville et al., (1987) and Means and Hubbard (1987) have revealed that most of the soluble organic material in produced water can be accounted for by short-chain aliphatic acid anions, such as acetate, proprionate, butyrate, and valerate.

In the present investigation, the targeted nonhydrocarbon analytes, steranes, triterpanes, ketones, and phenols, accounted for only about 1 to 2 percent of the TOC in the produced water samples (Table 4.1). Naphthenic acids (mono- and polycyclic carboxylic acids) could contribute to the concentration of nonvolatile soluble organic material in produced water. Compounds of this class are abundant in some crude oils and, because of their relatively high solubility compared to hydrocarbons, would tend to be enriched in produced water relative to their concentration in the oil in contact with the produced water. However, we experienced substantial difficulties in identifying these compounds and were unable to quantify them in the produced water samples.

The concentrations of total hydrocarbons, measured by either IR or GC, in produced water samples from Eugene Island and Lake Pelto were in the range of 20,000 to 48,000 μg/l (Tables 3.1 and 4.1). Total extractable content (roughly equivalent to total hydrocarbons by gravimetric analysis) in samples of produced water collected from four platforms during the preliminary survey ranged from 28,900 to 74,100 μg/l. These values are in the range of those reported by Jackson et al. (1981) and Lysyj (1982) for produced water samples from 16 platforms in the Gulf of Mexico (range of means, 11,000 to 106,000 μg/l by IR).

The C_{10} through C_{34} n-alkanes were present in produced water from Eugene Island and Lake Pelto at concentrations of 2700 and

600 μg/l, respectively. By comparison, the produced water from the C-2 separator platform in Trinity Bay, Texas, contained 13,400 μg/l total C_7 through C_{31} n-alkanes (Armstrong et al., 1979), and produced water from the Buccaneer Platform contained a mean of 1476 μg/l total C_{14} through C_{29} n-alkanes (Middleditch, 1981). The most abundant n-alkane in produced water from Eugene Island and Lake Pelto was the C_{14} or C_{15} homologue, respectively. Concentrations of individual n-alkanes decreased with increasing or decreasing chain length away from the C_{14} or C_{15} n-alkane. The pattern of n-alkane distributions was different in produced water samples from the C-2 separator platform (Trinity Bay, Texas) and the Buccaneer Platform (offshore Galveston, Texas). The dominant n-alkane in produced water from the C-2 separator platform was the C-17 homologue (Armstrong et al., 1979), whereas the dominant n-alkane in produced water from the Buccaneer Platform was the C_{24} homologue (Middleditch, 1981). These different n-alkane distributions undoubtedly reflect different hydrocarbon compositions of the petroleum from the different platforms and the strong inverse relationship between n-alkane chain length and aqueous solubility (McAuliffe, 1966).

The C_{10} through C_{34} n-alkanes accounted for only 15 to 31 percent of the total resolved saturates in the produced water samples from Eugene Island and Lake Pelto. The remainder of the saturates probably included a homologous series of branched and cyclic alkanes. Cyclic alkanes are substantially more water soluble than n-alkanes of similar molecular weight (McAuliffe, 1966), and therefore would be expected to be enriched in produced water relative to the n-alkanes. Middleditch (1981) reported a concentration of 2580 μg/l total cyclic alkanes in produced water from the Buccaneer Platform, a concentration 1.75 times the concentration of total n-alkanes in the sample.

The dominant hydrocarbons in produced water from Eugene Island and Lake Pelto were the low molecular weight aromatics, benzene through xylenes. Concentrations of these aromatics ranged from 2400 µg/l in produced water from Lake Pelto to 8500 to 9500 µg/l in produced water from Eugene Island (Table 3.5). By comparison, the total concentration of these compounds was about 2000, 9000, and 12,000 µg/l in produced water from six platforms evaluated by Lysyj (1982), the Buccaneer Platform off Galveston, Texas (Middleditch, 1981; Sauer, 1981), and the C-2 separator platform in Trinity Bay, Texas (Armstrong et al., 1979), respectively.

There is little information about the concentrations of total and individual PAH in produced water. Armstrong et al. (1979) reported a concentration of 1750 µg/l for total naphthalenes, biphenyls, fluorenes, and phenanthrenes in produced water from the C-2 separator platform. Middleditch (1981) reported 40 µg/l total naphthalenes and biphenyls in produced water from the Buccaneer Platform. Lysyj (1982) reported concentrations of 12 to 40 µg/l naphthalene and 15 µg/l phenanthrene in produced water samples from the Gulf of Mexico. By comparison, produced water samples collected from Eugene Island and Lake Pelto on the spring survey contained 80 and 142 µg/l, respectively, total naphthalenes, biphenyls, dibenzothiophenes, fluorenes, phenanthrenes, pyrenes, chrysenes, and perylenes (Table 4.1). Concentrations of total naphthalenes, dibenzothiophenes, fluorenes, and phenanthrenes in produced water samples collected at four platforms during the preliminary field survey ranged from 340 to 680 µg/l (Table 4.2). In all cases, the naphthalenes were more abundant than the higher molecular weight PAH. Produced water from both Eugene Island and Lake Pelto also contained significant amounts of phenanthrenes, and produced water from Lake Pelto contained slightly elevated levels of dibenzothiophenes, fluorenes, and pyrenes.

With a few exceptions, alkyl homologue distributions of different PAH were similar in the produced water samples collected in the preliminary and the spring surveys (Table 4.2). The C_2 naphthalene was the most abundant naphthalene homologue

TABLE 4.2. COMPARISON OF MEAN CONCENTRATIONS OF TOC AND SELECTED AROMATIC HYDROCARBONS (μg/l) IN SAMPLES OF PRODUCED WATER COLLECTED ON THE PRELIMINARY SURVEY AND THE SPRING SURVEY AT EUGENE ISLAND, BLOCK 105A, AND LAKE PELTO, TANK BATTERY NO. 1.

Compound	Eugene Island		Lake Pelto	
	Preliminary	Spring	Preliminary	Spring
TOC	220,100	222,000	306,500	298,000
Naphthalene	48.5	9.64	53.4	13.9
C_1	83.1	18.4	78.2	22.5
C_2	104	26.7	99.8	36.0
C_3	84.1	15.1	74.8	18.9
C_4	11.1	3.69	24.9	4.31
C_5	0.59	ND	2.82	ND
Dibenzothiophene	3.70	1.02	1.86	0.56
C_1	ND	0.20	3.56	1.91
C_2	ND	ND	4.31	1.15
C_3	ND	0.04	0.98	0.98
C_4	ND	0.004	ND	0.21
C_5	ND	ND	ND	ND
Fluorene	0.11	0.17	3.06	1.98
C_1	ND	0.31	6.85	2.81
C_2	ND	0.27	10.0	3.89
C_3	ND	ND	6.66	2.12
C_4	ND	ND	ND	0.51
C_5	ND	ND	ND	ND
Phenanthrene	0.70	0.85	7.32	4.34
C_1	ND	0.37	22.4	3.75
C_2	ND	0.44	22.8	10.1
C_3	ND	0.26	7.68	4.16
C_4	ND	ND	ND	ND
C_5	ND	ND	ND	ND

ND = Not Detected.

in produced water from both platforms collected on both cruises. However, the homologue distributions for the other PAH were different for produced water from the two platforms. For example, in produced water from Lake Pelto, the C_1 and C_2 homologues of dibenzothiophene, fluorene, and phenanthrene were substantially more abundant than the corresponding parent (unalkylated) compound or the more highly alkylated homologues. This was not the case for produced water from Eugene Island. These differences in the hydrocarbon composition of produced water from the two platforms undoubtedly reflect in part the different composition of crude oil from the two platforms. There also were dispersed oil droplets in the Lake Pelto produced water samples, as evidenced by the presence of high molecular weight alkanes and PAH at concentrations higher than their aqueous solubilities.

The relative distribution of hydrocarbons in produced water can be explained in terms of the solubility behavior of hydrocarbons. The solubility of petroleum hydrocarbons in seawater decreases logarithmically as hydrocarbon molecular weight increases (McAuliffe, 1966). Aromatic hydrocarbons are more water-soluble than saturate hydrocarbons of similar molecular weight. Therefore, the soluble fraction of petroleum in produced water will be greatly enriched in light aliphatic and especially aromatic hydrocarbons compared to the composition of the oil in equilibrium with the produced water (Neff and Anderson, 1981).

4.1.2 Steranes and Triterpanes

Steranes and triterpanes were analyzed in produced water because it was thought that they might contribute significantly to the as yet uncharacterized organic carbon in produced water; also, because of their persistence in the environment (Seifert and Moldowan, 1979), they might serve as useful markers of the fate of organic materials from produced water in the marine environment. Concentrations of these compounds were relatively low, though higher than concentrations of total targeted PAH, i produced water from the two platforms (Table 4.1). Concentrations of total steranes plus triterpanes in produced water from Eugene Island and Lake Pelto were estimated at 139 and 172 μg/l, respectively. There are no published concentrations of steranes and triterpanes in produced water from other sources, so we do not know if the values reported here are representative for produced waters generally. The relative abundances of different steranes and to a lesser exten triterpanes in produced water from the two platforms were quite different, indicating that these classes of compounds might be useful in "fingerprinting" produced water from different sources. However, the usefulness of these compounds in tracing the fate of produced water after discharge to the ocean will depend upon the resemblance of the sterane and triterpane assemblages in produced water to those in natural, uncontaminated marine sediments.

Steranes and triterpanes are widely distributed in higher plant or are the products of early diagenesis of organic materials (Tan and Heit, 1981; Quirk et al., 1984). Therefore, they tend to be ubiquitous in nearshore marine sediments. However, the steranes and triterpanes in fossil fuels have different chemica structures and occur in concentration ratios quite different from those in modern biogenic or early diagenic assemblages. Therefore, they are useful tracers of petroleum in the environment (Seifert and Moldowan, 1979). Although, in the present study, selected ratios of steranes and triterpanes in sediments near the two platforms were different from those in produced water, there was no indication of a gradient of steran or triterpane ratios with distance from either platform. However, the sterane and triterpane assemblage in sediments nea (20 m) the platform indicated the presence in the sediments of petroleum.

4.1.3. Other Organic Compounds

Several volatile ketones were identified in produced water from both platforms at concentrations of 1320 and 2230 µg/l (Table 4.1). Middleditch (1981) identified 2-butanone and 2-pentanone at concentrations of 300 and 160 µg/l, respectively, in produced water from the Buccaneer Platform. Sauer (1981) identified similar ketones in other produced water samples from the Buccaneer Platform. These investigators attributed the ketones to paint solvents used on the platform or to additives added to produced water during treatment.

Phenols are another group of slightly soluble organic compounds found in produced water at significant concentrations. In the present investigation, concentrations of total phenols in produced water from Eugene Island and Lake Pelto were 2720 and 675 µg/l, respectively. These values may be higher than actual concentrations in the produced water samples due to possible sample contamination. Lysyj (1982) reported concentrations of 18 to 840 µg/l phenol in produced water samples from five platforms off Louisiana, not greatly different from the phenol concentrations of 1430 and 291 µg/l reported for produced water samples from Eugene Island and Lake Pelto, respectively, in the present investigation. However, Lysyj (1982) did not detect any alkyl phenols in his samples. Phenols could be natural trace ingredients of the crude oil from the platforms or they could represent oxidation products of low molecular weight aromatics generated during treatment of the produced water on board the platform. Because of their relatively high aqueous solubility, phenols will tend to be enriched in produced water relative to their concentrations in crude oil in equilibrium with the produced water.

4.1.4 Salinity

The salinity of produced water collected from the four platforms visited during the preliminary survey ranged from 195 ppt at

Ship Shoal, Block 114 to 334 ppt at Eugene Island, Block 120. Salinity of produced water from Eugene Island and Lake Pelto di not vary significantly between the preliminary survey and the spring survey (Table 4.3). Reid (1983) reported salinities ranging from about 35 to 250 ppt in 20 samples of produced wate from Texas and Louisiana. The salinity of produced water discharged from nine production facilities to Texas bays ranged from 8 to 139 ppt (Mackin, 1971). Rittenhouse et al. (1969) reported a range of salinities of 3 to greater than 300 ppt for a large number of produced water samples from Canada and the United States. Thus, the produced waters sampled in the present investigation have salinities at the upper end of the normal range for produced water salinity.

4.1.5 Metals

The most abundant of the targeted metals in produced water from Eugene Island and Lake Pelto were barium, zinc, and lead (Table 4.3). These also were the only metals present in the produced water samples at concentrations substantially higher (> 1000-fold) than in natural seawater. Produced water samples collected from Ship Shoal, Block 114 and Eugene Island, Block 120 during the preliminary survey contained a mean of 14,650 an 91,700 µg/l barium, respectively, and 8293 and 1423 µg/l zinc, respectively. With two exceptions, barium and zinc, the concentrations of metals in produced water reported in this investigation are lower than mean metals concentrations reporte for produced water samples from the Buccaneer Platform (Middleditch, 1984) and from seven platforms off Louisiana (Lysyj, 1982) (Table 4.4). Because analysis of metals in concentrated saline brines, such as produced water, is difficult, many of the values reported for produced water from the Buccaneer Platform and offshore Louisiana may be inaccurate (Middleditch, 1984).

Zinc and possibly lead could be derived in part from galvanized

TABLE 4.3. COMPARISON OF SALINITY (PARTS PER THOUSAND) AND CONCENTRATIONS (µg/l) OF NINE METALS IN PRODUCED WATER FROM EUGENE ISLAND, BLOCK 105, LAKE PELTO, TANK BATTERY NO. 1, AND IN CLEAN COASTAL SEAWATER.

Metal	Seawater [1]	Eugene Island	Lake Pelto
Barium	20.0	37,400 (97,000)[2]	11,500 (31,000)
Cadmium	0.01	0.32	0.12
Chromium	0.08	1.11 (0.89)	0.71 (1.41)
Copper	0.10	6.36 (1.77)	0.40 (1.38)
Lead	0.005	17.9	1.50
Mercury	0.01	0.06	0.07
Nickel	0.20	0.40	1.27
Silver	0.01	<0.20	<0.20
Zinc	0.01	1,220 (617)	125 (156)
Salinity	32-35	183 (179)	150 (146)

[1] From Forstner and Wittman (1983).

[2] Values in parentheses are from analyses of produced water samples from the preliminary survey.

TABLE 4.4. COMPARISON OF CONCENTRATIONS OF SEVERAL METALS IN PRODUCED WATER FROM EUGENE ISLAND, BLOCK 105, LAKE PELTO, TANK BATTERLY NO. 1, THE BUCCANEER PLATFORM, TEXAS (MIDDLEDITCH, 1984), AND SEVEN PLATFORMS OFF THE LOUSIANNA COAST (LYSYJ, 1982). CONCENTRATIONS ARE IN μg/l (PARTS PER BILLION).

Metal	Eugene Island	Lake Pelto	Buccaneer	Lousianna
Barium	37,400-97,000	11,500-31,000	6.4-3,500	-
Cadmium	0.32	0.12	0.057-32	<25-56
Chromium	0.89-1.11	0.71-1.41	0.83-260	59-390
Copper	1.77-6.36	0.40-1.38	0.55-120	<25-137
Lead	17.9	1.50	0.78-760	160-915
Mercury	0.06	0.07	0.16-0.40	<0.3-0.4
Nickel	0.40	1.27	0.35-1,200	68-1,674
Silver	<0.20	<0.20	0.028-110	<1-152
Zinc	617-1,220	125-156	15-610	<25-640

steel structures in contact with the produced water or with deck drainage. The concentrations of barium in produced water from the two platforms were about 1000-fold higher than the solubility of barium in seawater (estimated by Chow, 1976, at 46 μg/l as Ba, based on a normal concentration of sulfate in seawater of 28 mM). The chemistry of barium in concentrated saline brines is poorly understood. Collins (1975) reported that barium can occur in produced water at concentrations as high as 100,000 μg/l. The extent to which this barium is present in particulate or colloidal form or in true solution is not known. There was no relationship in produced water samples collected during the preliminary survey between total suspended solids concentrations and barium concentrations in the samples. Filtration of the produced water samples did not result in a significant decrease in the barium concentrations in the samples, indicating that most of the barium probably was in solution or colloidal suspension. This may be possible in a saline brine if the concentrations of sulfate and carbonate are very low (Collins, 1975), a situation that is true for many produced waters. Trefry (personal communication) has suggested that much of the excess barium in produced water may be complexed to soluble organic material.

4.1.6 Radium Isotopes

Mean concentrations of ^{226}Ra plus ^{228}Ra, measured in samples collected from the preliminary field survey, are shown in Table 1.2. The highest activities are associated with the sample from Eugene Island, Block 120 (1215 pCi/liter, ^{226}Ra plus ^{228}Ra). This sample also possessed the highest concentration of TOC, suggesting a positive correlation between these two parameters. A consideration of the data in Table 1.2 indicates that the order of increasing radium activities in samples roughly parallels that of TOC contents, although the relationship is not necessarily linear. Landa and Reid (1983) and Kraemer and Reid

(1984) have identified the positive correlation between produce water salinity and Ra activity. The correlation between these parameters was not good for the four samples analyzed here. Although only four samples were analyzed, the data reported her suggest that organic carbon may also be correlated with radium activity in the produced waters.

Total ^{226}Ra plus ^{228}Ra concentrations measured by Kraemer and Reid (1984) in produced water samples from the U.S. Gulf coast ranged from less than 0.2 pCi/l in a produced water sample from a gas well in McAllen, Texas to 13,808 pCi/l in a produced wate sample from a gas well in Vermilion Parish, Louisiana. For produced water samples with salinities in the range of those reported in the present investigation (143 to 220 ppt), Kraemer and Reid (1984) reported total radium concentrations in the range of 1465 to 13,808 pCi/l. Thus, the produced water sample analyzed in the present investigation contained less radium than would be expected from the data of Kraemer and Reid (1984) based on salinity.

4.2 PRODUCED WATER DISCHARGE RATES

The platforms at Eugene Island, Block 105 and Lake Pelto, Tank Battery No. 1 discharge produced water at an average rate of about 1570 to 3000 barrels/day (bpd) (249,600 to 477,000 l/d). According to Walk, Hydel & Associates (1984), the average produced water discharge rate from an offshore platform usually is less than 1800 bpd (285,000 l/d), whereas discharges from large facilities handling produced water from many platforms ma be as high as 157,000 bpd (25 million l/d). Nine platforms investigated by Mackin (1971) discharged produced water to Texa bays at rates ranging from 384 to 36,500 bpd (61,000 to 5,800,000 l/d). Volumes of produced water discharged in 1975 from five platforms in the Gulf of Mexico examined in the Central Gulf Platform Study ranged from 301 to 18,240 bpd

(48,000 to 2,400,000 l/d) (Bedinger et al., 1981). The seven platforms in the Gulf of Mexico examined by Lysyj (1982) discharged 195 to 17,000 bpd (31,000 to 2,700,000 l/d) produced water. The Buccaneer platform examined by Middleditch (1981) discharged between 118 and 2000 bpd (18,760 and 318,000 l/d) of produced water between 1973 and 1978. Thus, the range of produced water discharges from the two platforms in the present investigation is in the lower to middle part of the range of produced water discharge rates that have been investigated from other platforms in the Gulf of Mexico.

4.3 HYDROGRAPHY

4.3.1 Temperature and Salinity

Temperature, salinity, and dissolved oxygen concentrations were quite uniform at all stations around both platforms during both the spring and fall surveys. As expected, both water temperatures and salinities were higher at both platforms in the fall than in the spring. This reflects the effects of increased freshwater runoff in the spring and summer warming of the coastal waters. Water temperatures were similar at Eugene Island and Lake Pelto. As a general rule, surface and bottom water salinity at Lake Pelto were 2 to 4 ppt lower than at Eugene Island at the time of both the spring and fall surveys. The range of salinities of bottom water at all stations in both seasons was only from 26 to 34 ppt. These salinities should be compatible with a mixed marine and lower estuarine (polyhaline) benthic fauna. However, we do not know the full range of salinities at each site during the year of this investigation. Quite frequently, the extremes of environmental factors, such as temperature and salinity, have a greater influence on the structure of the resident benthic communities than do the means.

4.3.2 Dissolved Oxygen Concentration

Concentrations of dissolved oxygen were near saturation in surface and bottom water at all stations around both platforms at both sampling times. Oxygen concentrations in bottom water were not determined during the preliminary survey. However, the REMOTS sediment profile imaging performed at each candidate platform provided data on the apparent depth in the sediment of the redox potential discontinuity (RPD), from which relative oxygen saturation of the overlying water can be inferred. At both Eugene Island and Lake Pelto, mean RPD depth was lowest at stations 20 m from the platform and increased with distance fro the platform. However, the shallowest RPD depths were 0.53 and 1.05 cm at Eugene Island and Lake Pelto, respectively, indicating that there was oxygen in the overlying water. The shallower RPD depths at stations near the platforms probably were due to the elevated biological or chemical oxygen demand o these sediments. At Ship Shoal, Block 114, one of the candidate platforms examined during the preliminary survey, RPD depth was zero at all but two stations. Depth and stratigraphy of the sulfidic sediment layer indicated that bottom water throughout the area had experienced periods of hypoxia and oxygen replenishment.

There have been many reports of seasonal episodes of hypoxic (≤ 2.0 mg/l) or anoxic (<0.5 mg/l) bottom water over large areas o the inner continental shelf (5 to 50 m water depth) off Louisiana (see Rabalais et al., 1985 for a recent review). Hypoxic bottom water has been recorded on the inner continental shelf of central Louisiana west of the Mississippi River delta every summer since 1972 (Renaud, 1985a; Rabalais et al., 1986). Based on satellite imagery, Leming and Stuntz (1984) estimated that approximately 6000 km^2 of the inner continental shelf between the Mississippi River delta and Caillou Bay had hypoxic bottom water during the summer of 1982. Hypoxic bottom water is most prevalent between May and September and appears to have a very patchy distribution in both time and space (Turner and Allen, 1982; Renaud, 1985b; Rabalais et al., 1985, 1986).

Maps of the distribution of hypoxic bottom water off central Louisiana (Turner and Allen, 1982; Renaud, 1985b; Rabalais et al., 1985) indicate that Eugene Island, Block 105 is not in an area that becomes hypoxic most summers. However, unpublished data provided by N. Rabalais of Louisiana Universities Marine Consortium indicate that the dissolved oxygen concentrations of bottom water at stations approximately 10 miles west-northwest and 30 miles southeast of the platform at Eugene Island, Block 105 were 0.85 and 2.21 mg/l, respectively, on 10 July 1986, a time half way between the spring and fall surveys in the present investigation. Therefore, it is possible that the stations around the platform at Eugene Island, Block 105 experienced an episode of hypoxic bottom water in the interval between the spring and fall surveys.

Apparently, the waters of shallow bays along the Louisiana coast are much less likely than inner continental shelf waters to experience seasonal hypoxic events. Bottom water in bays such as Terrebonne Bay, site of the Lake Pelto oil field, usually remains reasonably well mixed and oxygenated throughout the year.

The reasons for seasonal episodes of hypoxic bottom water on the inner shelf off Louisiana are not completely understood. There is a growing consensus that excess phytoplankton production in the area, stimulated by nutrient inputs from the Mississippi and Atchafalaya Rivers, produces large amounts of organic carbon that sinks to the bottom when the phytoplankton die. During the summer, there is water stratification in the area, leading to depletion of oxygen in bottom waters as the organic material on the bottom decomposes (Rabalais et al., 1985).

4.4 SEDIMENT GRAIN SIZE

Sediment texture varied greatly at different stations around th platforms at Eugene Island, Block 105 and Lake Pelto, Tank Battery No. 1, and even among replicate sediment samples taken at a station. The finest grained sediments contained 75 to 92 percent silt plus clay and were collected from stations closest to the platform at Eugene Island and farthest from the platform at Lake Pelto (Tables 3.18 and 3.48). The coarsest sediments contained 75 to 87 percent sand plus gravel and were collected at stations 300 and 1,000 m from the platform at Eugene Island and from stations 20 and 100 m from the platform at Lake Pelto. Thus, there was an indication of a gradient of increasing sediment grain size with distance from the platform at Eugene Island and of decreasing sediment grain size with distance from the platform at Lake Pelto.

The reasons for the different distributions of sediment grain size around the two platforms are unclear. As a general rule, physical structures, such as the legs of a platform, will cause localized scour, increasing the rate of erosion, particularly fine-grained sediments (Carstens, 1983). Mild scour around a platform would tend to result in an increase in the mean sediment grain size due to washout of fine-grained sediments. Severe scour might result in net erosion of sediments around t platform. Behrens (1981) estimated, based on geochemical and radioisotope techniques, that from one to two meters of sediments had eroded from around the Buccaneer Platform in the more than 10 years since its installation. Brooks et al. (1980 reported large seasonal variations in the distribution of grai size in surficial sediments around platform B in the Buccaneer field. Sediments within about 20 m of the platform ranged from very fine sand in the fall of 1978 to fine gravel (2-4 mm) in the spring of 1979. A similar but less dramatic change in sediment grain size was observed in the present investigation Station 1 at Eugene Island from a mean silt plus clay concentration of 80.2 percent in the spring to 42.9 percent in the fall. These patterns of changing sediment grain size near platforms in the fall than in the spring might be due to seasonal scour during storms, followed by more quiescent periods when fine grain sediments accumulate again.

Sediment grain size around the platform at Lake Pelto appears to be less variable on a seasonal basis. At the stations within 20 m of the platform, sediment percent silt plus clay increased by 0.6 to 8.9 percent between the spring and fall surveys. The coarse sediments near the platform at Lake Pelto may be derived from discharges of produced sand from the platform, or they could represent coarse materials placed at the platform site during construction of the platform. Approximately 1,000 cubic feet of produced sand are generated per year on the platform. Some of this sand was processed in a sand wash unit and discharged to the bay. The remainder was removed to an approved upland disposal site.

4.5 CHEMICALS AND FAUNA IN SEDIMENTS

4.5.1 Hydrocarbons and Total Organic Carbon

4.5.1.1 Distribution Patterns

At Eugene Island, there was a tendency for the concentration of total organic carbon (TOC) in sediments to be highest near the platform and decrease with distance from the platform. This was due in large part to the strong positive correlation between percent TOC and percent silt plus clay in the sediments around the platform, and the gradients of decreasing percent silt plus clay in sediments with distance from the platform.

At Lake Pelto, the coarsest sediments were located at the stations closest to the platform and there were no clear gradients of TOC with distance from the platform. If the platform is a source of "extra" organic carbon for the sediments, either from platform discharges or the biofouling community associated with submerged platform structures, then this lack of association between sediment grain size or distanc from the platform on the one hand and sediment TOC on the othe is to be expected. Because silt/clay size particles have a greater capacity for binding organic material than do larger particles, the concentration of organic carbon associated with sediment will tend to be related to the the distribution of sediment grain size in the sediment and the concentration of available organic mater in the water in contact with the sediment. Thus, superimposed gradients of decreasing sediment grain size and dissolved/suspended organic matter in the water column with distance from the platform will tend to result in a more or less even distribution of TOC in the sediments around the platform.

Patterns of hydrocarbon distributions in sediments around the platforms tended to parallel those of sediment TOC, with a few exceptions. At Lake Pelto, concentrations of total hydrocarbons and total PAH in sediments were highest at one or more stations 20 m from the platform and decreased with distance from the platform. There was a fairly uniform gradient of decreasing concentrations of total hydrocarbons in sediments with distance from the platform along most transects. However, concentrations of total PAH dropped to essentially background values at all stations 300 or 1000 m from the platform. Total targeted n-alkanes had a heterogeneous distribution in sediments around the platform. These hydrocarbon distributions reflect the multiple sources of the hydrocarbons in sediments around the platform, as discussed in greater detail below.

Patterns of hydrocarbon distribution in sediments around the platform at Eugene Island, Block 105 were slightly different than those described above for Lake Pelto. There was a gradient of decreasing concentrations of total hydrocarbons in sediments with distance from the platform along most transects. However, concentrations of both total targeted n-alkanes and PAH were elevated above apparent background values at only one or more stations on the 20-m ring. Sediments at stations 100 to 1000 m from the platform had relatively uniform concentrations of total n-alkanes and PAH in the range of 0.3 to 1.6 µg/g (parts per million) and 0.02 to 0.16 µg/g, respectively.

Although there was overlap, as a general rule, concentrations of total hydrocarbons, n-alkanes, and PAH were higher in sediments at Lake Pelto than at Eugene Island. These differences undoubtedly reflect a higher level of contamination of sediments from platform discharges as well as a greater input of hydrocarbons from other sources, such as the Mississippi River, in the shallow bay environment compared to the offshore environment.

Boehm and Requejo (1986) recently reviewed the hydrocarbon geochemistry of sediments from the outer continental shelf of the Atlantic and Gulf coasts of the U.S. and concluded that sediments from the inner shelf of Louisiana west of the Mississippi Delta contained higher hydrocarbon concentrations than sediments from the shelf east of the Mississippi and the Texas outer continental shelf. These hydrocarbon assemblages included contributions from petrogenic, pyrogenic, and diagenic sources, as discussed below and were derived from the Mississippi River outflow and from the extensive oil and gas production activities in the area.

Based on data from two nearshore sites (West Hackberry and Weeks Island), both west of the study sites in this investigation, Boehm and Requejo (1986) reported that typical concentrations of total hydrocarbons in sediments from the area ranged from 3 to 70 µg/g. At all sites, there was a direct correlation between sediment TOC and total hydrocarbon concentrations.

Concentrations of total targeted PAH (naphthalene through pyrene) in sediments from the two sites ranged from 0.4 to 1.1 μg/g. If these concentration ranges are used as an indication o the typical concentrations for hydrocarbons in sediments from the central Louisiana inner continental shelf, then hydrocarbon concentrations at a majority of stations around the two platforms examined in the present investigation can be considered to be typical of uncontaminated sediments. At Eugen Island, sediments at only the inner 20-m stations had total hydrocarbon and PAH concentrations in excess of or in the upper part of the range of these background concentrations.

At most stations at Eugene Island, PAH concentrations in sediments were below the range sited by Boehm and Requejo (1986). At Lake Pelto, sediments from several stations at 20 an 100 m from the platform contained concentrations of total hydrocarbons and PAH in excess or in the higher part of the range of typical concentrations. Most, stations at 300 and 1000 m from the platform contained sediments with hydrocarbon concentrations below or in the lower part of the range of background concentrations.

4.5.1.2 Diagnostic Parameters and Ratios

Several quantitative parameters and diagnostic ratios were selected to help interpret the data on distributions and abundances of n-alkanes and PAHs in sediments around each platform. The parameters and diagnostic ratios selected are described in Tables 4.5 and 4.6.

Simple ratios for the n-alkanes (Table 4.5) provide information on the generic type of source of the n-alkane assemblage. The relative proportion of different parent PAH within the PAH assemblage and the relative abundance of different alkyl homologues within each PAH homologous series can be used to assess the relative contributions of petrogenic, pyrogenic, and

TABLE 4.5. QUANTITATIVE PARAMETERS AND DIAGNOSTIC RATIOS FOR SATURATED HYDROCARBONS.

Parameter	Significance
Total n-alkanes (TALK) (μg/g)	Contains n-alkanes from n-C_{10} to n-C_{34}. This total is directly related to the fineness of the sediment and total organic carbon content.
n-alkanes C_{10}-C_{20} (LALK) (μg/g)	Crude petroleum contains abundant amounts of n-alkanes in this boiling range; unpolluted samples are very low in many of these alkanes.
LALK/TALK	This ratio indicates the relative abundance of C_{10}-C_{20} alkanes, characteristic of light crude and refined oils, with respect to total alkanes, which are diluted by terrigenous plant hydrocarbons (C_{23}-C_{31}).
TALK/Total Organic Carbon (TOC) (μg/mg TOC)	The ratio of total saturated hydrocarbons (TALK) to TOC has been used to monitor oil inputs. Small (tens of ppm) additions of petroleum to the sediment cause the ratio to increase dramatically, since n-alkanes (μg/g) increase and TOC (mg/g) does not.

TABLE 4.6. QUANTITATIVE PARAMETERS AND DIAGNOSTIC RATIOS FOR PAH.

Parameter	Significance
Naphthalene series, N (µg/g) = $C_0N+C_1N+C_2N+C_3N+C_4N+C_5N$	Particular combinations of ea of these homologous series pr information on the source of in samples used in diagnostic ratios.
Fluorene series, F (µg/g) = $C_0F+C_1F+C_2F+C_3F+C_4F+C_5F$	
Phenanthrene series, P (µg/g) = $C_0P+C_1P+C_2P+C_3P+C_4P+C_5P$	
Dibenzothiophene series, D (µg/g) = $C_0D+C_1D+C_2D+C_3D+C_4D+C_5D$	
4- and 5-ringed PAH series, 4-,5-PAH (µg/g) = $C_0Pyrn+C_1Pyrn+C_2Pyrn+C_3Pyrn+C_4Pyrn+C_5Pyrn+$ $C_0Chry+C_1Chry+C_2Chry+C_3Chry+C_4Chry+C_5Chry+$ $C_0Pery+C_1Pery+C_2Pery+C_3Pery+C_4Pery+C_5Pery$	
Total PAH (µg/g) = N+F+P+D+4-,5-PAH	The sum of 2-5 ringed aromati a good quantitative indicator petrogenic addition. The sum 2-3 ringed PAH is a better in since these components are mor prevalent in oil.
N/P and P/D	Specific PAH ratios that are to sources of PAH.
PAH/TOC (µg/mg TOC)	Analogous to TALK/TOC ratio.
Fossil Fuel Pollution Index (FFPI)[a]	Pyrogenic or combustion-derive assemblages are relatively mor enriched in 3-5 ringed PAH compounds; fossil fuels are hi enriched in 2-3 ringed PAH and nuclear organo-sulfur compound (e.g., dibenzothiophene and it homologues). This ratio is de to determine the approximate percentage of fossil fuel to t PAH.

$$^{a}\mathrm{FFPI} = \frac{N+P-(1/2\ (C_0P+C_1P))+D}{\text{Total PAH}} \times 100$$

$= 100$, fossil fuel PAH

$= 0$, combustion PAH

possibly biogenic/early diagenic PAH to the sample (Table 4.6). For example, crude oil frequently has naphthalene/phenanthrene and phenanthrene/dibenzothiophene (N/P and P/D) ratios that differ from ratios for pyrogenic PAH assemblages. However, these ratios vary greatly in petrogenic and pyrogenic assemblages from different sources, so that these ratios can not be used alone to identify the source of a PAH assemblage.

The fossil fuel pollution index (FFPI) is used to indicate petrogenic pollution (Boehm and Farrington, 1984). If the FFPI is 10 to 35 percent, the sediments are usually considered unimpacted by fossil fuels; a higher FFPI usually indicates petroleum pollution. Because of the way these ratios are formulated, a small addition of petroleum hydrocarbons from oil and gas operations would be observed as a dramatic increase in the values of these ratios or hydrocarbon assemblage characteristics.

The best way to use the diagnostic ratios is to follow trends or changes over distance or time in values for the diagnostic ratios in sediment or biota samples from the vicinity of the suspected contaminant source. In this study, comparisons have been made of diagnostic values for sediment samples collected along transects radiating out from the platforms (e.g., Stations 1, 2, 3, and 4) and between areas close to (i.e., 20 m, 100 m) and far away from (i.e., 300 m, 1000 m) the produced water discharges.

It should be noted that any one of these parameters or ratios alone does not provide enough information to formulate a conclusive argument for a particular interpretation. It is the combination of several of these values that gives credence to a proposed conclusion.

In this section, discussion of the data has been divided into two subsections based on the two study sites. For each site,

the produced water and sediment results from both the spring a
fall surveys are discussed.

4.5.1.2.1 Eugene Island. The n-alkane and PAH diagnostic parameters and ratios for Eugene Island produced water and sediments collected during the spring survey are presented in Tables 4.7 through 4.11. The diagnostic values for sediments from the fall survey are given in Table 4.12. The values for th diagnostic parameters and ratios in produced water form the basis for interpreting the values for sediments from the site.

The dominance of several fossil fuel indicators in produced water is overwhelming (Tables 4.7 and 4.8). The C_{10} through C_2 n-alkanes represent approximately 75 percent of the total C_{10} - C_{34} n-alkanes in the sample and account for 20 percent of all resolvable alkanes. Naphthalenes make up over 90 percent of all the indicator semivolatile aromatics (Table 4.8) and about 10 percent of all resolvable aromatic hydrocarbons in the sample o produced water collected at Eugene Island during the spring survey. The sample is dominated by low molecular weight aromatics (2-3 rings), as indicated by a FFPI near 100 percent. The P/D ratio is near 1.

The alkane parameter concentrations and diagnostic ratios (Tabl 4.9) for sediments from Eugene Island collected on the spring survey indicate that there is some petroleum hydrocarbon contribution, probably from produced water, to sediment samples close to the produced water discharge. On the west, north, and east transects, there is a decrease in the total n-alkane/total organic carbon (TALK/TOC) ratio in sediments with distance from the platform. There is also a decrease in the low molecular weight n-alkanes/total n-alkanes (LALK/TALK) ratio along the west transect, but not along the other three transects. Both ratios do not vary with distance from the platform along the south transect (Stations 13-16). The higher diagnostic ratios at the stations near the platform (except Station 5) indicate a

TABLE 4.7. ALKANE CONCENTRATIONS AND RATIOS FOR PRODUCED WATER FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

	Concentration (µg/L)		Ratio	
Site	LALK[a]	TALK[b]	LALK/TALK	TALK/TOC[c]
Eugene Island	2040	2680	0.76	12.0
Lake Pelto	457	606	0.75	2.0

[a] LALK = Sum of n-alkanes, C_{10}-C_{20}

[b] TALK = Sum of n-alkanes, C_{10}-C_{34}

[c] TOC = Total Organic Carbon (mg/g)

TABLE 4.8. CONCENTRATIONS OF PAH HOMOLOGOUS SERIES AND FOSSIL FUEL POLLUTION INDEX OF PRODUCED WATER FROM EUGENE ISLAND AND LAKE PELTO COLLECTED DURING THE SPRING SURVEY.

	Concentration (μg/L)									
Site	N[a]	F[b]	P[c]	D[d]	4-,5-PAH[e]	N+P+D	PAH[f]	N/P	P/D	FFPI[g]
Eugene I.	73.5	0.75	1.92	1.26	0.0	76.7	77.4	38	1.5	98
Lake Pelto	95.6	11.3	22.4	4.81	5.80	123	139.9	4.3	4.7	85

[a] $N = C_0N+C_1N+C_2N+C_3N+C_4N+C_5N$ (naphthalenes)

[b] $F = C_0F+C_1F+C_2F+C_3F+C_4F+C_5F$ (fluorenes)

[c] $P = C_0P+C_1P+C_2P+C_3P+C_4P+C_5P$ (phenanthrenes)

[d] $D = C_0D+C_1D+C_2D+C_3D+C_4D+C_5D$ (dibenzothiophenes)

[e] 4,5-PAH = $C_0Pyrn+C_1Pyrn+C_2Pyrn+C_3Pyrn+C_4Pyrn+C_5Pyrn+$(pyrenes)
$C_0Chry+C_1Chry+C_2Chry+C_3Chry+C_4Chry+C_5Chry+$(chrysenes)
$C_0Pery+C_1Pery+C_2Pery+C_3Pery+C_4Pery+C_5Pery$ (perylenes)

[f] PAH = N+P+F+D+4,5-PAH

[g] $$FFPI = \frac{N+P-(1/2\ (C_0P+C_1P))+D}{\text{Total PAH}} \times 100$$

TABLE 4.9. ALKANE CONCENTRATIONS AND RATIOS IN SEDIMENT SAMPLES FROM EUGENE ISLAND, STATIONS 1-16, COLLECTED DURING THE SPRING SURVEY.

	Concentration (µg/g Dry Weight)			
Station	LALK[a]	TALK[b]	LALK/TALK	TALK/TOC[c]
1	1.78	2.78	0.64	0.40
2	0.430	0.838	0.51	0.31
3	0.131	0.488	0.27	0.38
4	0.326	0.951	0.34	0.15
5	1.15	7.32	0.16	1.4
6	0.942	1.60	0.59	0.47
7	0.413	0.666	0.62	0.48
8	0.421	0.851	0.49	0.27
9	0.976	1.42	0.69	0.89
10	0.507	0.718	0.71	0.51
11	0.107	0.295	0.36	0.23
12	0.122	0.308	0.40	0.19
13	1.03	2.08	0.50	0.31
14	0.377	0.738	0.51	0.25
15	0.329	0.646	0.51	0.29
16	0.251	0.457	0.55	0.27

[a] LALK = Sum of n-alkanes, C_{10}-C_{20}

[b] TALK = Sum of n-alkanes, C_{10}-C_{34}

[c] TOC = Total Organic Carbon (mg/g)

TABLE 4.10. RATIO OF TOTAL PAH (μg/g) TO TOTAL ORGANIC CARBON (mg/g) IN SEDIMENT SAMPLES FROM EUGENE ISLAND AND LAKE PELTO, STATIONS 1-16, COLLECTED DURING THE SPRING SURVEY.

	PAH/TOC	
Station	Eugene Island	Lake Pelto
1	0.054	1.99
2	0.0130	0.47
3	0.015	0.061
4	0.019	0.035
5	0.083	0.438
6	0.029	0.851
7	0.011	0.060
8	0.033	0.024
9	0.027	0.236
10	0.008	1.35
11	0.012	0.035
12	0.011	0.058
13	0.040	0.82
14	0.026	0.86
15	0.051	0.046
16	0.007	0.040

TABLE 4.11. CONCENTRATIONS OF PAH HOMOLOGOUS SERIES AND FOSSIL FUEL POLLUTION INDEX (FFPI) OF SEDIMENT SAMPLES FROM EUGENE ISLAND, STATIONS 1-16, COLLECTED DURING THE SPRING SURVEY.

	Concentration (µg/g Dry Weight)									
Station	N[a]	F[b]	P[c]	D[d]	4-,5-PAH[e]	N+P+D	PAH[f]	N/P	P/D	FFPI[g]
1	0.048	0.079	0.146	0.001	0.099	0.195	0.373	0.33	146	36.5
2	0.001	0.003	0.001	0.0	0.030	0.002	0.035	1.0	-	4.3
3	0.0	0.0	0.0	0.0	0.019	0.0	0.019	-	-	0.0
4	0.002	0.006	0.029	0.0	0.087	0.031	0.124	0.07	-	19
5	0.060	0.083	0.116	0.023	0.159	0.199	0.441	0.52	5	40
6	0.003	0.030	0.010	0.001	0.055	0.014	0.099	0.30	10	11
7	0.001	0.004	0.001	0.0	0.010	0.002	0.016	1.0	-	9.4
8	0.006	0.033	0.011	0.0	0.052	0.017	0.102	0.55	-	15
9	0.019	0.001	0.004	0.0	0.019	0.023	0.043	4.8	-	49
10	0.001	0.0	0.0	0.0	0.010	0.001	0.011	-	-	9.1
11	0.001	0.001	0.005	0.0	0.009	0.006	0.016	0.20	-	22
12	0.0	0.003	0.001	0.0	0.013	0.001	0.017	-	-	2.9
13	0.020	0.037	0.045	0.0	0.169	0.065	0.271	0.44	-	18
14	0.004	0.006	0.015	0.0	0.052	0.019	0.077	0.27	-	20
15	0.013	0.019	0.050	0.0	0.031	0.063	0.113	0.26	-	37
16	0.0	0.0	0.0	0.0	0.012	0.0	0.012	-	-	0.0

[a] $N = C_0N+C_1N+C_2N+C_3N+C_4N+C_5N$ (naphthalenes)

[b] $F = C_0F+C_1F+C_2F+C_3F+C_4F+C_5F$ (fluorenes)

[c] $P = C_0P+C_1P+C_2P+C_3P+C_4P+C_5P$ (phenanthrenes)

[d] $D = C_0D+C_1D+C_2D+C_3D+C_4D+C_5D$ (dibenzothiophenes)

[e] 4,5-PAH = $C_0Pyrn+C_1Pyrn+C_2Pyrn+C_3Pyrn+C_4Pyrn+C_5Pyrn+$(pyrenes)
$C_0Chry+C_1Chry+C_2Chry+C_3Chry+C_4Chry+C_5Chry+$(chrysenes)
$C_0Pery+C_1Pery+C_2Pery+C_3Pery+C_4Pery+C_5Pery$ (perylenes)

[f] PAH = N+P+F+D+4,5-PAH

[g] $$\text{FFPI} = \frac{N+P-(1/2\ (C_0P+C_1P))+D}{\text{Total PAH}} \times 100$$

TABLE 4.12. CONCENTRATIONS OF PAH HOMOLOGOUS SERIES AND FOSSIL FUEL POLLUTION INDEX OF SEDIMENT SAMPLES FROM EUGENE ISLAND, STATIONS 1-4*, COLLECTED DURING THE FALL SURVEY.

	Concentration (μg/g Dry Weight)									
Station	N[a]	F[b]	P[c]	D[d]	4-,5-PAH[e]	N+P+D	PAH[f]	N/P	P/D	FFPI[g]
1	0.154	0.002	0.008	0.002	0.144	0.164	0.310	19	4.0	52
2	0.003	0.0	0.002	0.0	0.024	0.005	0.029	1.5	0	14
3	0.0	0.0	0.002	0.0	0.022	0.002	0.024	0	0	4.2
4	0.002	0.0	0.001	0.0	0.020	0.003	0.023	2.0	0	10

*Stations 1, 2, and 3--One sample from each station.
Stations 4--Mean value of 3 replicates from station.

[a] $N = C_0N+C_1N+C_2N+C_3N+C_4N+C_5N$ (naphthalenes)
[b] $F = C_0F+C_1F+C_2F+C_3F+C_4F+C_5F$ (fluorenes)
[c] $P = C_0P+C_1P+C_2P+C_3P+C_4P+C_5P$ (phenanthrenes)
[d] $D = C_0D+C_1D+C_2D+C_3D+C_4D+C_5D$ (dibenzothiophenes)
[e] 4,5-PAH = $C_0Pyrn+C_1Pyrn+C_2Pyrn+C_3Pyrn+C_4Pyrn+C_5Pyrn+$ (pyrenes)
$C_0Chry+C_1Chry+C_2Chry+C_3Chry+C_4Chry+C_5Chry+$ (chrysenes)
$C_0Pery+C_1Pery+C_2Pery+C_3Pery+C_4Pery+C_5Pery$ (perylenes)

[f] PAH = N+P+F+D+4,5-PAH

[g] $$\text{FFPI} = \frac{N+P-(1/2\ (C_0P+C_1P))+D}{\text{Total PAH}} \times 100$$

retention of petroleum hydrocarbons, probably derived from produced water, in the fine-grained sediments near the platform.

All the mean LALK and TALK values for sediments from three of the stations 20 m from the platform (Stations 1, 9, and 13) have small standard deviations for the three replicate samples from each station (see Appendix C, Tables C1 through C16). The small standard deviations indicate that the ratios, and therefore the indications of the petroleum hydrocarbon source and concentration trends in sediments, are real and, unlike Station 5, are not influenced by a sample with an abnormally high hydrocarbon concentration.

Station 5 has the highest TALK concentration of all the stations at Eugene Island. One replicate sample from Station 5 has a total n-alkane concentration of 19 μg/g, whereas the other two replicates have concentrations of 1.3 and 1.7 μg/g. The C_{20} through C_{31} n-alkane concentrations in this one replicate are 20 to 30 times higher than those in the other two replicates. The high mean TALK causes the alkane diagnostic ratios for Station 5 to be different from those for all other stations.

The n-alkane distribution and diagnostic ratios of the produced water sample (Table 4.7) do not resemble those that were determined in sediments from all stations at Eugene Island, with the possible exception of Stations 1 and 9, 20 m from the platform. The fossil fuel indicator LALK compounds do not dominate the n-alkane hydrocarbons in sediments as they do in the produced water. Even in the sediments close to the platform (20 m), the relative concentrations of the LALK compounds bear only a slight resemblance to those in the produced water. This is undoubtedly due in part to the inverse relation between n-alkane chain length and aqueous solubility, and the differential biodegradation of alkanes with different chain lengths and odd versus even numbers of carbons. Thus, the LALK assemblage in sediments either represents the results of weathering of the source LALK assemblage, or indicates that th major source of LALK in sediments is not produced water.

Concentrations of total naphthalenes, fluorenes, phenanthrenes dibenzothiophenes, and 4- and 5-ringed PAHs, as well as the diagnostic ratios PAH/TOC (total polynuclear aromatic hydrocarbons/total organic carbon), N+P+D (naphthalenes plus phenanthrenes plus dibenzothiophenes), N/P, P/D, and FFPI for sediments from Eugene Island are presented in Tables 4.10 through 4.12. Values for the diagnostic ratios in sediment samples from the spring survey indicate that the input of petroleum hydrocarbons to the sediments at the site is very lo or negligible; only at stations closest to the platform (Stations 1, 5, and possibly 9) are there traces of petrogenic PAH.

Except at Stations 1 and 5, the range of N+P+D values in sediments from the study site is very low, 0.0 to 0.065 μg/g. PAH/TOC ratios (Table 4.10) are also slightly higher at Statio 1 and 5 than at other stations, suggesting that petrogenic PAH are present in sediments near the platform but not at distance of 100 m or greater from the platform. The N+P+D concentratio in sediments from Stations 1 and 5 are elevated to only 0.2 μg/g. All of the FFPI values for sediments from the study site except those for sediments from three of the stations 20 m from the platform, are in the range typical for uncontaminated sediments with values of 30 percent or less. The stations 20 m from the platform have values that are near the upper limit of the range of 10 to 35 which is typical of uncontaminated sediments. The N/P and P/D ratios indicate negligible amounts of fossil fuel input into the sediments of the study site. Non of the sediment diagnostic values resemble those calculated for the produced water (Table 4.8). However, the stations near the platform do possess elevated concentrations of naphthalenes tha may be derived from produced water discharges.

The results for samples collected during the fall survey (Table 4.12) confirm the observations made on samples from the spring survey (Table 4.11). Sediment samples from Station 1 (20 m) are the only samples collected in the fall survey that show any evidence of petroleum hydrocarbon input. As observed in the spring survey, the level of contamination is small. The sediments from the other three stations sampled in the fall survey do not contain significant amounts of petroleum hydrocarbons.

4.5.1.2.2 Lake Pelto. The n-alkane and PAH diagnostic parameters and ratios for Lake Pelto produced water and sediment collected during the spring survey are presented in Tables 4.7 through 4.10 and 4.13 through 4.14. The diagnostic values for sediments collected during the fall survey are given in Table 4.15. The values for the diagnostic parameters and ratios for produced water from Lake Pelto form the basis for interpreting the values for sediments from the site.

The diagnostic values for n-alkanes of Lake Pelto produced water (Table 4.7) show a dominance of the fossil fuel indicator LALK. The LALK account for about 75 percent of the TALK and about 10 percent of all resolvable alkanes in the sample.

Naphthalenes account for about 70 percent of the indicator semivolatile aromatic hydrocarbons in produced water from Lake Pelto, compared to about 95 percent in produced water from Eugene Island (Table 4.8). They make up about 10 percent of all resolvable aromatics (f_2) in produced water from Lake Pelto. The other indicator PAHs are better represented in produced water from Lake Pelto than from Eugene Island. Total fluorenes, phenanthrenes, and 4- and 5-ringed PAHs, in particular, are present at significantly higher concentrations in the Lake Pelto produced water than in Eugene Island produced water. Because of the high concentration of phenanthrenes in Lake Pelto produced

TABLE 4.13. ALKANE CONCENTRATIONS AND RATIOS IN SEDIMENT SAMPLES FROM LAKE PELTO, STATIONS 1-16, COLLECTED DURING THE SPRING SURVEY.

	Concentration (μg/g Dry Weight)			
Station	LALK[a]	TALK[b]	LALK/TALK	TALK/TOC[c]
1	1.04	1.32	0.79	0.25
2	0.578	1.07	0.54	0.23
3	0.679	1.46	0.46	0.32
4	0.364	1.54	0.24	0.31
5	0.721	3.16	0.23	0.85
6	0.247	0.471	0.52	0.12
7	0.147	0.563	0.26	0.15
8	0.130	0.638	0.20	0.17
9	0.531	1.11	0.48	0.17
10	0.447	1.22	0.37	0.29
11	0.315	0.941	0.33	0.14
12	0.438	2.44	0.18	0.29
13	0.741	1.08	0.69	0.24
14	0.643	3.66	0.18	0.63
15	0.324	1.05	0.31	0.22
16	0.644	1.97	0.33	0.25

[a] LALK = Sum of n-alkanes, C_{10}-C_{20}

[b] TALK = Sum of n-alkanes, C_{10}-C_{34}

[c] TOC = Total Organic Carbon (mg/g)

TABLE 4.14. CONCENTRATIONS OF PAH HOMOLOGOUS SERIES AND FOSSIL FUEL POLLUTION INDEX (FFPI) OF SEDIMENT SAMPLES FROM LAKE PELTO, STATIONS 1-16, COLLECTED DURING THE SPRING SURVEY.

	Concentration (µg/g Dry Weight)									
Station	N[a]	F[b]	P[c]	D[d]	4-,5-PAH[e]	N+P+D	PAH[f]	N/P	P/D	FFPI[g]
1	3.31	1.28	2.39	0.401	3.00	6.10	10.4	1.4	6.0	52
2	0.033	0.115	0.667	0.048	1.30	0.748	2.16	0.05	14	24
3	0.001	0.004	0.073	0.002	0.199	0.076	0.279	0.01	37	18
4	0.001	0.015	0.043	0.0	0.113	0.044	0.172	0.02	-	20
5	0.146	0.116	0.479	0.040	0.839	0.665	1.62	0.31	12	34
6	0.071	0.120	1.19	0.063	1.87	1.33	3.32	0.06	19	27
7	0.0	0.013	0.074	0.001	0.142	0.075	0.230	0.0	74	20
8	0.0	0.003	0.001	0.0	0.086	0	0.090	0.0	-	0.6
9	0.016	0.130	0.386	0.048	0.932	0.450	1.51	0.04	8	21
10	0.062	0.297	2.12	0.111	3.08	2.29	5.66	0.03	19	24
11	0.007	0.030	0.055	0.0	0.133	0.062	0.225	0.13	-	22
12	0.031	0.067	0.108	0.017	0.259	0.156	0.482	0.29	6.4	29
13	0.566	0.543	0.884	0.192	1.50	1.64	3.69	0.64	4.6	38
14	0.174	0.247	1.34	0.122	3.13	1.64	5.01	0.13	11	22
15	0.003	0.023	0.044	0.001	0.145	0.048	0.216	0.07	44	18
16	0.003	0.017	0.042	0.001	0.249	0.046	0.312	0.07	42	12

[a] $N = C_0N+C_1N+C_2N+C_3N+C_4N+C_5N$ (naphthalenes)

[b] $F = C_0F+C_1F+C_2F+C_3F+C_4F+C_5F$ (fluorenes)

[c] $P = C_0P+C_1P+C_2P+C_3P+C_4P+C_5P$ (phenanthrenes)

[d] $D = C_0D+C_1D+C_2D+C_3D+C_4D+C_5D$ (dibenzothiophenes)

[e] 4,5-PAH = $C_0Pyrn+C_1Pyrn+C_2Pyrn+C_3Pyrn+C_4Pyrn+C_5Pyrn+$(pyrenes)
$C_0Chry+C_1Chry+C_2Chry+C_3Chry+C_4Chry+C_5Chry+$(chrysenes)
$C_0Pery+C_1Pery+C_2Pery+C_3Pery+C_4Pery+C_5Pery$ (perylenes)

[f] PAH = N+P+F+D+4,5-PAH

[g] $$\text{FFPI} = \frac{N+P-(1/2\ (C_0P+C_1P))+D}{\text{Total PAH}} \times 100$$

TABLE 4.15. CONCENTRATIONS OF PAH HOMOLOGOUS SERIES AND FOSSIL FUEL POLLUTION INDEX (FFPI) OF SEDIMENT SAMPLES FROM LAKE PELTO, STATIONS 1 AND 13 THROUGH 15*, COLLECTED DURING THE FALL SURVEY.

Station	Concentration (µg/g Dry Weight)									
	N[a]	F[b]	P[c]	D[d]	4-,5-PAH[e]	N+P+D	PAH[f]	N/P	P/D	FFPI[g]
1	0.303	0.136	1.06	0.142	2.74	1.50	4.37	.297	7.4	25.6
13	1.55	1.62	1.74	0.333	3.56	3.62	8.80	.89	5.2	39
14	0.020	0.382	0.17	0.012	0.358	0.202	0.942	.112	14	15
15	0.0	0.0	0.027	0.0	0.161	0.027	0.188	0	0	7.2

*Stations 1--Mean value of 3 replicates from station.
Stations 13, 14, and 15--One sample from each station.

[a] $N = C_0N+C_1N+C_2N+C_3N+C_4N+C_5N$ (naphthalenes)
[b] $F = C_0F+C_1F+C_2F+C_3F+C_4F+C_5F$ (fluorenes)
[c] $P = C_0P+C_1P+C_2P+C_3P+C_4P+C_5P$ (phenanthrenes)
[d] $D = C_0D+C_1D+C_2D+C_3D+C_4D+C_5D$ (dibenzothiophenes)
[e] 4,5-PAH = $C_0Pyrn+C_1Pyrn+C_2Pyrn+C_3Pyrn+C_4Pyrn+C_5Pyrn+$(pyrenes) $C_0Chry+C_1Chry+C_2Chry+C_3Chry+C_4Chry+C_5Chry+$(chrysenes) $C_0Pery+C_1Pery+C_2Pery+C_3Pery+C_4Pery+C_5Pery$ (perylenes)

[f] PAH = N+P+F+D+4,5-PAH

[g] $$FFPI = \frac{N+P-(1/2\ (C_0P+C_1P))+D}{} \times 100$$

different in the two produced waters. However, the values for N/P, P/D, and FFPI in produced water from Lake Pelto are still strongly indicative of fossil fuel.

The n-alkane diagnostic ratios, LALK/TALK and TALK/TOC for sediments from Lake Pelto (Table 4.9) decrease with distance from the platform. Higher ratios are found more frequently at the inner stations 20 and 100 m from the platform than at the outer stations 300 and 1000 m from the platform. However, there are three stations (Station 5, 12, and 14) at Lake Pelto that do not conform to this trend. In each case, one of the three replicate samples has a much higher concentration of TALK than the other two. At Station 5, one replicate contains 7 μg/g TALK, whereas the other two replicates contain approximately 1.5 μg/g. A Station 14 replicate contains 9 μg/g TALK, whereas the other replicates contain about 1.0 μg/g. The concentration of the C_{24} n-alkane alone in this replicate is 4.2 μg/g. One replicate sediment sample from Station 12 contains 5.1 μg/g TALK, compared to 1.0 μg/g in the other two replicates.

In each of the sample replicates with high concentrations of TALK, the concentrations of C_{19} through C_{30} n-alkanes are about an order of magnitude higher than the concentration of these alkanes in the other replicates. The predominance of C_{23} through C_{31} n-alkanes, especially when coupled with a predominance of odd over even n-alkanes, usually indicates hydrocarbons of terrigenous origin. The n-alkane assemblage in produced water is dominated by the C_{10} through C_{20} n-alkanes and has a LALK/TALK ratio of 0.75. LALK/TALK ratios for the replicate sediment samples from Stations 5, 12, and 14 with high TALK concentrations are approximately 0.10. With the exception of these samples with high TALK concentrations, the trend in the LALK/TALK diagnostic ratio (Table 4.9) indicates that there is some input of petroleum hydrocarbons to sediments close to the platform (20 m). The trend in the TALK/TOC ratio is less definitive, but still indicates an input of petroleum hydrocarbons.

The presence of petroleum hydrocarbons in sediments at the Lake Pelto study site is further and probably better confirmed by th PAH distributions and ratios. In Table 4.14, the diagnostic parameters and ratios are presented for sediments from each station sampled in the spring survey. The concentrations of naphthalenes, fluorenes, phenanthrenes, and dibenzothiophenes are highest in sediments from stations 20 or 100 m from the platform. In fact, the combined N+P+D concentrations are usually at least an order of magnitude higher in sediments from the inner stations 20 and 100 m from the platform than in sediments from the outer stations 300 and 1000 m from the platform, and decrease dramatically between the stations 100 an 300 m from the platform. Values for N+P+D at the inner station range from 0.45 to 6.1 μg/g, whereas values for the outer stations range from 0.0 to 0.156 μg/g. The same dramatic change between samples from the 100-m and 300-m stations is evident in the N/P and P/D ratios.

These trends in the diagnostic values for sediments collected during the spring survey are also evident for sediment samples collected during the fall survey (Table 4.15).

An interesting aspect of the PAH composition of produced water and sediments from Lake Pelto is the large contribution of 4- and 5-ring PAHs to the total PAH assemblage. Pyrene, chrysene, and perylene usually are indicators of pyrogenic PAH assemblages; however, these PAH are also present at elevated concentrations in the produced water from Lake Pelto. Produced water from Lake Pelto contains 5.8 μg/l total 4- and 5-ring PAH representing 4 percent of the total targeted PAHs in the produced water. The 4- and 5-ring PAHs are also found at high concentrations in sediments near the platform (20 m and 100 m). As for other hydrocarbons, concentrations of 4- and 5-ring PAH in sediments tend to decrease with distance from the platform.

Diagnostic parameters for sediments collected near the platform are similar to those for produced water from the platform. All the parameters and ratios except possibly the FFPI indicate that petroleum hydrocarbons are present in Lake Pelto sediments. The elevated concentrations of petroleum hydrocarbons in sediments within about 100 m of the platform, but not at stations further away indicate that these hydrocarbons are probably from platform discharges. The relatively high concentration of 4- and 5-ringed PAHs in the sediments at the inner (20 m and 100 m) stations influence the interpretation of the FFPI. The values for this index for sediments from stations near the platform are low and, taken alone without reviewing the other diagnostic parameters, would indicate that the sediments contain primarily non-petroleum PAH. A possible reason for the relatively low FFPI at the inner stations is the preferential deposition of 4- and 5-ring PAH near the source because of their lower solubility in water. Armstrong et al. (1979) also reported a preferential retention of high molecular weight PAH over lower molecular weight PAH in sediments near a produced water discharge to a shallow bay in Texas.

4.5.2 Steranes, Triterpanes, and Phenols

4.5.2.1 Distribution Patterns

Steranes and triterpanes were analyzed in sediments from four stations along one transect, and phenols were analyzed in sediments from all four stations 20 m from each platform. At both platforms, the concentrations of steranes and triterpanes in sediments were higher at the 20-m station than at stations further from the platform. However, there was not a clear gradient of decreasing sterane or triterpane concentrations in sediments with distance from either platform. Sterane and triterpane concentrations were higher in sediments from Lake Pelto than from Eugene Island. Apparent background concentrations of total steranes at Eugene Island and Lake Pelto were 0.09 to 0.18 and 0.30 to 0.45 μg/g, respectively. Apparent background concentrations of total triterpanes were 0.27 to 0.3 and 1.1 to 1.4 μg/g at Eugene Island and Lake Pelto, respectively.

The relative abundances and diagnostic ratios of different steranes in sediments are quite different than those in the produced water. These differences are more pronounced at Eugene Island than at Lake Pelto. These results indicate that produced water may not be the sole or even major source of steranes in sediments around the platforms.

There were slight differences in the diagnostic "maturity ratio for triterpanes in produced water and in sediments, particularl at Eugene Island, indicating a degree of similarity in the triterpanes in sediments and produced water at both platforms. However, there were many more triterpanes in the sediments than in the produced water. The sediment triterpanes were dominated by biogenic compounds such as diplotene, indicating a recent biogenic origin for a significant portion of the sediment triterpane assemblage (Seifert and Moldowan, 1979). The triterpane assemblage in sediment from the station 20 m from th Lake Pelto platform resembled that in produced water from the platform, indicating that the triterpanes in sediment from this station were derived in part from produced water.

Total phenols were detected in sediments from all four stations at 20 m from each platform at concentrations ranging from 448 t 12,700 ug/kg. However, the distribution of alkyl homologues in sediments did not resemble that in produced water from the two platforms. The phenol assemblage in sediments from both platforms was dominated by phenol, with only small amounts of one or more alkyl phenols present in some samples. The C_3-phenols were the most abundant alkyl phenols in all replicate sediment samples from all stations. By comparison, the dominant alkyl phenols in produced water from both platforms were the m-and p-cresols. These differences may indicate that the sediment phenols were not derived primarily from produced water discharges, or that the phenols had undergone fractionation and selective biodegradation following discharge.

Phenols can be derived from a multitude of natural biogenic as well as anthropogenic sources (Buikema et al., 1979). Phenol is very soluble (~66,000 mg/l), whereas the solubility of alkyl phenols decreases markedly with increasing degrees of alkylation. Therefore, if phenols from produced water were accumulating in sediments, we would expect the phenol assemblage in sediments to be greatly enriched in the more highly alkylated phenols compared to the produced water source. Most phenols are readily biodegraded by microorganisms present in most aquatic ecosystems (Buikema et al., 1979). However, the rate of biodegradation is homologue-specific. More highly alkylated phenols probably are biodegraded more slowly than phenol and cresols. A variety of hindered phenols are used as antioxidants in a wide variety of industrial and food products. These antioxidants have become nearly ubiquitous contaminants in freshwater and marine environments (Gusten et al., 1973), and appear to be resistant to biodegradation. Anthropogenic antioxidants may contribute to the C_3-phenols detected in all sediment samples.

4.5.3 Metals

4.5.3.1 Distribution Patterns

Of the nine metals analyzed in sediments from the vicinity of both platforms, only barium and mercury were present in sediments from some stations at concentrations higher than would be expected for natural clean sediments (Table 4.16). Although barium may occur naturally in clean natural sediments at concentrations as high as 8000 $\mu g/g$, most marine sediments contain less than about 1000 $\mu g/g$. According to Boothe and

TABLE 4.16. COMPARISON OF TYPICAL CONCENTRATIONS (μg/g) OR CONCENTRATION RANGES OF NINE METALS IN CLEAN NEARSHORE MARINE SEDIMENTS AND IN SEDIMENTS COLLECTED AT STATIONS AROUND THE PLATFORMS AT EUGENE ISLAND, BLOCK 105 AND LAKE PELTO, TANK BATTERY NO. 1 DURING THE SPRING AND FALL SURVEYS.

Metal	Marine Sediments[1]	Eugene Island	Lake Pelto
Barium	80-8,100	528-2,270	864-5,040
Cadmium	0.3-1.0	0.015-0.118	0.068-0.480
Chromium	10-200	4.32-17.93	4.96-13.60
Copper	8-700	1.66-8.17	4.34-14.22
Lead	6-200	4.44-94.16[2]	5.37-26.6
Mercury	0.1-0.2	0.010-0.234	0.010-1.021
Nickel	30-70	6.71-18.6	5.63-15.1
Silver	0.06	<0.005-0.034	<0.005-0.140
Zinc	5-4,000	24.3-61.3	32.4-114.9

[1] From Forstner and Wittmann (1983) and Salomons and Forstner (1984).

[2] Value for one replicate. Other replicates contained less than 5.0 μg/g lead.

Presley (1985), background concentrations of barium in sediments of the Gulf of Mexico range from less than 200 to about 800 μg/g dry weight. Barium concentrations were higher in sediments from Lake Pelto than from Eugene Island. However, no gradients of decreasing barium concentrations in sediments with distance from the platform were detected at either platform. The highest sediment barium concentration (5040 μg/g) was detected in sediment collected from Station 1 (20 m southwest of the platform) at Lake Pelto during the fall survey. However, mean concentrations of 2500 μg/g or higher were detected in sediments from at least one station from each ring around the platform at Lake Pelto. At Eugene Island, the highest mean concentrations of barium in sediments were from stations located 300 and 1000 m south of the platform. These results suggest that barium contamination of sediments is general throughout the area around the platforms at Eugene Island and especially Lake Pelto. This barium could be derived from drilling mud discharges or from produced water discharges. Some of the "excess" barium could also have been derived from the Mississippi River outflow. Chan and Hanor (1982) detected higher concentrations of dissolved barium in coastal water from the central Louisiana coast than in water from the open Gulf of Mexico, and attributed it to desorption of barium from river-borne suspended material during natural processes of estuarine mixing.

The elevated levels of mercury in sediments at Lake Pelto and to a lesser extent at Eugene Island are more difficult to explain. Concentrations of mercury in produced water from both platforms were only slightly higher than typical background mercury concentrations in seawater. Therefore, the excess mercury in sediments probably was not derived from produced water discharges.

Boothe and Presley (1985) detected elevated concentrations of mercury in sediments near two production platforms located in 76 and 79 m of water off Louisiana. Elevated mercury concentrations were correlated with elevated barium concentrations and the investigators concluded that the mercury was derived from mercury-contaminated barite discharged with drilling muds. In the present investigation, the correlation between concentrations of mercury and barium in sediments from Lake Pelto was fairly low ($p \geq 0.2$), indicating that much of the mercury in sediments was from a source other than barite. Othe possible sources of mercury in sediments of Terrebonne Bay are the Mississippi River outflow, sacrificial anodes on metal platform and work boat structures, and mercurial biocides that might have been used in the past for produced water treatment. At Eugene Island, mercury concentration was elevated in only o sediment sample from the fall survey (Station 3, located 300 m west of the platform).

There were no consistent gradients of metal concentrations in sediments with distance from either platform. At Lake Pelto, concentrations of some metals (chromium, nickel and silver) sh a tendency to increase with distance along some transects whereas there is some indication of a decrease in concentratio of some other metals (cadmium, lead, mercury, and zinc) with distance from the platform. At Eugene Island, concentrations o cadmium, copper, lead, nickel, and zinc in sediments tended to decrease with distance from the platform along one or more transects. These apparent gradients were small in all cases an may be related more to the distribution of sediment grain size and TOC around the platform than to discharges from the platform.

4.5.4 Benthic Infauna

4.5.4.1 Distribution Patterns

There were many unusual features of the benthic communities around the platforms at Eugene Island and Lake Pelto. At both locations, the fauna was dominated by one species, *Mediomastus* ambiseta, at all stations. The dominant taxa at all stations were short lived, opportunistic species such as the polychaetes M. ambiseta and Streblospio benedicti and the bivalve mollusc Mulinia lateralis. Juvenile forms were very abundant, representing more than 50 percent of the total number of individuals of several species at many stations. These features of the benthic communities at both platforms are characteristic of communities under natural environmental or pollutant stress (Boesch and Rosenberg, 1981).

Benthic communities with many of the same characteristics were described by Gaston (1985) and Gaston et al. (1985) off Cameron, Louisiana, by Shaw and Vittor (1985) in Chandeleur and Breton Sounds east of the Mississippi River delta, and by Armstrong et al. (1979) in Trinity Bay, Texas. Benthic fauna at two sites off Cameron, Louisiana in 10 m of water resembled the benthic fauna at Eugene Island in 8.5 m of water. Several species, including the polychaetes M. ambiseta (identified as M. californiensis), Nereis (Neanthes) micromma, and Paraprionospio pinnata, and the bivalves M. lateralis and Tellina versicolor, were abundant at both locations. Gaston et al. (1985) also reported that the benthic fauna off Cameron, Louisiana, was dominated by juveniles, and attributed the apparently stressed fauna to seasonal hypoxia of the bottom water in the area.

Shaw and Vittor (1985) reanalyzed 49 benthic infaunal samples from the 1970-71 Chevron Main Pass Oil Spill Study and 100 samples from the 1980-81 Mississippi River-Gulf Outlet Survey. These samples were from stations located throughout Chandeleur and Breton Sounds at water depths from about 5 to 100 m. The three top dominants in samples collected in 1981 during the Mississippi River-Gulf Outlet Survey were Mediomastus sp., Mulinia lateralis, and Spiophanes bombyx, all among the top five dominant species at Eugene Island in the spring. The cumacean Oxyurostylis sp., the second most abundant species at Eugene Island in the spring, was the twelfth most abundant species in the 1981 Mississippi River-Gulf Outlet samples. The Chevron samples were processed with a relatively coarse (1.2 mm) sieve Nevertheless, seven of the top 15 dominant species from the Chevron samples were among the 15 top dominant species in the spring samples from Eugene Island. Thus, there is a great similarity between the benthic communities at Eugene Island, Block 105, and Chandeleur and Breton Sounds. The authors did n suggest any reasons for the composition of the benthic communities in Chandeleur and Breton Sounds.

Dominant infauna in Trinity Bay, Texas, included the polychaet *Mediomastus ambiseta* (identified as *M. californiensis*), *Streblospio benedicti*, and oligochaetes (including *Peloscolex gabriella*) (Armstrong et al., 1979). These taxa were also dominant in sediments at Lake Pelto. Both locations are semienclosed bays with water depths of about 2 m. The stressed fauna of Trinity Bay was attributed to periodic low salinity which dropped to about 2 ppt during periods of maximum outflow of the Trinity River. There was no evidence of periodic hypoxi bottom water in Trinity Bay.

The reasons for a benthic fauna dominated by opportunistic species and juvenile life stages at Eugene Island and Lake Pel are not known. Although hypoxic bottom water was not documente at either location in the present or other investigations, it possible that transient episodes of bottom water hypoxia occurred at either or both sites sometime before the spring survey and during the six month interval between the spring an fall surveys. There are no major river inflows to Terrebonne Bay, so it is unlikely that salinity of bottom water around th Lake Pelto platform would fluctuate enough on a seasonal basis to stress the resident benthic communities. Many of the specie that were represented primarily by juveniles at the two study sites are relatively short-lived, rapidly maturing species. Thus, the abundance of juvenile forms of these species in both the spring and fall samples indicates that the disturbance(s) controlling infaunal community structure and age composition are periodic, recurring events that prevent the development of a more persistent community.

It is unlikely that the disturbance influencing benthic community structure throughout the area around the two platforms is produced water discharges or past discharges of drilling muds alone. However, superimposed on the general area-wide community structure of the benthic fauna are indications of altered community parameters at some stations near the platforms.

There were substantial differences in benthic faunal community structure at both Eugene Island and Lake Pelto between the spring and fall surveys. These seasonal fluctuations in the species composition and relative abundance of different species in the community are typical of polyhaline muddy or fine sand bottom communities of estuaries and shallow coastal waters (Boesch et al., 1976). Opportunistic species exhibit great reproductive potential, rapid growth and maturation and high mortality. They are adapted to exploit variable, unpredictable habitats and their abundance in any location varies widely. Benthic communities composed primarily of opportunists often are quite productive, with a rapid production and turnover of biomass (Rhoads et al., 1978; Boesch and Rosenberg, 1981).

Given the variability of such communities, the question arises whether it is possible to detect anything but a massive impact of produced water discharges on benthic community structure. Certainly, it is more difficult than if the communities under investigation were highly diverse, stable, and long-lived. In designing the present investigation, we predicted that, if chronic discharges of produced water were producing an impact in the benthos, this impact would be discernible as a gradient in benthic community structure with distance from the platform or level of contamination of the sediments with chemicals derived from produced water. The statistical evaluations of the infaunal data performed in this investigation should be able t discern any gradients that might occur.

4.5.4.1.1 Eugene Island, Block 105, Platform A. At Eugene Island, faunal density was greatest near the platform and decreased with distance from the platform. However, diversity was lower near the platform than at stations farther away. The trends were due to the fact that the fauna at the inner static was dominated by the polychaete *Mediomastus ambiseta*. Similari analysis revealed that the benthic fauna of the four stations m from the platform were similar to one another and different from the fauna at stations further away. The results of the fa survey revealed that many of the juveniles present in the spri did not survive until the fall, but were replaced by new juveniles of the same and different species. Diversity and abundance patterns were the same in the fall as in the spring. However, because of changes in the composition of the secondar infaunal species, the fall samples did not cluster by NESS wi the spring samples.

These characteristics of the distributions of benthic communities in sediments around the platform can be explained part by the influence of sediment grain size on benthic community structure. There was a strong correlation between faunal density and percent silt plus clay ($p<0.01$). There was also a strong correlation between the concentration of total hydrocarbons and percent silt plus clay in sediments around th platform at Eugene Island ($p<0.01$). However, there was no correlation between faunal density and the concentration of total hydrocarbons in sediments. These results suggest that, a Eugene Island, Block 105, the distribution and composition of benthic communities around the platform was influenced more by gradients of sediment grain size than by any concentration gradients in sediments of contaminants derived from produced water discharges. If produced water discharges were influencin infaunal community structure, this effect was minor and restricted primarily to within 20 m of the platform.

4.5.4.1.2 Lake Pelto, Tank Battery No. 1. The gradient of decreasing sediment grain size with distance from the platform obscured any gradients that might have existed in the benthic fauna because of impacts of produced water discharges. As a general rule, benthic communities at Lake Pelto were more diverse than benthic communities at Eugene Island. Highest diversities were recorded at stations that had coarse sediments near the platform. There was no clear relationship between distance from the platform and density of the benthic infauna.

As at Eugene Island, *Mediomastus ambiseta* was the dominant infaunal taxon at all stations around Lake Pelto in both the spring and fall. However, it accounted for a greater percentage of the total faunal density at stations away from the platform than at stations near the platform. At the stations 20 m from the platform, the polychaete *Streblospio benedicti* was the second most abundant species in the spring. This species was less abundant at stations further from the platform in the spring and was absent from all four stations analyzed in the fall. A similar pattern of distribution and relative abundance of these two polychaete species was observed around the C-2 separator platform in Trinity Bay, Texas (Armstrong et al., 1979). In that study, *S. benedicti* was the dominant species at stations closest to the discharge, whereas it was replaced as the most abundant species by *M. ambiseta* (*M. californiensis*) at stations further away from the platform.

The mean percent juveniles in the total infauna at different stations ranged from 25.2 to 52.9 percent in the spring and from 24.2 to 35.8 percent in the fall. There was no relationship between percent juveniles and distance from the platform. Of the top three dominants in the spring, *Streblospio benedicti* and *Mulinia lateralis* were represented primarily by juveniles at all but one station at 1000 m, whereas *Mediomastus ambiseta* was represented primarily by adults. This situation was also the case in the fall, except that *S. benedicti* was no longer presen at any stations. These results imply a rapid and continual recruitment of juveniles at all stations around the platform at Lake Pelto. However, the juveniles rarely persisted to adult stages, and some taxa were replaced by others in different seasons.

Cluster analysis revealed that two of the stations at 20 m (Stations 1 and 13) were very similar to one another. Station 5 was the least like the other stations at 20 m. The two stations analyzed at 1000 m were quite different from all the other stations sampled in the spring. This pattern of distribution of infaunal communities slightly resembled the pattern of distribution of sediment grain size. However, there was not a statistically significant correlation between percent silt plus clay in sediments and species density or diversity ($p=0.2$). Samples from the fall survey clustered separately from all samples from the spring survey, reflecting the changes in the composition of the dominant infauna from spring to fall. Stations 1 and 13 (20 m) resembled each other more than they resembled the stations at 100 and 300 m analyzed in the fall.

Sediments from Stations 1, 9, and 13 had the highest concentrations of total hydrocarbons, and sediments from Stations 1 and 13 contained the highest concentrations of total PAH and highest FFPI values, indicating, particularly in the case of Station 1, petroleum contamination of the sediments. However, there was not a significant correlation between any biological diversity or density parameters and concentrations o total hydrocarbons or PAH in sediments at Lake Pelto. Nevertheless, the distinct infaunal community structure at Stations 1 and 13 could be due in part to sediment contaminated with hydrocarbons from produced water discharges.

4.6 CONCLUSIONS

4.6.1 Produced Water

One of the objectives of this project was to determine the chemical composition and variability over time of produced water from a few offshore platforms in the Gulf of Mexico. The analyses performed have produced a much more complete picture of produced water composition than was available previously. In particular, the data on polycyclic aromatic hydrocarbons, steranes, triterpanes, and phenols in produced water are unique. The data on concentrations of nine metals in produced water are probably more accurate than any published data.

However, we experienced difficulty in characterizing the naphthenic acid fraction of produced water. Additional research should be performed to improve methods for derivatizing these compounds and identifying their methyl esters in gas chromatograms. We were able to establish that the f_3 fraction contained a wide diversity of polar organic compounds, including naphthenic acids, some of them at relatively high concentrations. Characterization of this polar organic fraction of produced water, which according to Lysyj (1982) may contain most of the organic carbon in produced water, will require a dedicated research effort.

Based on the limited comparative data available, it was concluded that produced water from the two platforms that were the focus of this investigation is fairly typical of produced waters from wells in the Gulf of Mexico and elsewhere in the U.S. It does not contain substantially higher or lower concentrations of any of the target organic compounds or metals than produced water from other sources. Salinity and total organic carbon concentrations are also similar to those of produced waters from other sources. Therefore, it can be inferred that the impacts of discharges of produced water from these platforms will be similar to impacts of produced water discharges from other platforms at similar water depths, assuming that the rates of produced water discharge are simila

4.6.2 Chemicals and Fauna in Sediments

The major focus of this project was to determine the distribution in sediments of contaminants derived from long-te produced water and drilling mud discharges, and to characteriz the patterns of benthic infaunal community structure around tw offshore production platforms. The data were analyzed to determine if there was any relation between either sediment contamination or distance from the platform on the one hand, a benthic community parameters on the other.

There is a relatively high "background" of total hydrocarbons, total n-alkanes, and to a lesser extent total PAH in sediments around both platforms. This background includes petrogenic, pyrogenic, and biogenic/diagenic hydrocarbons and probably is derived in large part from a combination of the Mississippi River outflow and the extensive petroleum production activitie occurring in the area. Superimposed on this background are low to moderate concentrations of hydrocarbons in sediments near t platforms that appear to have been derived from platform discharges, probably produced water.

At Eugene Island, Block 105, sediments from stations 100 m or farther from the produced water discharge did not contain greater than trace or background quantities of petroleum hydrocarbons. Sediments from stations 20 m from the platform contained low concentrations of petroleum hydrocarbons. Thus, can be concluded that discharges of produced water at a rate o about 1570 bpd (250,000 l/d) to inner continental shelf waters with a depth of about 8.5 m has resulted in a low to moderate level of contamination of surficial sediments with petroleum hydrocarbons out at least to 20 m but not to 100 m from the platform.

At Lake Pelto, Tank Battery No. 1, sediments out to at least 100 m but not as far as 300 m from the platform contained petroleum hydrocarbons, probably derived from produced water discharges. Sediments from stations nearest the produced water discharge contained higher concentrations of petroleum hydrocarbons than sediments from stations further away. Thus, we can conclude that discharges of produced water at a rate of about 2750 pbd (437,000 l/d) to a shallow, partially enclosed bay with a water depth of about 2 m have resulted in a low to moderate level of contamination of surficial sediments with petroleum hydrocarbons out at least to 100 m but not as far as 300 m from the platform.

Steranes and triterpanes, although present in produced water at elevated concentrations, have limited use at the present time as tracers of the fate of produced water discharges in the marine environment. This is because it is difficult to separate and differentiate the steranes and triterpanes that are unique to petroleum from those that are ubiquitous components of marine sediments. By identifying and characterizing unique features of the sterane and triterpane assemblages in produced water, it will be possible to use them effectively as tracers of produced water discharges.

Evaluation of the sediment metals data does not reveal any consistent patterns of distribution or abundance of any metal around either platform. This may be because of a strong influence from the Mississippi River outflow, and continual reworking and redistribution of sediments around both platforms due to seasonal storms. The elevated concentrations of barium in sediments throughout the area around both platforms probably were derived in part from drilling mud and produced water discharges from the platforms being surveyed and from other platforms in the area. The origin of the elevated mercury in sediments at several stations near the Lake Pelto platform are unexplained. The distribution of mercury around the platform suggests that at least part of it was derived from the platform. The source probably was not produced water or drilling mud discharges. Several other metals show minor gradients within the range of normal background values of decreasing concentration with distance from the platform along some transects. Produced water discharges could have contributed to these gradients. If so, the contribution of the produced water discharges to the concentrations observed was small.

The benthic fauna at both Eugene Island and Lake Pelto are pioneer communities characteristic of disturbed marine and estuarine environments. The nature of the disturbance is unclear. At the offshore site it may be periodic hypoxia of the bottom water, which is known to occur each summer in the general area but not specifically in Block 105 of Eugene Island. There is little documentation of seasonal hypoxic events in the shallow bays along the Louisiana coast and they are much less likely to occur there than in offshore waters because of the generally good mixing and lack of stratification in these shallow bays. Therefore, the nature of the disturbance at Lake Pelto is not known. Several other investigations have revealed that pioneer communities resembling those described at Eugene Island and Lake Pelto are widespread on the shallow inner continental shelf and coastal bays and estuaries all along the northern and northwestern Gulf of Mexico. The wide distribution of these benthic communities would suggest that it is the Mississippi River outflow with its massive load of suspended particles that represents the major "disturbance" controlling benthic community structure throughout the region.

The distribution in sediments around the two platforms of contaminants, probably derived from produced water discharges, and of benthic communities is influenced by the patterns of distribution of sediment grain size. The available evidence indicates that sediment texture has a greater influence on benthic community structure than contaminant concentrations in sediments, even at stations close to the platforms. Nevertheless, there is an indication that benthic communities within about 20 m of both platforms are influenced by sediment contamination.

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