Exxon Valdez Oil Spill
Restoration Project Final Report

Recovery of Pink Salmon Spawning Areas after the *Exxon Valdez* Oil Spill

Restoration Project 97194
Final Report

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Study History: Restoration Project 97194 was initiated in 1997 (Pink Salmon Spawning Habitat Recovery) and was funded for close out in 1998. This project examined the level of oil contamination in pink salmon streams in 1989-90 and 1995 by analyzing sediment samples collected in 1989-90 by ADFG (Oil Spill Response) and similar samples collected in 1995 by the Auke Bay Laboratory. A journal article regarding the project's principal findings has been submitted for publication to the Transactions of the American Fisheries Society.

Abstract: To assess recovery of pink salmon (*Oncorhynchus gorbuscha*) spawning habitat in Prince William Sound after the *Exxon Valdez* oil spill, we analyzed sediment samples from stream deltas from 1989-1991 and 1995. In 1989, petroleum hydrocarbon concentration at 172 stream deltas (1-8 samples each) was bimodally distributed: 85 deltas had no detectable petroleum hydrocarbons (detection limit 2 μg/g); 87 deltas had 2-45,000 μg/g. In 1995, petroleum hydrocarbons were still detected at eight of nine oiled streams we resampled, with mean concentration up to 242 μg/g. The polynuclear aromatic hydrocarbon (PAH) fraction was also analyzed to determine origin and toxic potential. The PAH in 1995 consisted mostly of the more toxic compounds with high molecular weight. Composition was consistent with weathered *Exxon Valdez* oil, and total PAH concentration ranged up to 1,300 ng/g. Interpolation between 1989 and 1995 indicated that PAH concentration exceeded 3,800 ng/g (minimum sediment concentration that reduces salmon embryo survival in the laboratory) at some stream deltas through 1993, but all streams were below this level by 1994. We conclude that tidal leaching of residual PAH into incubation substrate could explain persistent impaired embryo survival in pink salmon through 1993, and that spawning habitat had recovered by 1994.

Key Words: *Exxon Valdez*, intertidal, oil spill, pink salmon, polycyclic aromatic hydrocarbons, Prince William Sound, spawning habitat, stream.

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EXECUTIVE SUMMARY

Introduction

The *Exxon Valdez* oil spill in Prince William Sound (PWS), Alaska, in March 1989 contaminated 2,000 km of coastal habitat. Contamination of intertidal spawning areas for pink salmon (*Oncorhynchus gorbuscha*) caused increased embryo mortality and possible long-term developmental and genetic damage. Most wild PWS pink salmon spawn in intertidal stream deltas, and therefore, were susceptible to a marine oil spill. The embryo, a critical stage of salmon development, was vulnerable because of its long incubation in intertidal gravel and its large lipid-rich yolk which will accumulate petroleum hydrocarbons from low-level, intermittent exposures.

Residual oil from a spill can remain toxic for long periods because the most toxic components are the most persistent. Petroleum is a complex mixture of alkanes and aromatic hydrocarbons, of which the alkyl-substituted and multi-ring polynuclear aromatic hydrocarbons (PAH) that predominate in weathered oil are the most toxic. These lipophilic PAH may cause physiological injury if they accumulate in tissues after lengthy exposure.

Pink salmon embryos in oiled PWS streams continued to show increased mortality compared to non-oiled streams through 1993, more than 4 years after the oil spill, but appeared to have recovered in 1994 (Bue et al. 1998). No significant difference in embryo mortality between oiled and non-oiled streams was detected in 1994, 1995, or 1996 (Bue et al. 1998; Craig et al. 1998). Possible causes of the persistent elevated mortality were 1) physiological injury from continuing exposure to residual oil; 2) genetic damage incurred in the initial acute exposure in 1989-1990; and 3) inherent differences between habitat conditions and fish stocks at oiled and non-oiled streams.

The objectives of this study were to assess the recovery of spawning habitat and examine the hypothesis of continuing exposure of salmon embryos to residual oil.

Methods

To assess habitat recovery, we analyzed sediment samples from 172 PWS stream deltas from 1989-1991 and resampled 12 streams in 1995. Most samples were from archived sediment samples taken by the Alaska Department of Fish and Game (ADFG) in August-November 1989 to document oil contamination. At each of 172 streams, ADFG took at least one sediment sample from the intertidal area near or in the stream channel. At seven "benchmark" streams, ADFG mapped the delta to show the distribution of oil and location of fixed sample plots. Besides the extensive 1989 samples, the ADFG also took a small number of samples in August 1990 and March 1991 during cleanup and monitoring activities. The 1989-1991 samples were stored frozen in hydrocarbon-free glass jars until we acquired them in 1995.

In March 1995, we resampled 12 stream deltas, including all seven ADFG benchmark streams. Ten of these streams were considered to be contaminated by oil in 1989; however, based on analysis of the 1989 samples, we reclassified one stream as "non-oiled" because it had no detectable petroleum hydrocarbons. We also resampled two non-oiled stream as controls, resulting in a total of nine oiled streams and three non-oiled streams. At each stream, we took at least three sediment samples from the stream delta, one each from the upper, middle, and lower intertidal zone. At the seven benchmark streams, we sampled at the same fixed plots as in 1989. Samples were taken with hydrocarbon-free spoons from pits (5-30 cm deep) and frozen until analyzed.

All samples were first screened by ultraviolet fluorescence to measure total concentration of petroleum hydrocarbons (method detection limit, 2 μg/g). Selected samples with detected oil were then analyzed by gas chromatography/mass spectroscopy (GC/MS) to determine origin, state of weathering, and potential for continuing toxicity. Total PAH (TPAH) concentration was calculated as the sum of all measured PAH except perylene (produced by diagenesis). We used a regression of TPAH on TPHC to estimate TPAH for samples that were not analyzed by GC/MS.

Results And Discussion

In 1989, TPHC at the 172 streams ranged from below the method detection limit of 2 μg/g to over 45,000 μg/g. About one-half of the deltas (51%) had detectable petroleum hydrocarbons (TPHC: 2 to 45,000 μg/g; TPAH: up to 900,000 ng/g). Oiling depended on location and orientation of streams in the oil trajectory. Stream deltas with a high TPHC were typically located on northeast shorelines and points exposed to prevailing southwesterly currents. Streams with no detectable oil were often located in bays oriented away from currents or protected behind points of land. Maps of the benchmark streams showed that oil was distributed on stream deltas in large patches of varying thickness. Heavy oil patches were 3-28 cm thick, and had a TPAH concentration >100,000 ng/g. The heaviest deposits were often in the mid- to upper intertidal zone ("Bathtub Ring").

Data for 1990 and 1991 were limited but indicated continued oil contamination. Samples from the stream bank in 1990 at 10 streams (one sample per stream) had a TPHC of 12,000 to 37,500 μg/g. In 1991, a single sample from the stream bank had a TPHC of over 5,000 μg/g. The TPHC at 6 of the 10 stream deltas in 1990 was greater than in 1989. The increase at these sites between 1989 and 1990 could be a spurious result of the small number of samples, or it could be due to remobilization of stranded oil during 1989-1990 winter storms.

In 1995, petroleum hydrocarbons were detected in sediment at eight of the nine oiled streams. Mean TPHC ranged from 6 to 242 μg/g; TPAH exceeded 100 ng/g at five streams and 1,000 ng/g at three streams. Oil concentration was low in most areas but with patches of higher concentration at some streams. The pattern of PAH relative concentrations indicated *Exxon Valdez* oil in a moderately to highly weathered condition, depleted in PAH with low molecular weight, such as naphthalenes. Phenanthrenes and chrysenes were comparatively abundant, and within homologous series, the more-substituted components were more abundant. Thus, although TPAH concentration had decreased greatly by 1995, the residual PAH consisted of the alkyl-substituted and multi-ring PAH, which are the most toxic components of oil (Rice et al. 1977; Black et al. 1983).

At the nine oiled streams sampled in 1995, mean TPHC declined by more than 98% between 1989 and 1995, at an average annual rate of 70% ± 3%. Differences in recovery rate among streams probably resulted from many factors, particularly the degree of protection in bays from storm surges. The lowest annual rate for stream deltas (55%) was in a protected southeast-facing bay, whereas the highest rate (82%) was at an exposed northwest shore.

Interpolation between 1989-1991 and 1995 based on assumed exponential decay indicated persistent high levels of TPAH at oiled streams through at least the fall of 1993. Interpolated TPAH concentration was still more than 3,800 ng/g (the lowest TPAH sediment concentration shown to reduce salmon embryo survival in the laboratory) at some stream deltas in fall 1993, but all streams were below this level in 1994. These results could explain why other Trustee-funded studies found pink salmon embryo mortality at oiled streams to be greater than at non-oiled streams through the fall 1993, but not significantly different in 1994, 1995, or 1996 (Bue et al. 1998; Craig et al., in press).

The likely mechanism for continuing exposure of salmon embryos to residual oil involves tidal leaching of PAH from weathered oil deposits in the stream delta and transport to salmon redds via interstitial water during ebb tide. Interstitial water flow in intertidal salmon redds is variable, but basic to the question of how oil spilled into the marine environment affects salmon eggs. On a falling tide, water from the hydrated, contaminated sides of a stream can flow interstitially down slope and into the salmon redds. As the tide ebbs further, freshwater flow returns, dominated by uncontaminated upstream water.

Obtaining an accurate measure of the PAH concentration to which salmon embryos were exposed in intertidal streams is impossible. Sampling of wetted streambed sediment does not measure actual exposure levels because direct oil contamination from stream sediments is unlikely. Measuring aqueous PAH concentration at low tide during freshwater flow has no bearing on PAH concentration carried by saltwater intrusion at high tide. Sampling of the adjacent stream delta sediments indicates the presence of oil and the potential for exposure, but also does not measure actual exposure concentration. Elevated egg mortality in oiled streams is the net result of long-term, low-level, intermittent exposures that are impossible to accurately measure.

Conclusion

Results support the hypothesis that tidal leaching of residual oil in stream deltas impaired embryo survival in pink salmon through 1993, 4 years after the oil spill. After 1993, residual TPAH concentration in stream deltas had declined to below threshold levels associated with increased embryo mortality, so that spawning habitat had essentially recovered. Persistent effects of marine oil spills are most likely in sessile animals with high lipid content, which provide a means for accumulating hydrocarbons from dilute concentrations over long periods. Because of these characteristics, pink salmon embryos in intertidal streams are particularly vulnerable to persistent damage after marine oil spills.

INTRODUCTION

The *Exxon Valdez* oil spill in Prince William Sound (PWS), Alaska, in March 1989 was the largest ever in U.S. waters and contaminated 2,000 km of coastal habitat (Bragg 1994). Contamination of intertidal spawning areas for pink salmon (*Oncorhynchus gorbuscha*) caused increased embryo mortality and possible long-term developmental and genetic damage (Bue et al., 1998). Pink salmon support valuable fisheries and are a critical part of the PWS ecosystem. Most wild PWS pink salmon spawn in intertidal stream deltas (Helle 1970), and therefore, were susceptible to a marine oil spill. The embryo, a critical stage of salmon development, was vulnerable because of its long incubation in intertidal gravel and its large lipid-rich yolk which will accumulate petroleum hydrocarbons from low-level, intermittent exposures (Moles et al. 1987, Marty et al. 1997).

Residual oil from a spill can remain toxic for long periods because the most toxic components are the most persistent. Petroleum is a complex mixture of alkanes and aromatic hydrocarbons, of which the alkyl-substituted and multi-ring polynuclear aromatic hydrocarbons (PAH) are the most toxic (Rice et al. 1977; Black et al. 1983). These large PAH predominate in weathered oil (Short and Heintz 1997). The large PAH probably contribute little to acute toxicity of oil-water solutions because of their low solubility and resulting low concentration in water and the short period of acute exposures. These lipophilic PAH, however, may cause physiological injury if they accumulate in tissues after lengthy exposure (Heintz et al., in press). Short and Heintz (1997) demonstrated that PAHs, including the more-toxic and less-soluble components, are lost from oil to the water column according to first-order kinetics, and these PAH are readily adsorbed onto hydrophobic matrices, such as egg lipids (Heintz et al., in press).

Pink salmon embryos in oiled PWS streams continued to show increased mortality compared to non-oiled streams through 1993, more than 4 years after the oil spill, but appeared to have recovered in 1994 (Bue et al. 1998). No significant difference in embryo mortality between oiled and non-oiled streams was detected in 1994, 1995, or 1996 (Bue et al. 1998; Craig et al. 1998). Possible causes of the persistent elevated mortality were 1) physiological injury from continuing exposure to residual oil; 2) genetic damage incurred in the initial acute exposure in 1989-1990; and 3) inherent differences between habitat conditions and fish stocks at oiled and non-oiled streams. In this study, we assess the recovery of spawning habitat and examine the hypothesis of continuing exposure of salmon embryos to residual oil.

To evaluate habitat recovery, we analyzed archived sediment samples collected from 172 PWS stream deltas in 1989-1991 and resampled 12 streams in 1995. By interpolating between years, we determined that tidal leaching of residual oil in stream deltas could explain the impaired embryo survival in pink salmon through 1993, 4 years after the oil spill. After 1993, residual TPAH concentration in stream deltas had declined to below threshold levels associated with increased embryo mortality, so that spawning habitat had essentially recovered.

OBJECTIVES

The major hypothesis of this project was that residual oil from beached deposits continues to seep into salmon spawning areas, contributing to poor embryo survival. Specific objectives were to:

1. Measure oil in stream gravels collected in 1989-91;
2. Measure oil in stream gravels collected in 1995;
3. Examine PAH profiles in 1989 and 1995 samples and compare to *Exxon Valdez* crude to confirm oil source;
4. Determine causes of variability in initial concentration and subsequent recovery;
5. Evaluate state of weathering of the 1995 samples; and
6. Examine the relationship between oil concentrations and pink salmon embryo mortality.

METHODS

Sample Acquisition

Most samples for this study were from archived sediment samples taken by the Alaska Department of Fish and Game (ADFG) in August-November 1989. In 1989, the ADFG attempted to sample most anadromous fish streams in the affected area of PWS to document oil contamination. At each of 172 streams, at least one sediment sample was taken from the intertidal area near or in the stream channel. Only one sample was taken at most (69%) streams because the principal objective was to collect evidence of the presence or absence of oil. At 53 streams (31%), two or more samples were taken to better portray contamination in different parts of the intertidal zone. The ADFG also mapped seven "benchmark" stream deltas (Table 1) to show the distribution of oil and location of fixed sample plots with distance and bearing from a marked point. Sample plots ranged from 0.1 m to 18 m from the stream (mean, 2.7 m). Besides the extensive 1989 samples, the ADFG also took samples from 12 streams in August 1990 and 4 streams in March 1991 during cleanup and monitoring activities.

Sample locations were documented by field notes, photographs, and video tape. Sample locations ranged from the wetted streambed to 30 m from the stream channel, but most samples were from the stream delta within 3 m of the stream, and not from the wetted streambed. The 1990 and 1991 samples were from both the wetted streambed and from the stream bank.

The 1989-1991 samples were stored frozen in hydrocarbon-free glass jars until we acquired them in January 1995. The samples remained continuously frozen in the original sealed storage boxes until analysis. We deemed these samples suitable for meaningful chemical analysis because we could verify their continuous frozen storage and could unambiguously identify them with chain-of-custody records. The total numbers we analyzed were 308 samples from 1989, 14 samples from 1990, and 9 samples from March 1991. Another 25 sediment samples from 1989 and 1990 were analyzed by the Geochemical and Environmental Research Group (GERG) at Texas A&M University, College Station, Texas. Those results have been reported elsewhere (GERG 1990, 1991, Wiedmer et al. 1996) and are included here where chemical analysis was comparable.

In March 1995, we resampled 12 stream deltas in PWS (Table 1; Fig. 1) to assess habitat recovery. Ten of these streams were considered to be contaminated by oil in 1989. These ten "oiled" streams included all of the seven ADFG benchmark streams and six of the study streams used by Bue et al. (1996, 1998) (three of which were also ADFG benchmark streams). Based on analysis of the 1989 samples, however, we reclassified one stream as "non-oiled" because it showed no detectable petroleum hydrocarbons. We resampled two additional non-oiled streams as controls, resulting in a total of nine oiled streams and three non-oiled streams.

Sampling in 1995 followed the methods used by ADFG in 1989. At each stream, we took at least three sediment samples from the stream delta, one each from the upper, middle, and lower intertidal zone. At the seven benchmark streams, we sampled at the same fixed plots as in 1989. At some streams, we took additional samples to increase coverage of the stream delta. A total of 71 sediment samples were taken in 1995, including 25 fixed plots, 36 from lower, middle, and upper intertidal stations at each stream, and 10 additional samples. Samples were taken from pits (5-30 cm deep) dug with a trowel, and sediment was scooped with a hydrocarbon-free spoon into a hydrocarbon-free jar and frozen until analyzed. Any obvious oil residue was noted.

Hydrocarbon Analysis

All samples were first analyzed by ultraviolet fluorescence (UVF) adapted from Krahn et al. (1991, 1993) as described by Babcock et al. (1996) to measure total concentration of petroleum hydrocarbons. Based on results of the UVF analysis, selected samples with detected oil were analyzed further by GC/MS for quantitative determination of individual PAH analytes.

In the UVF analysis, samples were extracted twice with methylene chloride, then concentrated or diluted to match a calibration curve for an *Exxon Valdez* oil (EVO) standard. These extracts were analyzed with a high-performance liquid chromatograph with fluorescence detector. Excitation and emission wavelengths were 260 nm and 380 nm, respectively. Total petroleum hydrocarbon concentration (TPHC; μg/g wet weight) was estimated based on the response of the EVO standard. The TPHC method detection limit (MDL) was determined experimentally to be 2 μg/g according to methods of Glaser et al. (1981).

The GC/MS analysis determined concentrations of 44 individual PAH analytes, including unsubstituted and alkyl-substituted homologues of PAH with two to five rings. The PAH included five prominent homologous series: naphthalenes, fluorenes, dibenzothiophenes, phenanthrenes, and chrysenes. The MDL was determined experimentally (Glaser et al. 1981) for each PAH analyte and was generally about 1 ng/g. Total PAH (TPAH) concentration was calculated as the sum of the concentrations of all measured PAH above MDL except perylene (produced by diagenesis; Venkatesan 1988). The methods, MDLs, accuracy, and precision of the GC/MS analysis are summarized in Short et al. (1996a).

The TPHC obtained by UVF could be used to estimate TPAH concentration because they were highly correlated. The regression of TPAH concentration (ng/g dry wt) on TPHC in samples analyzed by both methods was TPAH = $1.59(\text{TPHC} + 1)^{1.14} - 1$ ($R^2 = 0.88$; $N = 83$).

Determination of Petroleum Source

A model of the weathering of PAH in EVO (Short and Heintz 1997) was used to test whether the pattern of PAH concentrations in sediments was consistent with either weathered EVO or natural background. The model states that individual PAH are lost from oil at the same relative rates regardless of the weathering environment. The model was validated successfully by comparison with thousands of samples from the study area. The model uses experimentally determined loss-rate constants for 14 PAH analytes and their measured concentrations in environmental samples and unweathered EVO to calculate an index of weathering (w) which summarizes the exposure history of the samples. Bootstrapped error distributions from the weathering model and also from samples of the natural background PAH provide a basis for testing the null hypotheses that the pattern of PAH concentrations in a sample was consistent with weathered EVO or, alternatively, with natural background. The hypothesis tests are only approximate when some of the 14 model analytes are below MDL.

Model of Spawning Habitat Recovery

The recovery of pink salmon spawning areas after the oil spill can be evaluated with a negative exponential model to interpolate TPAH concentration in stream deltas between 1989 and 1995. Assume TPAH concentration at stream deltas declines with time as

$$C_t = C_0 \, e^{-k\,t} \,, \tag{1}$$

where C_0 is initial concentration and C_t is concentration at time t. The loss-rate constant k may be calculated from C_0 and the 1995 concentration (C_{1995}) as

$$k = \frac{1}{t} \ln(\frac{C_0}{C_{1995}}) \,. \tag{2}$$

We used the most recent TPHC data before 1995 as the estimate of C_0 and interpolated between those data and C_{1995}. The time t between the 1995 samples and the 1989, 1990, and 1991 samples was approximately 5.5, 4.5, and 4 years, respectively. We used TPHC in equations (1 and 2) and calculated TPAH_t from TPHC_t based on the regression equation described above.

RESULTS AND DISCUSSION

Initial Oil Contamination in 1989-1991

Initial oil contamination varied greatly among streams. In 1989, TPHC at the 172 streams ranged from below the MDL of 2 µg/g to approximately 95,000 µg/g (Appendix 1). Distribution of sediment concentration across streams was bimodal: 85 (49%) deltas had no petroleum hydrocarbons at MDL, and 65 (38%) deltas had 1,000-95,000 µg/g. Only 22 deltas had an intermediate TPHC of 2-1,000 µg/g. Most stream deltas (69%) had only one sample and no measure of within-stream variance. For the 53 streams with two or more samples, variance was high, with a mean coefficient of variation (standard deviation/mean) of 112%. Sediment concentration at a stream delta sometimes ranged from MDL to more than 10,000 µg/g, indicating a patchy distribution of oil.

Although the 1989 sampling program was not randomized in the statistical sense, field notes, site maps, and photos of sampling in 1989 indicate that the samples were generally not just from heavily oiled areas. Samples in 1989 were taken adjacent to the stream or in the stream channel, whereas oil was often indiscernible or distributed broadly across the delta.

Oiling of stream deltas in 1989 depended on location and orientation of streams in the oil trajectory (Fig. 1). Stream deltas with a high TPHC (>1,000 µg/g) were typically located on northeast shorelines and points exposed to prevailing southwesterly currents. Streams with no detectable oil were often located in bays oriented away from currents or protected behind points of land. The distribution of oiled and non-oiled streams, however, overlapped (Fig. 1). Stream deltas with no detectable oil were often near others with high TPHC, particularly at the margins of the oil slick.

Maps and associated notes of oil deposits at the benchmark streams showed that oil was distributed in large patches of varying thickness (Fig. 2). Heavy oil patches were 3-28 cm thick, and had a TPAH concentration >100,000 ng/g, though measured TPAH did not necessarily correlate with visual assessments. The heaviest deposits were often in the mid- to upper intertidal zone ("Bathtub Ring"), with lighter deposits in the lower zone. At some stream deltas, the north-facing area had more oil than the opposite stream bank (e.g., Fig. 2), reflecting prevailing currents in the oil trajectory.

Data for 1990 and 1991 were limited but indicated continued oil contamination. In 1990, 4 of the 14 samples (from 12 streams) were from the wetted streambed and had TPHC near MDL (0-15 µg/g). In the 10 samples from the stream bank, however, TPHC ranged from about 12,000 to 37,500 µg/g (Table 2). In 1991, eight of the nine samples (from four streams) were from the wetted streambed and had TPHC ranging from MDL to 46 µg/g. The only sample from the stream bank in 1991 had a TPHC of over 5,000 µg/g.

At 6 of 10 stream deltas in 1990 (excluding samples from the wetted streambed), TPHC in samples was greater than in 1989 (Table 2), though the difference was not significant ($P = 0.13$; paired t-test). Caution is warranted, however, in interpreting this result because of the small number of samples. Data from 1990 and several streams in 1989 were limited to only one sample per stream. Also, because samples from 1990 were analyzed for TPHC but not TPAH, we could only compare 1989 and 1990 with TPHC data, which eliminated some samples analyzed by GERG (1990, 1991) for TPAH but not TPHC. The lack of decrease and possible increase in TPHC between 1989 and 1990 could be a spurious result of the small number of samples and patchy distribution of oil, or it could be due to remobilization of stranded oil during 1989-1990 winter storms. Over the 1989-1990 winter, oil coverage of PWS beaches declined by 50-80%, (Wolfe et al. 1994). Some of this remobilized oil probably was redeposited, increasing the oil concentration at some streams. Maps of oil deposits at the benchmark streams in 1989 showed discrete oil patches, as well as areas with no oil. Redistribution of oil during winter likely spread it to previously unoiled areas. Brannon et al. (1995) also found higher TPAH concentrations in spring 1990 than in fall 1989 in four of eight oiled streams in their study.

The high variance in TPHC concentration between streams and years was expected given the patchy distribution of oil contamination in general, separation in time, and the combination of factors that remobilize oil and degrade it. The sampling design in 1989 for the 172 streams was done for litigation purposes to document whether oil was present or not, and not to accurately assess oil distribution within the deltas or the consequences of time after sampling. These samples do not provide valid statistical averages for those streams. Hence, TPHC could rise in 1990 at some of the sites (Table 2), either because of sampling problems or from oil remobilization. The significance of the sampling of 172 streams in 1989 is the number of stream deltas that were contaminated and the high concentrations that were often found.

As measured by GC/MS, the pattern of PAH concentrations was consistent with weathered EVO. In 1989-1991, TPAH concentration in 75 sediment samples from 44 stream deltas (including those from GERG (1990, 1991) ranged from MDL to over 900,000 ng/g (Appendix 2). Using the Short and Heintz (1997) weathering model, we analyzed the relative concentrations of PAH in 16 samples with TPAH >100 ng/g and at least 13 model analytes > MDL (Appendix 3). In all 16 samples, the PAH pattern was consistent with weathered EVO ($P = 0.10$ to 0.95). The PAH were not consistent with the natural background ($P < 0.0001$) in any of these samples.

Residual Oil in 1995

In 1995, petroleum hydrocarbons were detected in sediment at eight of the nine oiled streams we resampled. At the eight deltas with detected oil, mean TPHC was significantly ($P < 0.05$; *t*-test on log TPHC) greater than 0 µg/g and ranged from 6 to 242 µg/g (Fig. 3A). At the four other stream deltas, TPHC did not exceed 3 µg/g in any sample. At deltas with detected oil, TPAH exceeded 100 ng/g at five streams, and 1,000 ng/g at three streams (Fig. 3B; Appendix 2).

Samples from fixed plots at the seven benchmark streams in 1995 showed that residual TPHC and TPAH concentrations were low in most areas but with patches of higher concentration at some streams (Table 3; Fig. 2). Deltas of streams 16920, 16780, and 16613, in particular, had significant TPAH at some plots. The 1995 TPAH concentration at fixed plots was not correlated ($r = 0.0$) with the 1989 concentration. The lack of correlation was probably due to variation in oil weathering and loss rate on a small spatial scale within the stream deltas. The highest concentrations in 1995, however, were from areas that had heavy deposits of oil in 1989 (Fig. 2).

The pattern of PAH relative concentrations in 1995 indicated EVO in a moderately to highly weathered condition. Using the Short and Heintz (1997) weathering model, we analyzed the PAH pattern in 10 sediment samples with TPAH concentration >75 ng/g and at least 13 model analytes > MDL (Appendix 3). The weathering index w was 6.3 ± 0.5 (mean ± SE), which was significantly ($P < 0.01$; t-test) greater than in 1989 (3.7 ± 0.5; $N = 16$). The relative concentrations of PAH in 1995 was consistent ($P > 0.01$) with weathered EVO in 9 of the 10 samples analyzed (Appendix 3). The ability to confirm EVO as the PAH source, however, depended on the weathered condition of the sample, as w and P_{oil} (probability of incorrectly concluding the sample was inconsistent with EVO) were inversely related ($r = -0.66$; $P < 0.05$). The null hypothesis that the PAH was consistent with the natural source was rejected for all 10 samples ($P < 0.0001$). Compared to less-weathered EVO, the 1995 samples were depleted in PAH with low molecular weight (Fig. 4). Naphthalenes were depleted, whereas the phenanthrenes and chrysenes were comparatively abundant. Within homologous series, the more-substituted components were more abundant.

Although TPAH concentration at oiled streams had decreased greatly by 1995, the residual PAH consisted of the most toxic components of EVO. Toxicity of oil components is directly related to molecular weight and alkylation of the aromatic nucleus (Rice et al. 1977). The less-toxic naphthalenes comprised about 50% of unweathered EVO (Short et al. 1996b) but were greatly reduced in 1995, whereas the phenanthrenes and chrysenes, the most toxic components of EVO (Heintz et al., in press), were most persistent (Fig. 4). Because of the greater persistence of the larger PAH, weathered oil is more toxic per unit mass than less-weathered oil (Heintz et al, in press.

Habitat Recovery

Oiled stream deltas sampled in 1995 showed a variable recovery rate. At the nine oiled streams (mean 1989-1990 TPHC >1,000 μg/g), mean TPHC declined by more than 98% by 1995 (Table 4). Petroleum hydrocarbons at the three non-oiled streams were nearly undetectable in both 1989 and 1995. The loss-rate constant k averaged 1.25 ± 0.10 (mean ± SE) and ranged from 0.79 to 1.73 (Table 4). This instantaneous loss rate implied an average annual loss of 70% ± 3%.

The 70% average annual loss of oil from stream deltas was similar to the annual loss from PWS beaches of 75-80% (Wolfe et al. 1994). Differences in loss rate between streams was probably due to the effects of many physical factors, particularly the degree of protection in bays from storm surges. The lowest rate for stream deltas (55%) was in a protected southeast-facing bay, whereas the highest rate (82%) was at an exposed northwest shore.

Interpolation between 1989-1991 and 1995 based on model (1) indicated persistent high levels of TPAH at oiled streams through at least the fall of 1993 (Fig. 5). Estimated TPAH concentration at the nine oiled streams sampled in 1995 decreased from a mean of 88,000 ng/g in fall 1989 to 523 ng/g in fall 1994. Mean TPAH concentration was approximately 19,000 ng/g in fall 1991 and 5,000 ng/g in fall 1992. Interpolated TPAH ranged up to 5,000 ng/g in fall 1993 and up to 2,000 ng/g in 1994.

Residual TPAH concentration was probably still high enough to impair embryo survival at some stream deltas through fall 1993. The lowest TPAH sediment concentration shown to reduce salmon embryo survival in the laboratory is 3,800 ng/g (Heintz et al., in press). Model (1) interpolations indicated that some stream deltas still had a TPAH concentration more than 3,800 ng/g in fall 1993, but all streams were below this level in 1994 (Fig. 5).

The minimum effective sediment concentration observed in the laboratory (Heintz et al., in press) probably is not directly applicable to PWS stream deltas because of differences in laboratory and field conditions. Nevertheless, our results on residual PAH concentrations could explain why pink salmon embryo mortality at oiled streams was significantly greater than at non-oiled streams through the fall 1993, but was not significantly different in 1994, 1995, or 1996 (Bue et al. 1998; Craig et al., in press). The hypothesis of continuing exposure of salmon embryos to residual PAH was further supported by Wiedmer et al. (1996) who demonstrated cytochrome P-4501A induction in salmon alevins from oiled PWS streams at least through spring 1991.

Mechanism of Oil Exposure

The likely mechanism for continuing exposure of salmon embryos to residual oil involves leaching of PAH from weathered oil deposits in the stream delta and transport to salmon redds via interstitial water during ebb tide. A large portion (40%) of the oil from the spill was deposited in the PWS intertidal zone (Wolfe et al. 1994, Spies et al. 1996). Tidal action could allow PAH to dissolve from residual oil and be carried via interstitial water to salmon embryos over the 6-month incubation period.

Simulations using a laboratory stream confirmed tidal leaching as the likely mechanism for continuing exposure of salmon embryos to residual oil (Heintz et al., in press). In this study, PAH dissolved from weathered oil in sediment and was accumulated by salmon embryos downstream. Toxic PAH, including those with low solubility in water, were delivered to salmon embryos via the aqueous medium, and not through direct contact with oil in incubation substrate. Further, weathered oil was more toxic per unit mass than less-weathered oil, and embryo survival was reduced by a weathered PAH sediment concentration as low as 3,800 ng/g and an aqueous concentration as low as 1 ppb.

Interstitial water flow in intertidal salmon redds is variable, but basic to the question of how oil spilled into the marine environment contacts and affects salmon eggs. In PWS, where the diurnal tide range is about 4 m, as much as 2,000 m of a stream can be used for spawning and later covered by seawater at high tide (Helle et al. 1964). Interstitial water flow is complicated because the freshwater gradient is interrupted during two high tides per day, and spawning areas may be flooded by seawater for up to 80% of the time (Helle et al. 1964). On a rising tide, the fresh water floats on top of the seawater, and interstitial water in the stream bed quickly reaches maximum salinity of over 20 ppt. On the falling tide, water from the hydrated, contaminated sides of a stream can flow interstitially down slope and into the salmon redds. As the tide ebbs further, freshwater flow returns, dominated by uncontaminated upstream water.

At first, many involved in damage assessment after the oil spill believed that salmon spawning habitat in intertidal streams would be protected by the flow of fresh water. Because oil floats, direct mortality from oil exposure was considered unlikely (Brannon et al. 1995). Monitoring of TPAH by Brannon et al. (1995) confirmed that surficial streambed substrate does not receive acute direct contamination from oil. Surficial sediment from the streambed in 1989 through 1991 in their study had much lower TPAH concentration than sediment from the stream delta (Table 5). Mean TPAH concentration up to 267 ng/g was measured in streambed surficial sediment in 1989, compared to more than 311,000 ng/g in the stream delta. However, mean TPAH in streambed sediment declined only slightly from 1989 to 1991 (89 ng/g in 1989 and 64 ng/g in 1991), indicating chronic PAH inputs from leaching of residual oil in the stream delta.

Obtaining an accurate assessment of the PAH concentration to which salmon embryos were intermittently exposed in intertidal streams is impossible. Sampling of streambed sediment does not measure actual exposure levels because direct oil contamination from stream sediments is unlikely. Measuring aqueous PAH concentration at low tide during freshwater flow has no bearing on PAH concentration carried by saltwater intrusion at high tide. Sampling of the adjacent stream delta sediments indicates the presence of oil and the potential for exposure, but also does not measure actual exposure concentration. Thus, neither sampling approach gives a realistic measure of the low-level, intermittent exposures in salmon redds. The elevated egg mortality measured by Bue et al. (in press) in oiled streams was an estimate of the net result of the long-term, low-level, intermittent exposures that are impossible to accurately measure.

CONCLUSION

Results support the hypothesis that tidal leaching of residual oil in stream deltas impaired embryo survival in pink salmon through 1993, 4 years after the *Exxon Valdez* oil spill. After 1993, residual TPAH concentration in stream deltas had declined to below threshold levels associated with increased embryo mortality, so that spawning habitat had essentially recovered. Persistent effects of marine oil spills are most likely in sessile animals with high lipid content, which provides a means for accumulating hydrocarbons from dilute concentrations over long periods. Because of these characteristics, pink salmon embryos in intertidal streams are particularly vulnerable to persistent damage after marine oil spills.

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Table 1.--Beach segment, stream number, and location of the 12 stream deltas in Prince William Sound sampled by the Alaska Department of Fish and Game (ADFG) in 1989 and resampled for this study in 1995. Beach segment is an identifier assigned for oilspill response, and stream number is from the 1989 ADFG stream catalogue. Asterisk indicates study sites of Bue et al. (in press).

Beach segment	Stream number	Location
ADFG Benchmark Streams		
CH002*	2262016180	Chenega Is., north
EV017*	2264016630	Evans Is., Little Shelter Bay
EV025	2264016613	Evans Is., Shelter Bay
KN103	2261016922	Knight Is., Lower Passage
KN132	2261016920	Knight Is., Herring Bay, west
KN701	2263016840	Knight Is., Marsha Bay
LA018*	2264016780	Latouche Is., Sleepy Bay
Other Streams		
CH001*	2262016280	Chenega Is., east
EV900*	2264016650	Evans Is., Latouche Passage
KN401*	2263016820	Knight Is., Snug Harbor
Control		
LA041*	2265016370	Latouche Is., southwest
KN551*	2262016864	Knight Is., Lower Herring Bay

Table 2.--Total petroleum hydrocarbon concentration (TPHC, µg/g) in streambank sediment from Prince William Sound stream deltas in 1989 and 1990. Data for 1989 are means ±SE (number of samples *N* is in parentheses) or single samples; data for 1990 are from single samples. All samples were taken from the stream delta adjacent to the stream.

Stream[a]	1989		1990	Change 1989 to 1990
16630	5,791 ± 1,716	(8)	30,204	+24,413
16920	97 ± 89	(4)	20,713	+20,615
16620	213 ± 169	(3)	21,973	+21,760
16783	2,596	(1)	19,024	+16,427
16780	3,628 ± 2,458	(3)	17,462	+13,835
16182	1,256	(1)	11,940	+10,684
13030	22,572	(1)	19,526	-3,046
16865	44,997 ± 24,603	(2)	37,497	-7,500
16613	29,801	(1)	20,486	-9,315
16840	35,526 ± 11,954	(4)	22,328	-13,198

[a] Last five digits of ADFG stream catalog number.

Table 3.--Change in total petroleum hydrocarbon concentration (TPHC) and total polynuclear aromatic hydrocarbon concentration (TPAH) at fixed plots at seven benchmark stream deltas in Prince William Sound, Alaska, between 1989 and 1995. Blanks are missing data from samples analyzed for TPAH (GERG 1990, 1991) but not for TPHC and for samples analyzed for TPHC but not for TPAH.

	Sample	TPHC (µg/g)		TPAH (ng/g)	
Stream[a]	plot	1989	1995	1989	1995
16280	1	82	18		4
	2	188	33	2,982	76
	3		9	46,000	
16630	1		44	10,000	33
	2		18	47,000	11
	3	9,226	8	23,908	
	4	8,431	1		
16920	1		292	32,000	596
	2		724	4,000	2,800
	3	362	424	3,200	403
	4	27	4		
16780	1		106	0	1,125
	2		112	2,000	191
	3	2,315	59	74,857	117
	4	182	27		89
16613	1		153	427,000	44
	2		328	229,000	1,769
	3	29,801	24	136,348	13
16922	1	24,432	8		2
	2	3,506	2		
	3	16,390	4	73,820	
	4	94,844	6		
16840	1	46,617	2	967,907	
	2		1	679,000	
	3	43,772	2		

[a] Last five digits of ADFG stream catalog number.

Table 4.--Decline in total petroleum hydrocarbon concentration (TPHC) in sediment at 12 Prince William Sound, Alaska, stream deltas that were sampled in both 1989 and 1995. The exponential decay coefficient *k* was calculated as the difference in logarithm of mean TPHC in the most recent samples and in 1995 divided by number of intervening years as described in text. Number of samples per stream in 1989 and 1995 is in parentheses; in other years, sample size was 1 or 2. Oiled streams are those where TPHC exceeded 1,000 μg/g.

	TPHC (μg/g wet weight)					Annual
Stream[a]	1989	1990	1991	1995	*k*	% Loss
			Oiled Streams			
16180	10,054 (6)			7 (3)	1.32	73%
16280	5,443 (7)			31 (7)	0.94	61%
16630	5,791 (8)	26,088		13 (10)	1.73	82%
16920	97 (4)	20,713		240 (7)	0.99	63%
16820	3,756 (5)			1 (4)	1.44	76%
16780	3,628 (3)	17,462		58 (7)	1.27	72%
16613	29,801 (1)	20,486		99 (6)	1.18	69%
16922	28,217 (5)			6 (7)	1.54	79%
16840	35,526 (4)	22,328	5,629	242 (7)	0.79	55%
			Non-Oiled Streams			
16650	1 (3)			2 (6)		
16370	3 (3)			1 (4)		
16864	0 (1)			1 (3)		

[a] Last five digits of ADFG stream catalog number.

Table 5.--Total polynuclear aromatic hydrocarbon concentration (ng/g) in samples taken from the surface of the wetted streambed by Brannon et al. (1995) and from the stream delta in the present study at nine streams in Prince William Sound, Alaska.

	Streambed surface[b]				Stream delta[c] 1989
Stream[a]	Fall 1989	Spring 1990	Fall 1990	Spring 1991	
16180	194	182	2	5	1,316
16280	1	384	21	224	24,491
16630	233		31	96	26,969
16650	5	12	2	2	0
16820	1	1	2	1	63,826
16780	267	2,818	108	236	17,971
16640	62	413	2	6	311,201
16860	17	1	3	1	0
16850	18	1			1
Mean	89	435	21	64	56,622

[a] Last five digits of ADFG stream catalog number.

[b] Means of three to six samples; data from Brannon et al. (1995).

[c] Means of one to six samples.

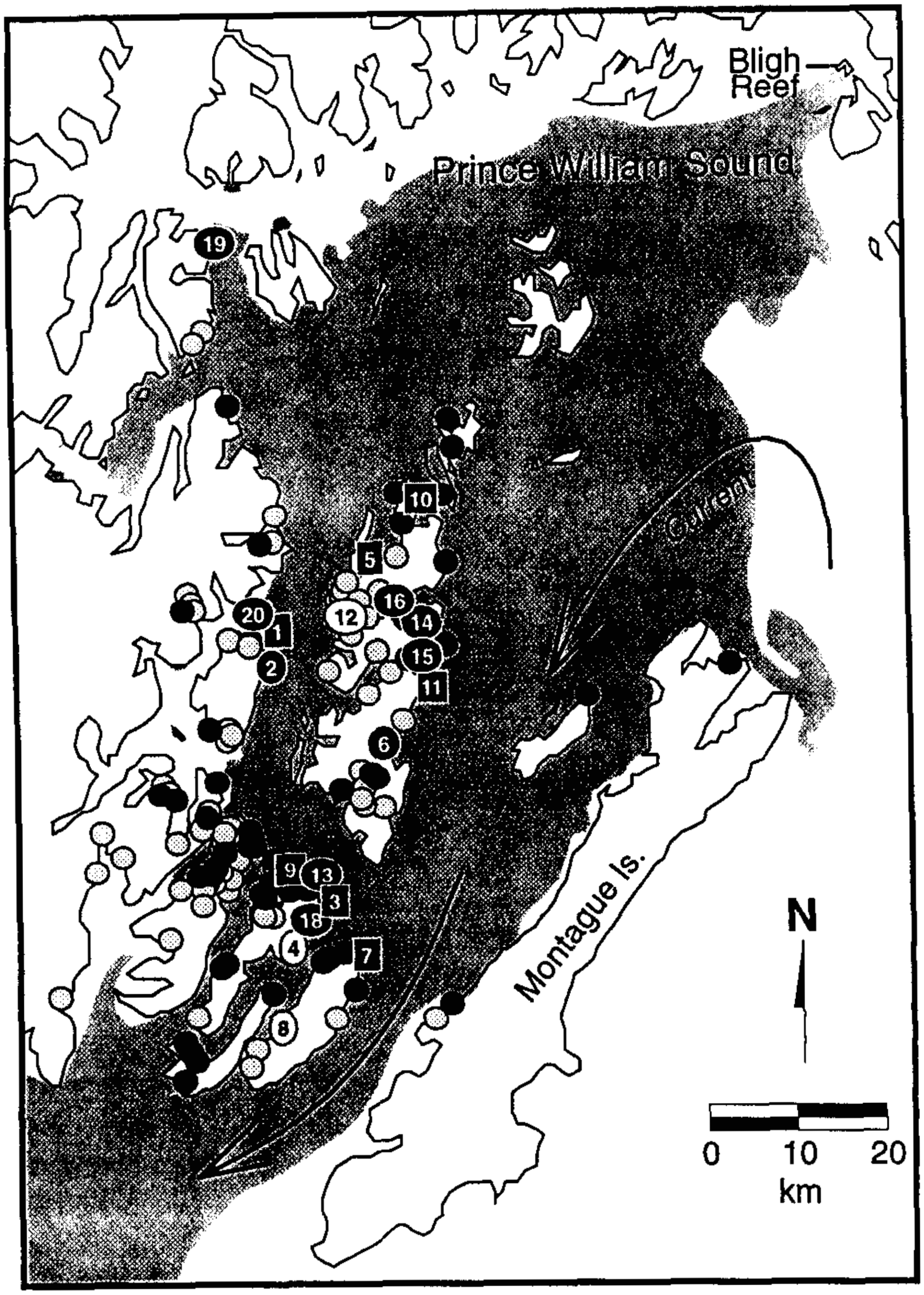
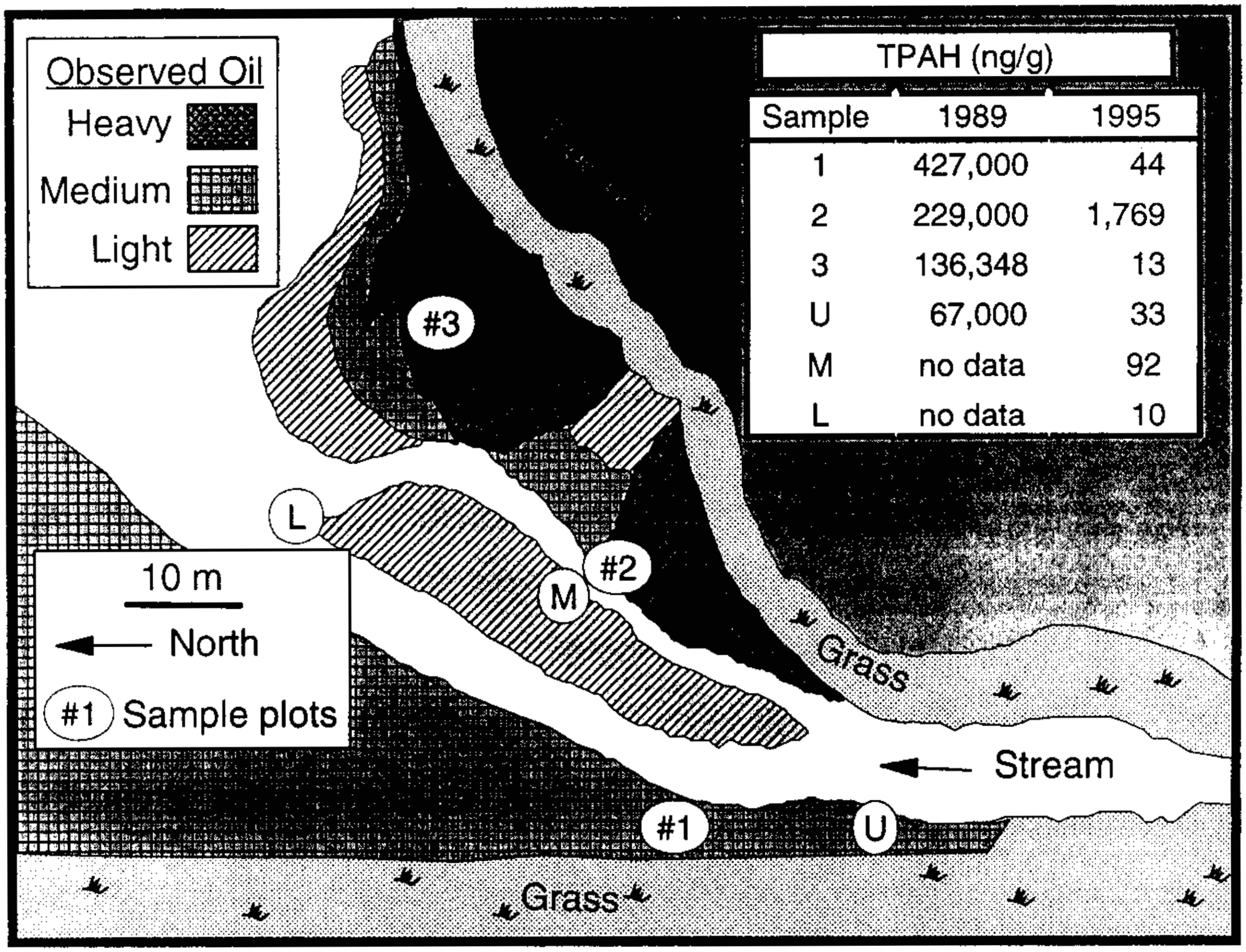


Figure 1.—Distribution of stream deltas in Prince William Sound, Alaska, in 1989 with high total petroleum hydrocarbon concentration (TPHC >1,000 ug/g) (closed symbols) and with no TPHC at method detection limit (2 µg/g) (open symbols). Symbols numbered 1-12 are stream deltas sampled for this study in 1995 (listed in Table 1); symbols 13-15 are additional streams sampled by Brannon et al. (1995) (referred to in Table 5); symbols 16-20 are streams sampled in 1990 (referred to in Table 2). Symbols 1-8 are streams used by Bue et al. (1996); rectangles are benchmark deltas mapped by Alaska Department of Fish and Game. Gray area shows the extent of observed *Exxon Valdez* oil (Spies et al. 1996).



TPAH (ng/g)

Sample	1989	1995
1	427,000	44
2	229,000	1,769
3	136,348	13
U	67,000	33
M	no data	92
L	no data	10

Figure 2.—Map of the stream delta at Shelter Bay (stream no. 16613) in Prince William Sound, Alaska, showing distribution of observed oil in November 1989 after the March 1989 *Exxon Valdez* oil spill and location of fixed sampling plots. Table insert shows total polynuclear aromatic hydrocarbon concentration (TPAH) in sediment from each sampling plot in 1989 and 1995. Original map was drawn by the Alaska Department of Fish and Game.

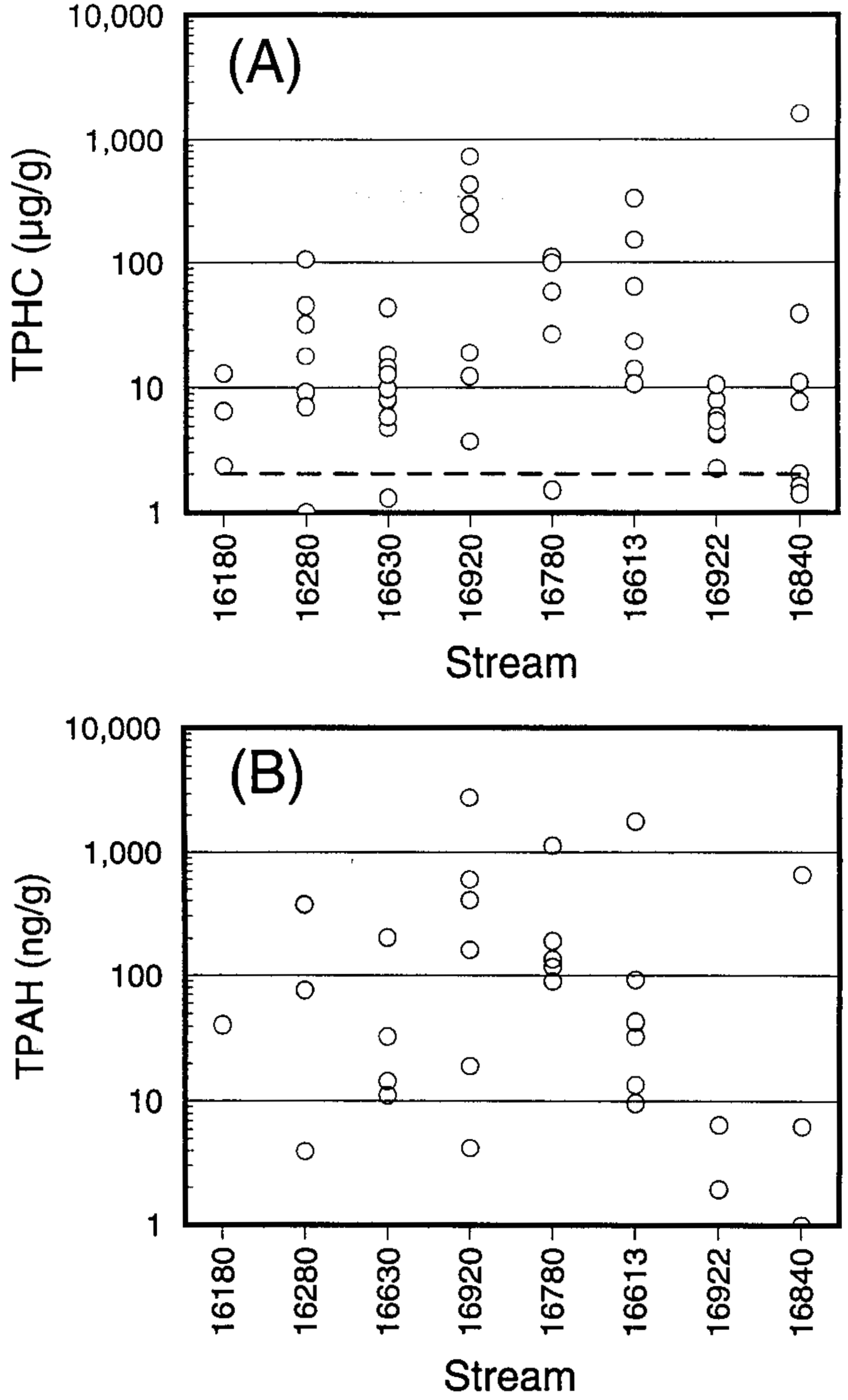


Figure 3.—Total petroleum hydrocarbon concentration (TPHC; log scale) (A) and concentration of total polynuclear aromatic hydrocarbons (TPAH; log scale) (B) in individual sediment samples from stream deltas in Prince William Sound, Alaska, in 1995. The stream number is the abbreviated Alaska Department of Fish and Game stream catalog number. The dashed line in (A) shows the method detection limit for TPHC of 2 µg/g. Streams with TPHC <10 µg/g in all samples are omitted.

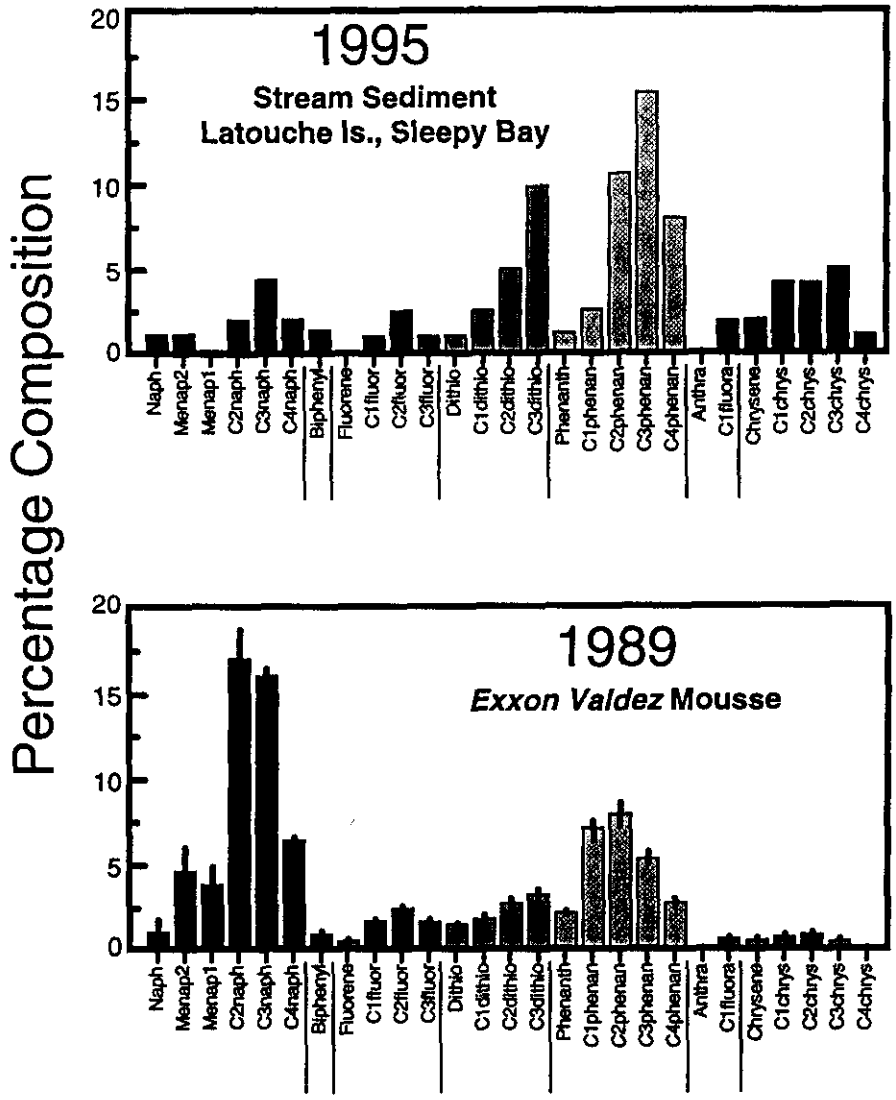


Figure 4.—Relative concentration of polynuclear aromatic hydrocarbons (PAH) in a 1995 sediment sample from a stream delta (stream no. 16780) in Prince William Sound, Alaska, and in three samples (mean and range) of *Exxon Valdez* mousse. Names of PAH are abbreviations used in Short et al. (1996). The 1995 sample had a weathering index (Short and Heintz 1997) of 5.3, compared to the 1995 range of 4.8-9.2.

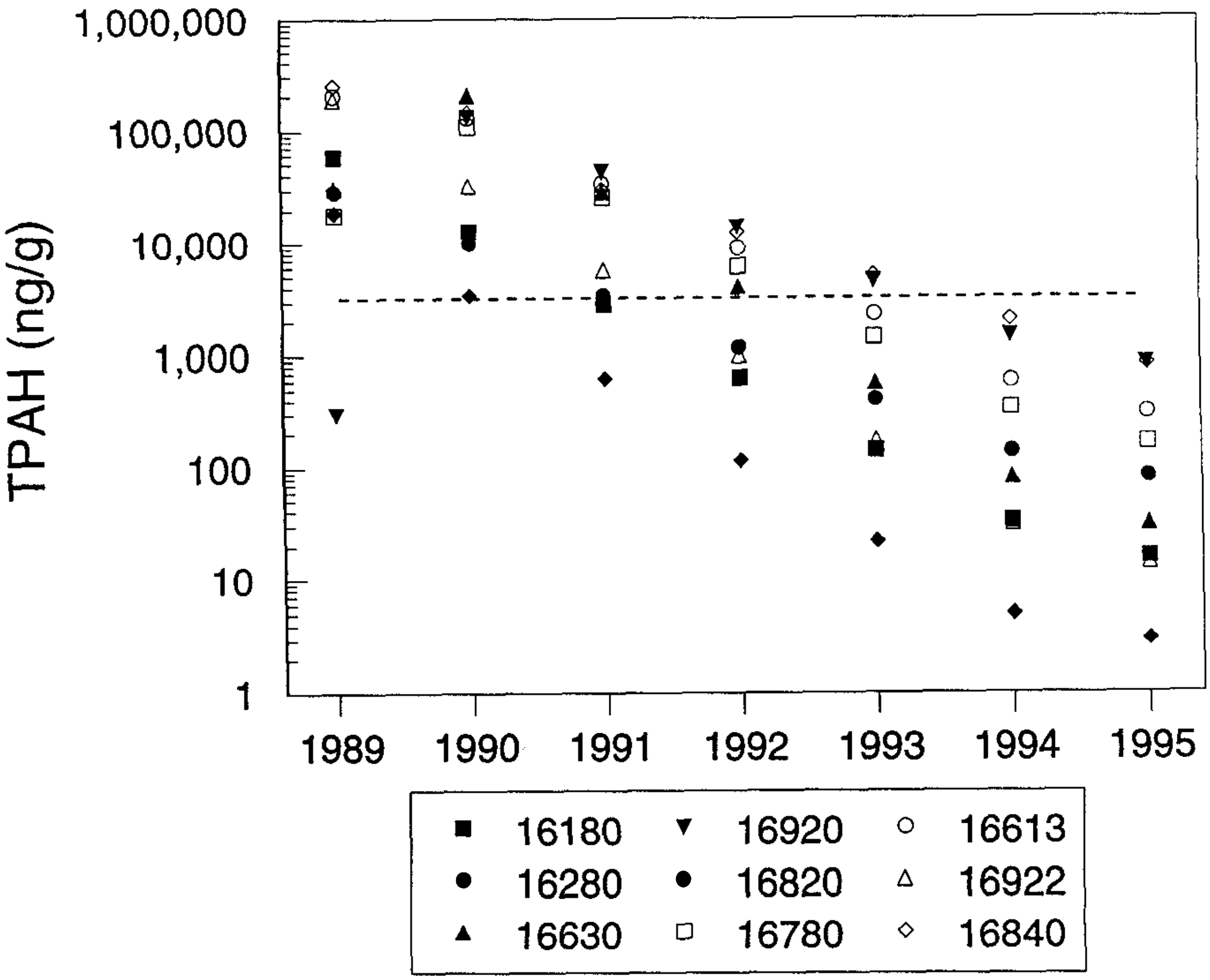


Figure 5.—Estimated total polynuclear aromatic hydrocarbon concentration (TPAH; log scale) at nine stream deltas in Prince William Sound, Alaska, in fall from 1989 to 1994 and in spring 1995. Estimated TPAH is regressed from means of observed total petroleum hydrocarbon concentration where available (Table 4), as described in text, and interpolated data between 1989-1991 and 1995 assuming a negative exponential model. The dashed horizontal line shows the lowest observed sediment concentration (3,800 ng/g) associated with increased pink salmon embryo mortality in the laboratory (Heintz et al., in press). Stream numbers in legend are abbreviated from the Alaska Department of Fish and Game stream catalog.

Appendix 1.--Total petroleum hydrocarbon concentration (TPHC; µg/g wet weight) measured by ultraviolet fluorescence in sediments from 172 stream deltas in Prince William Sound sampled by the Alaska Department of Fish and Game (ADFG) in 1989. Sample number is an identification number in the EVOS database (Short et al. 1996); Collector's identification number is an identification number assigned to each sample by ADFG; segment number is a beach identification number assigned for Oilspill Response.

Sample number	Collector's identification	Segment number	Stream number	Sample date	TPHC
706201	89WPOO1V	KN103	2261016922	10/20/89	24432
706202	89WP002V	KN103	2261016922	10/20/89	3506
706203	89WP003V	KN103	2261016922	10/20/89	16390
706204	89WP004V	KN103	2261016922	10/20/89	94844
706205	89WP005V	KN701	2263016840	10/20/89	46617
706206	89WP007V	KN701	2263016840	10/20/89	43772
706207	89WP010V	LA018	2264016780	10/22/89	2315
706208	89WP011V	LA018	2264016780	10/22/89	182
706209	89WP012V	CH002	2262016180	11/02/89	82
706210	89WP013V	CH002	2262016180	11/02/89	188
706211	89WP015V	KN132	2261016982	11/05/89	27
706212	89WP016V	KN132	2261016982	11/05/89	362
706213	89WP021V	EV017	2264016630	11/06/89	9226
706214	89WP022V	EV017	2264016630	11/06/89	8431
706215	89WP025V	EV025	2264016613	11/07/89	29801
706216	89RLG005V	CH001	2262016280	08/13/89	1228
706217	89RLG017V	CH001	2262016280	08/13/89	45
706218	89RLG019V	CH001	2262016280	08/13/89	1
706219	89RLG138V	LA041	2265016370	08/29/89	2
706220	89RLG139V	LA041	2265016370	08/29/89	5
706221	89RLG140V	LA041	2265016370	08/29/89	2
706222	89TWC042V	KN401	2263016820	08/15/89	1
706223	89TWC043V	KN401	2263016820	08/15/89	2
706224	89TWC044V	KN401	2263016820	08/15/89	1
706225	89TWC045V	KN401	2263016820	08/15/89	1
706226	89TWC151V	EV900	2264016650	08/31/89	1
706227	89TWC152V	EV900	2264016650	08/31/89	2
706228	89TWC153V	EV900	2264016650	08/31/89	1
706229	89RLG014V	KN401	2263016820	08/25/90	18775
706230	89AW158V	MN003	2271017120	09/03/89	4
706231	89AW159V	MN003	2271017120	09/03/89	5
706232	89AW160V	MN003	2271017120	09/03/89	2
706233	89AW161V	MN003	2271017130	09/03/89	6
706234	89AW162V	MN003	2271017130	09/03/89	3
706235	89AW163V	MN003	2271017130	09/03/89	2
706236	89AW164V	MN003	2271017130	09/03/89	14759

Appendix 1.--Continued.

Sample number	Collector's identification	Segment number	Stream number	Sample date	TPHC
706237	89AW165V	MN003	2271017150	09/03/89	1
706238	89AW166V	MN003	2271017150	09/03/89	3
706239	89AW167V	MN003	2271017150	09/03/89	2
706240	89AW168V	MN003	2271017150	09/03/89	16870
706241	89AW169V	MN003	2271017260	09/03/89	0
706242	89AW170V	MN003	2271017260	09/03/89	1
706243	89AW171V	MN003	2271017260	09/03/89	0
706244	89LBR001V	EV017	2264016630	08/07/89	10173
706245	89LBR002V	EV017	2264016630	08/07/89	11216
706246	89LBR003V	EV014	2264016640	08/07/89	28606
706247	89LBR004V	KN701	2263016840	08/07/89	51714
706248	89LBR005V	GR103	2272017880	08/07/89	20290
706249	89LBR006V	CH002	2262016180	09/07/89	22534
706250	89LBR007V	KN129	2261016975	07/11/89	710
706301	89LBR008V	LA018	2264016780	07/11/89	8386
706302	89RLG007V	CH017	2262016270	08/13/89	0
706303	89RLG009V	CH002	2262016180	08/13/89	7
706304	89RLG011V	CH002	2262016180	08/13/89	59
706305	89RLG013V	CH002	2262016180	08/13/89	15231
706306	89RLG015V	CH002	2262016180	08/13/89	0
706307	89RLG021V	CH017		08/13/89	0
706308	89RLG023V	CH017		08/13/89	0
706309	89RLG025V	KN120	2261016940	08/14/89	1
706310	89RLG026V	KN132	2261016982	08/14/89	0
706311	89RLG027V	KN132	2261016982	08/14/89	0
706312	89RLG029V	KN129	2261016975	08/14/89	65
706313	89RLG030V	KN129	2261016975	08/14/89	4
706314	89RLG031V	KN129	2261016975	08/14/89	10
706315	89RLG032V	KN129	2261016975	08/14/89	12694
706316	89RLG063V	KN205	2263016860	08/18/89	1
706317	89RLG064V	KN205	2263016860	08/18/89	1
706318	89RLG065V	KN205	2263016860	08/18/89	1
706319	89RLG066V	KN205	2263016860	08/18/89	36566
706320	89RLG066VX	KN205	2263016860	08/18/89	1
706321	89RLG067V	KN705	2263016830	08/18/89	1
706322	89RLG068V	KN705	2263016830	08/18/89	1
706323	89RLG069V	GR103	2272017880	08/20/89	8
706324	89RLG070V	GR103	2272017880	08/20/89	4
706325	89RLG071V	GR103	2272017880	08/20/89	11
706326	89RLG077V	EB001	2253015060	08/21/89	1
706327	89RLG078V	EB001	2253015060	08/21/89	0

Appendix 1.--Continued.

Sample number	Collector's identification	Segment number	Stream number	Sample date	TPHC
706328	89RLG079V	EB001	2253015060	08/21/89	0
706329	89RLG080V	EB008	2253015130	08/21/89	0
706330	89RLG081V	EB008	2253015130	08/21/89	0
706331	89RLG082V	EB008	2253015130	08/21/89	0
706332	89RLG083V	EB008	2253015130	08/21/89	44855
706333	89RLG084V	EB008	2253015130	08/21/89	1
706334	89RLG085V	EB008	2253015130	08/21/89	0
706335	89RLG086V	EB009	2253015140	08/21/89	0
706336	89RLG087V	KN575	2262016960	08/22/89	0
706337	89RLG088V	KN575	2262016960	08/22/89	0
706338	89RLG089V	KN575	2262016960	08/22/89	0
706339	89RLG090V	KN575	2262016960	08/22/89	1
706340	89RLG091V	KN575	2262016960	08/22/89	0
706341	89RLG092V	KN575	2262016960	08/22/89	0
706342	89RLG093V	CH900	2262016200	08/22/89	0
706343	89RLG094V	CH900	2262016200	08/22/89	0
706344	89RLG095V	CH900	2262016200	08/22/89	0
706345	89RLG096V	CH900	2262016200	08/22/89	
706346	89RLG097V	CH900	2262016200	08/22/89	
706347	89RLG098V	EW001	2262016050	08/22/89	
706348	89RLG099V	EW001	2262016050	08/22/89	1
706349	89RLG100V	EW001	2262016050	08/22/89	8
706350	89RLG101V	EW001	2262016050	08/22/89	0
706401	89RLG102V	EW001	2262016050	08/22/89	27115
706402	89RLG103V	KN211	2261016880	08/24/89	172
706403	89RLG104V	KN211	2261016880	08/24/89	23982
706404	89RLG105V	KN213	2263016853	08/24/89	2465
706405	89RLG106V	KN213	2263016853	08/24/89	39817
706406	89RLG107V	EV014	2264016640	08/24/89	26
706407	89RLG108V	EV014	2264016640	08/24/89	9
706408	89RLG109V	EV014	2264016640	08/24/89	2
706409	89RLG110V	EV014	2264016640	08/24/89	9726
706410	89RLG111V	EV017	2264016630	08/24/89	140
706411	89RLG112V	EV017	2264016630	08/24/89	141
706412	89RLG113V	EV017	2264016630	08/24/89	98
706413	89RLG114V	EV017	2264016630	08/24/89	6904
706414	89RLG115V	EV017	2264016620	08/24/89	6
706415	89RLG116V	EV017	2264016620	08/24/89	85
706416	89RLG117V	EV017	2264016620	08/24/89	547
706417	89RLG118V	LA036	2264016764	08/24/89	3868
706418	89RLG119V	LA036	2264016764	08/26/89	1

Appendix 1.--Continued.

Sample number	Collector's identification	Segment number	Stream number	Sample date	TPHC
706419	89RLG120V	LA036	2264016764	08/26/89	1
706420	89RLG121V	LA036	2264016764	08/26/89	1
706421	89RLG122V	LA040	2265016384	08/26/89	0
706422	89RLG123V	LA040	2265016384	08/26/89	0
706423	89RLG124V	LA040	2265016384	08/26/89	0
706424	89RLG124VX	LA041	2265016380	08/26/89	0
706425	89RLG125V	LA041	2265016380	08/26/89	1
706426	89RLG126V	LA041	2265016380	08/26/89	0
706427	89RLG127V	LA029	2264016788	08/27/89	2
706428	89RLG128V	LA029	2264016788	08/27/89	0
706429	89RLG129V	LA029	2264016788	08/27/89	0
706430	89RLG130V	LA029	2264016788	08/27/89	
706431	89RLG131V	LA031	2264016785	08/27/89	2
706432	89RLG132V	LA031	2264016785	08/27/89	3618
706433	89RLG133V	LA031	2264016785	08/27/89	1
706434	89RLG134V	LA031	2264016785	08/27/89	
706435	89RLG135V	LA039	2264016720	08/29/89	0
706436	89RLG136V	LA039	2264016720	08/29/89	0
706437	89RLG137V	LA039	2264016720	08/29/89	0
706438	89RLG141V	MN500	2272017610	08/29/89	49
706439	89RLG142V	MN500	2272017610	08/29/89	3
706440	89RLG143V	MN500	2272017610	08/29/89	12
706441	89RLG144V	MN500	2272017610	08/29/89	10817
706442	89RLG181V			09/08/89	4242
706443	89RLG182V	EV071	2264016475	09/08/89	16070
706444	89RLG183V	EV071	2264016477	09/08/89	11921
706445	89RLG184V	EV070	2264016509	09/08/89	897
706446	89RLG186V	EV070	2264016498	09/09/89	1
706447	89RLG187V	LA021	2264016776	09/09/89	7821
706448	89RLG188V	LA021	2264016774	09/09/89	1921
706449	89RLG189V	LA034		09/11/89	58
706450	89RLG190V	EV064	2265016448	09/11/89	0
706501	89RLG191V	EV066	2265016452	09/11/89	5
706502	89RLG192V	BA008	2264016249	09/11/89	1
706503	89RLG193V	BA008	2264016243	09/11/89	0
706504	89RLG194V		2265016106	09/11/89	1
706505	89RLG284V	KN575	2262016949	10/08/89	0
706506	89RLG285V	KN575	2262016947	10/08/89	409
706507	89RLG286V	KN575	2262016961	10/08/89	0
706508	89RLG287V	KN575	2262016964	10/08/89	1
706509	89RLG288V	KN575	2262016963	10/08/89	1

Appendix 1.--Continued.

Sample number	Collector's identification	Segment number	Stream number	Sample date	TPHC
706510	89RLG289V	KN574	2262016944	10/08/89	1
706511	89RLG290V	KN601	2264016859	10/08/89	0
706512	89RLG291V	KN601	2264016855	10/09/89	5214
706513	89RLG292V	KN602	2264016853	10/09/89	6453
706514	89RLG293V	KN603	2264016845	10/09/89	771
706515	89RLG294V	KN603	2264016835	10/09/89	1
706516	89RLG295V	KN603	2264016833	10/09/89	0
706517	89RLG296V	KN603	2264016831	10/09/89	0
706518	89RLG297V	KN603	2264016829	10/09/89	1
706519	89RLG298V	KN604	2264016809	10/09/89	4
706520	89RLG299V	KN604	2264016805	10/09/89	0
706521	89RLG300V	BP001		10/10/89	1
706522	89RLG301V	BP002	2264016181	10/10/89	0
706523	89RLG302V	BP002		10/10/89	7260
706524	89RLG303V	CH014	2262016255	10/10/89	18217
706525	89RLG304V	CH016	2262016258	10/10/89	83
706526	89RLG305V	CH009	2262016182	10/10/89	1256
706527	89RLG306V	MA003	2251015003	10/10/89	1323
706528	89RLG307V	EL052	2261016902	10/11/89	2860
706529	89RLG308V	EL015	2261016906	10/11/89	11124
706530	89RLG309V	KN211	2261016875	10/11/89	928
706531	89RLG310V	KN5004	2261016956	10/13/89	1
706532	89RLG311V	CU007	2242013010	10/13/89	39
706533	89RT001V	EV003	2264016590	12/07/89	51409
706534	89RT002V	BP004	2262016397	12/07/89	22211
706535	89RT003V	BP004	2262016397	12/07/89	33231
706536	89TWC033V	KN605	2264016797	08/15/89	2
706537	89TWC034V	KN605	2264016797	08/15/89	5
706538	89TWC035V	KN605	2264016797	08/15/89	100
706539	89TWC036V	KN605	2264016797	08/15/89	5
706540	89TWC037V	KN602	2264016851	08/15/89	3
706541	89TWC038V	KN602	2264016851	08/15/89	3
706542	89TWC039V	KN602	2264016851	08/15/89	6149
706543	89TWC040V	KN411	2263016810	08/15/89	0
706544	89TWC041V	KN411	2263016810	08/15/89	0
706545	89TWC049V	KN701	2263016840	08/16/89	3
706546	89TWC051V	KN704	2263016850	08/16/89	0
706547	89TWC052V	KN704	2263016850	08/16/89	0
706548	89TWC053V	KN704	2263016850	08/16/89	1
706549	89TWC054V	KN704	2263016850	08/16/89	15959
706550	89TWC055V	KN704	2263016844	08/16/89	2

Appendix 1.--Continued.

Sample number	Collector's identification	Segment number	Stream number	Sample date	TPHC
706601	89TWC056V	KN704	2263016844	08/16/89	0
706602	89TWC057V	KN704	2263016844	08/16/89	0
706603	89TWC058V	KN704	2263016844	08/16/89	17694
706604	89TWC059V	KN134	2263016865	08/16/89	1
706605	89TWC060V	KN134	2263016865	08/16/89	0
706606	89TWC061V	KN134	2263016865	08/16/89	0
706607	89TWC062V	KN134	2263016865	08/16/89	20394
706608	89TWC145V	EV008	2264016543	08/31/89	0
706609	89TWC146V	EV008	2264016543	08/31/89	0
706610	89TWC147V	EV008	2264016543	08/31/89	0
706611	89TWC148V	EV900	2264016652	08/31/89	0
706612	89TWC149V	EV900	2264016652	08/31/89	0
706613	89TWC150V	EV900	2264016652	08/31/89	0
706614	89TWC155V	BA002	2264016451	08/31/89	1
706615	89TWC156V	BA002	2264016451	08/31/89	1
706616	89TWC157V	BA002	2264016451	08/31/89	23
706617	89TWC172V		2265016520	09/04/89	0
706618	89TWC173V		2265016520	09/04/89	0
706619	89TWC174V		2265016520	09/04/89	1
706620	89TWC175V	WH502	2262016330	09/04/89	12
706621	89TWC176V	WH502	2262016330	09/04/89	1
706622	89TWC177V	WH502	2262016330	09/04/89	1
706623	89TWC178V	WH502	2262016340	09/04/89	0
706624	89TWC179V	WH502	2262016340	09/04/89	0
706625	89TWC180V	WH502	2262016340	09/04/89	0
706626	89TWC195V	EW013	2262016027	09/12/89	1
706627	89TWC196V	EW001	2262016036	09/12/89	0
706628	89TWC197V	EW001	2262016034	09/13/89	1
706629	89TWC198V		2265016086	09/13/89	1
706630	89TWC199V		2265016192	09/13/89	1
706631	89TWC200V		2265016194	09/13/89	4
706632	89TWC201V		2265016154	09/13/89	1
706633	89TWC202V	ER001	2264016715	09/14/89	2
706634	89TWC203V	ER021		09/14/89	3016
706635	89TWC204V	ER005	2265016432	09/14/89	5342
706636	89TWC205V	ER006	2265016430	09/14/89	11810
706637	89TWC206V	ER007	2265016428	09/14/89	5178
706638	89TWC207V	ER019	2265016406	09/14/89	7802
706639	89TWC208V	BS503	2265016244	09/14/89	0
706640	89TWC209V	CU008	2242013014	09/15/89	0
706641	89TWC210V	CU010	2242013020	09/15/89	1

Appendix 1.--Continued.

Sample number	Collector's identification	Segment number	Stream number	Sample date	TPHC
706642	89TWC211V	CU013	2242013030	09/15/89	22572
706643	89TWC212V	CU015	2242013062	09/15/89	0
706644	89TWC213V		2262016194	09/16/89	0
706645	89TWC214V	BP004	2262016194	09/16/89	78655
706646	89TWC217V	BA005	2264016351	09/17/89	0
706647	89TWC218V	BA005	2264016337	09/17/89	0
706648	89TWC219V	BA005	2264016335	09/17/89	0
706649	89TWC220V		2262016192	09/18/89	0
706650	89TWC221V	BA005	2264016346	09/18/89	0
706701	89TWC222V	BA005	2264016332	09/18/89	2
706702	89TWC223V	BA005	2264016328	09/18/89	0
706703	89TWC224V	BA005	2264016324	09/18/89	0
706704	89TWC225V	BA006	2264016319	09/18/89	1
706705	89TWC226V	BA006	2264016315	09/18/89	0
706706	89TWC227V	BA006	2264016305	09/18/89	0
706707	89TWC228V	BA006	2264016303	09/18/89	0
706708	89TWC229V	BA006	2264016301	09/18/89	19435
706709	89TWC230V	BA006	2264016285	09/18/89	7297
706710	89TWC231V	BA006	2264016289	09/19/89	28876
706711	89TWC232V	BA006	2264016317	09/19/89	26313
706712	89TWC233V	BA006	2264016285	09/19/89	0
706713	89TWC235V	BA006	2264016272	09/19/89	0
706714	89TWC236V	FL002	2264016390	09/20/89	6448
706715	89TWC237V	FL002	2264016388	09/20/89	13762
706716	89TWC238V	FL002	2264016384	09/20/89	4194
706717	89TWC239V	FL004	2264016381	09/20/89	
706718	89TWC240V	FL005	2264016400	09/20/89	4
706719	89TWC241V	BA001	2264016369	09/20/89	27268
706720	89TWC242V	BA001	2264016372	09/20/89	577
706721	89TWC243V	BA001	2264016414	09/20/89	1
706722	89TWC244V	EV003	2264016590	09/20/89	4866
706723	89TWC245V	EV005	2264016582	09/20/89	6779
706724	89TWC246V	EV005	2264016580	09/20/89	3965
706725	89TWC247V	EV005	2264016577	09/20/89	1
706726	89TWC248V	EV005	2264016575	09/21/89	0
706727	89TWC249V	EV007	2264016561	09/21/89	0
706728	89TWC250V	EV007	2264016563	09/21/89	0
706729	89TWC251V	EV007	2264016559	09/21/89	17910
706730	89TWC252V	EV007	2264016557	09/21/89	0
706731	89TWC253V	BA003	2264016461	09/21/89	0
706732	89TWC254V	BA003	2264016466	09/21/89	0

Appendix 1.--Continued.

Sample number	Collector's identification	Segment number	Stream number	Sample date	TPHC
706733	89TWC255V	BA003	2264016466	09/21/89	0
706734	89TWC256V	NA026	2224012950	09/22/89	2
706735	89TWC257V	IN031	2261016916	09/22/89	4033
706736	89TWC258V	KN103	2261016922	09/22/89	1914
706737	89TWC259V	KN110	2261016928	09/22/89	6439
706738	89TWC260V	KN120	2261016940	09/22/89	4821
706739	89TWC261V	KN134	2263016865	09/22/89	69599
706740	89TWC262V	KN007	2263016872	09/22/89	24788
706741	89TWC263V	KN201	2263016869	09/22/89	10715
706742	89TWC264V	KN511	2262016862	09/22/89	1
706743	89TWC265V	KN511	2262016863	09/22/89	0
706744	89TWC266V	KN551	2262016864	09/23/89	0
706745	89TWC267V	KN551	2262016866	09/23/89	0
706746	89TWC268V	KN511	2262016868	09/23/89	0
706747	89TWC269V	KN552	2262016889	09/23/89	0
706748	89TWC270V	KN553	2262016895	09/23/89	0
706749	89TWC271V	KN551	2262016835	09/23/89	0
706750	89TWC272V	KN511	2262016844	09/23/89	0
706801	89TWC273V	KN551	2262016846	09/23/89	1
706802	89TWC274V	KN551	2262016848	09/23/89	0
706803	89TWC275V	KN551	2262016850	09/23/89	0
706804	89TWC277V	KN575	2262016952	09/23/89	6
706805	89TWC278V	WH003	2262016322	09/25/89	48136
706806	89TWC279V	WH003	2262016321	09/25/89	0
706807	89TWC280V	WH003	2262016320	09/25/89	0
706808	89TWC281V	WH003		09/25/89	19483
706809	89TWC282V	LA015	2264016783	09/25/89	2596
706810	89TWC283V	LA015	2264016782	09/25/89	834
706849	89RLG002V	CH001	2262016280	08/13/89	37737
706850	89RLG004V	CH001	2262016280	08/13/89	20297
706851	89RLG006V	CH001	2262016280	08/13/89	1018
706852	89RLG008V	CH017	2262016270	08/13/89	0

Appendix 2.--Total polynuclear aromatic hydrocarbon (TPAH) concentration (ng/g) and concentration of individual PAH analytes in sediment samples from Prince William Sound stream deltas from 1989 and 1995. Samples analyzed by GERG (1990, 1991) are not included. Sample# is an identification number in the EVOS database (Short et al. 1996); numbers beginning with 6 are from 1995; numbers beginning with 7 are from 1989. Collector's ID# is the identification number assigned by the sampler. Acronyms for PAH analytes are abbreviations of those used in the EVOS database (Short et al. 1996). Dash indicates PAH below method detection limit.

Sample ID	Collector's ID#	TPAH	NAPH	MEN2	MEN1	DIMET	C2NAP	TRIME	C3NAP	C4NAP	BIPHE	FLUO	C1FLU	C2FLU	C3FLU
601301	KN103-1	2	1	-	-	-	-	-	-	-	-	-	-	-	-
601307	KN103-7	7	-	-	-	-	-	-	-	-	-	-	-	-	-
601313	KN701-4	1	-	-	-	-	-	-	-	-	-	-	-	-	-
601314	KN701-5	6	1	-	-	-	-	-	-	-	-	-	-	-	-
601315	KN701-6	1	1	-	-	-	-	-	-	-	-	-	-	-	-
601316	KN701-7	650	-	-	-	-	-	-	-	-	-	-	-	-	-
601320	KN132-1	596	1	-	-	-	-	-	-	6	-	6	-	5	7
601321	KN132-2	2,800	14	-	-	-	-	-	17	23	-	-	-	27	37
601322	KN132-3	403	-	-	-	-	-	-	-	11	-	-	-	6	6
601324	KN132-5	19	1	-	-	-	-	-	-	-	-	-	-	-	-
601325	KN132-6	162	4	1	1	-	-	-	-	-	-	-	-	-	-
601326	KN132-7	4	1	-	-	-	-	-	-	-	-	-	-	-	-
601338	CHOO2-1	4	-	-	-	-	-	-	-	-	-	-	-	-	-
601339	CHOO2-2	76	1	3	1	1	6	-	4	2	-	-	-	-	-
601342	CHOO2-5	368	-	-	-	-	-	-	-	-	-	-	-	-	-
601348	CHOO2-11	373	1	-	-	-	2	1	6	16	-	-	-	8	8
601349	CHOO1-1	41	1	-	-	-	-	-	3	1	-	-	-	1	-
602002	EV017-1	33	2	2	1	1	4	-	2	-	-	-	-	-	-
602003	EV017-2	11	1	1	1	-	2	-	-	-	-	-	-	-	-
602007	EV017-6	202	3	3	1	2	5	1	6	6	-	4	-	3	-
602010	EV017-9	14	2	1	1	-	3	-	-	-	-	-	-	-	-
602012	EV025-1	44	2	-	-	-	-	-	5	-	-	-	-	-	-
602013	EV025-2	1,769	14	-	-	-	-	-	19	20	-	-	-	20	32
602014	EV025-3	13	4	-	1	-	-	-	-	-	-	-	-	-	-
602015	EV025-4	33	7	1	1	-	-	-	2	-	-	-	-	-	-

Appendix 2. Continued.

Sample ID	Collector's ID#	TPAH	NAPH	MEN2	MEN1	DIMET	C2NAP	TRIME	C3NAP	C4NAP	BIPHE	FLUO	C1FLU	C2FLU	C3FLU
602016	EV025-5	92	3	1	1	-	-	-	3	-	-	-	-	2	-
602017	EV025-6	10	2	0	1	-	-	-	-	-	-	-	-	-	-
602028	EV900-5	6	5	-	-	-	-	-	-	-	-	-	-	-	-
602030	LA018A-1	1,125	6	9	5	7	24	11	45	23	-	-	15	23	15
602031	LA018A-2	191	2	3	2	2	6	2	12	13	-	-	2	5	1
602032	LA018A-3	117	2	2	1	-	5	-	6	6	-	-	2	3	1
602033	LA018A-4	89	2	1	1	-	3	-	4	4	-	-	2	3	-
602034	LA018A-5	136	1	2	2	1	5	1	7	8	-	-	2	5	5
706203	89WP003V	73,820	-	-	-	-	-	906	5,009	7,910	-	-	828	3,745	1,907
706205	89WP005V	967,907	-	1,090	3,514	14,096	64,449	24,190	143,731	89,179	1,277	3,442	20,234	38,462	15,813
706207	89WP010V	74,857	-	-	-	-	-	338	2,038	6,219	-	-	681	3,617	2,122
706210	89WP013V	2,982	4	-	-	-	-	-	35	117	-	-	16	87	90
706212	89WP016V	3,200	7	-	-	-	-	-	26	155	-	-	13	126	106
706213	89WP021V	23,908	-	-	-	-	-	-	1,494	3,677	-	-	-	975	650
706215	89WP025V	136,348	-	-	-	-	-	2,702	14,470	15,771	-	-	2,354	6,859	3,463
706216	89RLG005V	2,981	-	-	-	-	-	-	-	-	-	-	-	-	-
706217	89RLG017V	963	1	3	2	4	18	12	60	70	2	2	12	37	25
706218	89RLG019V	5	0	-	-	-	1	-	-	-	-	-	-	-	-
706219	89RLG138V	11	2	1	1	-	2	-	2	-	-	-	-	-	-
706220	89RLG139V	40	2	1	1	1	3	1	3	1	-	1	1	2	-
706221	89RLG140V	5	1	0	0	-	1	-	1	-	-	-	-	-	-
706222	89TWC042V	0	0	-	-	-	-	-	-	-	-	-	-	-	-
706223	89TWC043V	1	-	-	-	-	-	-	-	-	-	-	-	-	-
706224	89TWC044V	16	4	1	0	-	1	-	1	-	-	-	-	-	-
706225	89TWC045V	0	-	-	-	-	-	-	-	-	-	-	-	-	-
706226	89TWC151V	0	-	-	-	-	-	-	-	-	-	-	-	-	-
706227	89TWC152V	0	0	-	-	-	-	-	-	-	-	-	-	-	-
706228	89TWC153V	1	-	-	-	-	-	-	-	-	1	-	-	-	-

Appendix 2. Continued.

Sample ID	Collector's ID#	TPAH	NAPH	MEN2	MEN1	DIMET	C2NAP	TRIME	C3NAP	C4NAP	BIPHE	FLUO	C1FLU	C2FLU	C3FLU
706229	89RLG014V	319,113	-	-	-	801	3,663	3,745	19,983	33,128	-	-	4,247	16,111	9,585
706230	89AW158V	114	5	5	2	3	7	-	4	-	4	7	8	2	-
706246	89LBR003V	622,243	-	-	-	4,016	20,643	13,166	73,976	46,045	-	1,798	13,344	24,877	10,352
706316	89RLG063V	0	-	-	-	-	-	-	-	-	-	-	-	-	-
706321	89RLG067V	5	-	1	-	-	-	-	-	-	-	-	-	-	-
706327	89RLG078V	0	-	-	-	-	-	-	-	-	-	-	-	-	-
706330	89RLG081V	1	1	-	-	-	-	-	-	-	-	-	-	-	-
706342	89RLG093V	1	1	-	-	-	-	-	-	-	-	-	-	-	-
706406	89RLG107V	159	6	3	1	2	6	1	7	5	1	1	2	4	-
706417	89RLG118V	14,957	-	-	-	-	-	122	534	1,129	-	-	132	695	326
706425	89RLG125V	18	14	1	1	-	-	-	-	-	-	-	-	-	-
706431	89RLG131V	4	1	1	-	-	-	-	-	-	-	-	-	-	-
706438	89RLG141V	379	13	20	5	6	15	2	11	10	7	18	33	14	-
706443	89RLG182V	182,932	-	-	-	794	3,909	4,289	24,135	16,534	-	-	3,879	9,167	3,035
706447	89RLG187V	72,416	-	-	-	-	145	1,152	7,695	11,777	-	-	910	4,191	1,503
706510	89RLG289V	26	5	4	1	2	3	-	-	-	-	-	-	-	-
706514	89RLG293V	86,970	87	-	-	-	115	366	1,852	2,169	-	50	985	3,347	2,874
706522	89RLG301V	13	11	2	-	-	-	-	-	-	-	-	-	-	-
706536	89TWC033V	201	2	5	2	4	12	4	15	12	-	2	4	5	-
706543	89TWC040V	1	-	1	-	-	-	-	-	-	-	-	-	-	-
706546	89TWC051V	1	-	-	-	-	-	-	-	-	-	-	-	-	-
706604	89TWC059V	0	-	-	-	-	-	-	-	-	-	-	-	-	-
706608	89TWC145V	0	-	-	-	-	-	-	-	-	-	-	-	-	-
706626	89TWC195V	9	9	-	-	-	-	-	-	-	-	-	-	-	-
706633	89TWC202V	14	5	-	-	-	-	-	-	-	-	-	-	-	-
706638	89TWC207V	219,949	-	228	320	2,670	9,807	6,145	32,534	23,601	139	596	5,224	13,213	8,182
706646	89TWC217V	5	2	2	-	-	-	-	-	-	-	-	-	-	-
706704	89TWC225V	3	3	-	-	-	-	-	-	-	-	-	-	-	-
706714	89TWC236V	8,447	-	-	-	-	-	-	-	1,137	-	-	-	442	150
706723	89TWC245V	46,231	-	-	-	-	-	235	1,369	3,945	-	-	490	2,348	1,255

Appendix 2. Continued.

Sample ID	Collector's ID#	DITHI	C1DIT	C2DIT	C3DIT	PHENA	MEPH	C1PHE	C2PHE	C3PHE	C4PHE	ANTH	FLUO	PYRE	C1FLU
601301	KN103-1	-	-	-	-	-	-	0	-	-	-	-	-	-	-
601307	KN103-7	-	-	-	-	-	0	1	1	-	-	-	1	-	1
601313	KN701-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
601314	KN701-5	-	-	-	-	-	-	-	-	2	1	-	-	-	0
601315	KN701-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
601316	KN701-7	-	-	-	53	-	2	4	17	55	58	-	-	-	42
601320	KN132-1	-	-	11	55	10	2	5	37	118	58	24	5	8	28
601321	KN132-2	-	14	110	440	-	12	46	221	505	294	-	13	20	67
601322	KN132-3	-	3	17	43	-	2	7	48	92	38	-	2	3	12
601324	KN132-5	-	-	-	-	1	-	1	-	1	1	-	4	3	1
601325	KN132-6	-	-	-	13	-	-	-	5	23	13	-	2	-	8
601326	KN132-7	-	-	-	-	-	-	-	-	-	-	-	0	-	-
601338	CHOO2-1	-	-	-	-	-	-	-	0	2	0	-	-	-	-
601339	CHOO2-2	-	-	2	4	1	1	3	8	12	4	-	0	-	1
601342	CHOO2-5	-	-	16	47	-	-	5	27	86	30	-	5	-	10
601348	CHOO2-11	-	4	29	42	2	4	12	52	84	27	-	4	4	7
601349	CHOO1-1	-	1	3	4	1	1	3	7	8	1	-	0	-	0
602002	EV017-1	-	-	-	-	1	0	2	1	1	0	-	1	-	1
602003	EV017-2	-	-	-	-	1	0	2	1	1	-	-	0	-	-
602007	EV017-6	-	1	9	13	8	2	8	22	35	10	23	4	3	4
602010	EV017-9	-	-	-	-	1	0	2	0	-	-	-	1	-	-
602012	EV025-1	-	-	2	2	1	1	4	6	8	2	-	-	-	1
602013	EV025-2	-	8	73	260	-	7	23	140	353	191	-	3	-	32
602014	EV025-3	-	-	-	-	1	-	2	1	-	-	-	0	-	0
602015	EV025-4	-	-	-	-	0	-	1	1	2	1	-	0	-	1
602016	EV025-5	-	-	4	7	1	1	3	9	16	8	-	1	-	2
602017	EV025-6	-	-	-	-	0	-	1	0	-	-	-	0	-	-
602028	EV900-5	-	-	-	-	-	-	1	-	-	-	-	-	-	-
602030	LA018A-1	7	19	57	111	12	13	53	128	203	95	-	8	-	19

Appendix 2. Continued.

Sample ID	Collector's ID#	DITHI	C1DIT	C2DIT	C3DIT	PHENA	MEPH	C1PHE	C2PHE	C3PHE	C4PHE	ANTH	FLUO	PYRE	C1FLU
602031	LA018A-2	1	3	11	13	3	2	9	22	27	11	-	2	2	3
602032	LA018A-3	-	2	6	8	3	1	6	14	19	7	-	2	-	2
602033	LA018A-4	-	1	6	8	1	1	4	11	17	6	-	1	-	2
602034	LA018A-5	-	2	8	11	2	1	5	14	21	9	-	1	-	2
706203	89WP003V	-	1,164	4,938	6,175	-	764	2,198	13,505	14,492	4,205	-	-	-	1,016
706205	89WP005V	12,660	23,651	40,524	43,996	16,519	21,701	86,351	126,665	101,818	28,979	-	-	2,133	7,638
706207	89WP010V	-	1,319	5,080	6,790	-	942	3,141	13,923	15,644	4,918	-	27	341	1,173
706210	89WP013V	-	19	144	334	-	14	45	374	735	290	-	-	16	79
706212	89WP016V	-	26	202	352	-	13	34	510	780	290	-	-	17	69
706213	89WP021V	-	306	1,814	2,228	-	-	-	4,177	5,791	1,503	-	-	-	430
706215	89WP025V	-	3,272	8,433	9,383	-	2,593	7,897	23,373	22,292	6,122	-	-	-	1,660
706216	89RLG005V	-	-	322	556	-	-	-	535	796	215	-	-	-	81
706217	89RLG017V	6	25	68	85	12	18	71	158	157	33	-	1	4	9
706218	89RLG019V	-	-	-	-	1	0	1	0	-	0	-	0	-	-
706219	89RLG138V	-	-	-	-	1	0	1	1	0	-	-	0	-	-
706220	89RLG139V	1	1	2	1	3	1	5	5	3	0	-	1	-	0
706221	89RLG140V	-	-	-	-	0	0	1	0	-	-	-	-	-	-
706222	89TWC042V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706223	89TWC043V	-	-	-	-	0	-	-	-	-	-	-	0	-	-
706224	89TWC044V	-	-	-	-	2	0	1	1	0	0	-	1	2	0
706225	89TWC045V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706226	89TWC151V	-	-	-	-	-	-	-	-	-	-	-	0	-	-
706227	89TWC152V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706228	89TWC153V	-	-	-	-	-	-	-	-	-	-	-	0	-	-
706229	89RLG014V	563	3,833	20,008	30,368	917	2,604	9,701	46,492	59,720	15,289	-	453	1,471	6,067
706230	89AW158V	-	-	-	-	11	2	11	3	0	1	-	2	5	5
706246	89LBR003V	9,055	24,621	32,081	30,106	13,059	16,743	67,844	92,115	71,090	20,234	-	446	1,787	5,587
706316	89RLG063V	-	-	-	-	-	-	0	-	-	-	-	-	-	-
706321	89RLG067V	-	-	-	-	-	0	1	1	-	-	-	0	-	-
706327	89RLG078V	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 2. Continued.

Sample ID	Collector's ID#	DITHI	C1DIT	C2DIT	C3DIT	PHENA	MEPH	C1PHE	C2PHE	C3PHE	C4PHE	ANTH	FLUO	PYRE	C1FLU
706330	89RLG081V	-	-	-	-	0	-	-	-	-	-	-	-	-	-
706342	89RLG093V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706406	89RLG107V	1	2	3	4	7	2	9	13	10	2	-	7	6	3
706417	89RLG118V	-	305	1,229	1,375	-	208	556	2,981	3,300	752	-	-	-	221
706425	89RLG125V	-	-	-	-	0	0	1	-	-	-	-	0	-	-
706431	89RLG131V	-	-	-	-	-	0	1	1	0	-	-	-	-	-
706438	89RLG141V	-	-	-	-	53	4	38	16	9	1	5	7	11	10
706443	89RLG182V	1,523	7,187	10,038	9,044	2,311	4,150	15,865	26,014	20,867	5,393	-	131	574	1,651
706447	89RLG187V	-	1,574	4,706	4,594	-	536	1,736	10,696	10,568	2,724	-	57	290	944
706510	89RLG289V	-	-	-	-	1	1	2	2	1	1	-	1	-	-
706514	89RLG293V	736	3,353	7,859	9,194	1,253	2,323	9,329	15,654	14,170	4,844	57	67	278	669
706522	89RLG301V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706536	89TWC033V	-	-	1	2	6	2	8	12	14	6	-	5	6	7
706543	89TWC040V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706546	89TWC051V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706604	89TWC059V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706608	89TWC145V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706626	89TWC195V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706633	89TWC202V	-	-	-	-	1	1	3	2	1	-	-	0	-	-
706638	89TWC207V	718	4,962	11,389	9,254	1,638	3,939	15,440	25,529	24,956	7,216	242	90	589	2,577
706646	89TWC217V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706704	89TWC225V	-	-	-	-	-	-	-	-	-	-	-	-	-	-
706714	89TWC236V	-	112	714	871	-	54	78	1,338	1,951	498	-	-	-	155
706723	89TWC245V	-	994	3,453	3,987	47	512	1,865	8,619	9,314	2,536	-	22	202	758

Appendix 2. Continued.

Sample ID	Collector's ID#	BENAN	CHRYS	C1CHR	C2CHR	C3CHR	C4CHR	BENZO	BENEP	BENAP	PERYL	INDEN	DIBEN	BENZOP
601301	KN103-1	-	-	-	-	-	-	-	-	-	-	-	-	1
601307	KN103-7	-	0	1	-	-	-	-	-	-	-	-	-	1
601313	KN701-4	-	-	-	-	-	-	-	-	-	-	-	-	1
601314	KN701-5	-	-	1	0	0	-	-	-	-	-	-	-	1
601315	KN701-6	-	-	-	-	-	-	-	-	-	-	-	-	-
601316	KN701-7	-	32	70	49	110	48	6	43	7	-	-	6	48
601320	KN132-1	3	29	48	27	30	12	12	25	4	-	3	2	13
601321	KN132-2	6	86	174	188	268	82	24	70	8	-	-	-	34
601322	KN132-3	-	14	28	13	20	10	5	13	1	-	-	-	10
601324	KN132-5	1	1	1	-	-	-	2	-	1	-	-	-	1
601325	KN132-6	-	11	18	9	19	9	3	14	2	-	-	-	8
601326	KN132-7	-	1	1	-	-	-	-	-	-	-	-	-	1
601338	CHOO2-1	-	-	1	-	-	-	-	-	-	-	-	-	1
601339	CHOO2-2	-	4	5	2	2	1	2	4	-	-	-	-	2
601342	CHOO2-5	-	15	29	35	32	6	9	15	-	-	-	-	-
601348	CHOO2-11	1	12	21	4	3	3	5	7	1	-	1	-	3
601349	CHOO1-1	-	1	2	-	-	-	-	-	-	-	-	-	-
602002	EV017-1	-	3	3	-	0	1	1	3	-	-	-	-	1
602003	EV017-2	-	1	0	-	-	-	-	-	-	-	-	-	-
602007	EV017-6	1	7	8	1	0	0	3	3	1	-	-	-	1
602010	EV017-9	-	1	0	-	-	-	1	1	-	-	-	-	-
602012	EV025-1	-	3	4	-	-	-	-	-	-	-	-	-	1
602013	EV025-2	-	42	100	114	164	51	16	46	6	-	-	-	34
602014	EV025-3	-	1	1	-	-	-	1	-	-	-	-	-	1
602015	EV025-4	-	4	4	-	-	1	2	4	-	-	-	-	2
602016	EV025-5	-	4	7	2	2	3	3	5	1	-	1	-	4
602017	EV025-6	-	1	1	-	-	-	1	-	-	-	-	-	2
602028	EV900-5	-	0	-	-	-	-	-	-	-	-	-	-	-
602030	LA018A-1	-	23	43	41	61	13	7	19	-	-	-	-	9

Appendix 2. Continued.

Sample ID	Collector's ID#	BENAN	CHRYS	C1CHR	C2CHR	C3CHR	C4CHR	BENZO	BENEP	BENAP	PERYL	INDEN	DIBEN	BENZOP
602031	LA018A-2	-	5	9	2	2	3	2	5	-	-	-	-	3
602032	LA018A-3	-	4	5	1	1	1	2	3	-	-	-	-	1
602033	LA018A-4	-	2	4	1	-	1	1	2	-	-	-	-	1
602034	LA018A-5	-	4	6	1	2	1	1	3	-	-	-	-	1
706203	89WP003V	-	965	1,748	1,478	778	88	-	-	-	-	-	-	-
706205	89WP005V	-	6,553	11,607	9,185	5,683	1,043	-	1,726	-	-	-	-	-
706207	89WP010V	-	1,152	2,029	1,638	1,104	186	124	310	-	-	-	-	-
706210	89WP013V	-	95	158	132	106	20	17	40	-	-	-	-	13
706212	89WP016V	-	77	140	115	86	18	10	28	-	-	-	-	-
706213	89WP021V	-	-	500	360	-	-	-	-	-	-	-	-	-
706215	89WP025V	-	1,031	2,071	1,725	875	-	-	-	-	-	-	-	-
706216	89RLG005V	-	200	195	81	-	-	-	-	-	-	-	-	-
706217	89RLG017V	-	12	22	20	5	0	3	5	-	-	-	-	-
706218	89RLG019V	-	1	-	-	-	-	-	-	-	-	-	-	-
706219	89RLG138V	-	0	-	-	-	-	-	-	-	-	-	-	-
706220	89RLG139V	-	1	0	-	-	-	-	-	-	-	-	-	-
706221	89RLG140V	-	-	-	-	-	-	-	-	-	-	-	-	-
706222	89TWC042V	-	-	-	-	-	-	-	-	-	-	-	-	-
706223	89TWC043V	-	0	-	-	-	-	-	-	-	-	-	-	-
706224	89TWC044V	1	1	-	-	-	-	-	-	-	-	-	-	-
706225	89TWC045V	-	-	-	-	-	-	-	-	-	-	-	-	-
706226	89TWC151V	-	-	-	-	-	-	-	-	-	-	-	-	-
706227	89TWC152V	-	-	-	-	-	-	-	-	-	-	-	-	-
706228	89TWC153V	-	-	-	-	-	-	-	-	-	-	-	-	-
706229	89RLG014V	566	5,310	9,786	5,539	2,463	1,223	1,632	2,887	411	-	-	-	549
706230	89AW158V	-	3	2	-	-	-	8	5	1	-	1	-	6
706246	89LBR003V	-	6,003	9,617	5,559	4,186	915	1,103	1,875	-	-	-	-	-
706316	89RLG063V	-	-	-	-	-	-	-	-	-	-	-	-	-
706321	89RLG067V	-	1	-	-	-	-	-	-	-	-	-	-	-
706327	89RLG078V	-	-	-	-	-	-	-	-	-	-	-	-	-
706330	89RLG081V	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 2. Continued.

Sample ID	Collector's ID#	BENAN	CHRYS	C1CHR	C2CHR	C3CHR	C4CHR	BENZO	BENEP	BENAP	PERYL	INDEN	DIBEN	BENZOP
706342	89RLG093V	-	-	-	-	-	-	-	-	-	-	-	-	-
706406	89RLG107V	3	6	4	-	-	-	16	8	5	5	4	-	5
706417	89RLG118V	-	285	470	196	-	-	-	142	-	-	-	-	-
706425	89RLG125V	-	-	-	-	-	-	-	-	-	7	-	-	-
706431	89RLG131V	-	-	-	-	-	-	-	-	-	-	-	-	-
706438	89RLG141V	1	10	8	2	-	-	20	11	2	8	3	3	12
706443	89RLG182V	-	2,575	4,194	2,477	1,692	181	495	827	-	-	-	-	-
706447	89RLG187V	70	1,264	2,323	1,411	680	160	251	458	-	-	-	-	-
706510	89RLG289V	-	2	1	-	-	-	2	-	-	23	-	-	-
706514	89RLG293V	33	1,044	1,655	1,157	724	241	157	248	21	-	-	-	57
706522	89RLG301V	-	-	-	-	-	-	-	-	-	-	-	-	-
706536	89TWC033V	3	5	13	11	9	-	7	7	4	2	2	-	4
706543	89TWC040V	-	-	-	-	-	-	-	-	-	-	-	-	-
706546	89TWC051V	-	1	-	-	-	-	-	-	-	-	-	-	-
706604	89TWC059V	-	-	-	-	-	-	-	-	-	-	-	-	-
706608	89TWC145V	-	-	-	-	-	-	-	-	-	-	-	-	-
706626	89TWC195V	-	-	-	-	-	-	-	-	-	-	-	-	-
706633	89TWC202V	-	-	-	-	-	-	-	-	-	-	-	-	-
706638	89TWC207V	236	2,219	3,798	631	447	216	374	654	-	-	-	-	176
706646	89TWC217V	-	1	-	-	-	-	-	-	-	-	-	-	-
706704	89TWC225V	-	-	-	-	-	-	-	-	-	-	-	-	-
706714	89TWC236V	-	302	465	180	-	-	-	-	-	-	-	-	-
706723	89TWC245V	-	819	1,394	843	643	116	165	297	-	-	-	-	-

Appendix 3.--Results from analysis of the relative concentrations of polynuclear aromatic hydrocarbons (PAH) in sediment samples from stream deltas in Prince William Sound in 1989 and 1995, based on the weathering model of Short and Heintz (1997). Sample# is an identification number in the EVOS database (Short et al. 1996); Segment# is a beach identification number assigned for Oilspill Response; P_{oil} is the probability of Type-1 error when rejecting the null hypothesis that the PAH pattern is consistent with similarly weathered *Exxon Valdez* oil; W is the weathering index; N is the number of PAH analytes above detection limits used in the weathering model, and TPAH is total polynuclear aromatic hydrocarbon concentration in ng/g dry weight. Values for P_{oil} and W are only approximate for $N < 14$.

Sample#	Segment#	P_{oil}	W	N	TPAH
			1989 Sediments		
706203	KN103	0.94	3.5	14	73,820
706205	KN701	0.66	0.9	14	967,907
706207	LA018	0.88	4.2	14	74,857
706210	CH002	0.20	7.6	14	2,982
706212	KN132	0.91	7.3	14	3,200
706215	EV025	0.56	1.6	14	136,348
706217	CH001	0.95	2.9	14	963
706229	KN401	0.86	4.1	14	319,113
706246	EV014	0.66	1.2	14	622,243
706417	LA036	0.70	4.2	14	14,957
706443	EV071	0.54	2.1	14	182,932
706447	LA021	0.49	3.7	14	72,416
706514	KN603	0.10	2.9	14	86,970
706638	ER019	0.10	1.3	14	219,949
706714	FL002	0.27	7.1	13	8,447
706723	EV005	0.86	4.2	14	46,231
			1995 Sediments		
601321	KN132	0.01	9.0	14	2,800
601322	KN132	0.05	8.5	13	403
601348	KN401	0.09	6.4	14	373
602007	EV017	0.04	6.0	13	202
602013	EV025	0.04	8.4	14	1,769
602030	LA018	0.08	5.3	14	1,125
602031	LA018	0.05	4.8	14	191
602032	LA018	0.05	5.0	14	117
602033	LA018	0.10	5.0	13	89
602034	LA018	0.11	4.8	14	136