Exxon Valdez Oil Spill State/Federal
Natural Resource Damage Assessment
Final Report

Hydrocarbon Residues in Tissues of Sea Otters (*Enhydra Lutris*) Collected Following the *Exxon Valdez* Oil Spill

Marine Mammal Study 6-16
Final Report

Brenda E. Ballachey[1]

U.S. Fish and Wildlife Service
Alaska Fish and Wildlife Research Center
1011 East Tudor Road
Anchorage, AK 99503

Kimberly A. Kloecker

U.S. Geological Service
Biological Resources Division
Alaska Science Center
1011 East Tudor Road
Anchorage, AK 99503

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[1] Current address: U.S. Geological Service, Biological Resources Division, Alaska Science Center, 1011 East Tudor Road, Anchorage, AK 99503

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Study History: Marine Mammal Study 6 (MM6), titled *Assessment of the Magnitude, Extent and Duration of Oil Spill Impacts on Sea Otter Populations in Alaska*, was initiated in 1989 as part of the Natural Resource Damage Assessment (NRDA). The study had a broad scope, involving more than 20 scientists over a three year period. Final results are presented in a series of 19 reports that address the various project components.

Abstract: Ten moderately to heavily oiled sea otters were collected in Prince William Sound early during the *Exxon Valdez* oil spill and up to seven tissues from each were analyzed for hydrocarbons. All of the animals had gross pathological lesions consistent with exposure to crude oil as an ultimate cause of death. Aliphatic and aromatic hydrocarbons were detected in all tissues. The alkane series C20 through C30 frequently was observed at relatively high concentrations in all tissue types, as were the aromatic compounds naphthalene, its alkylated derivatives C1-C4-naphthalene, and biphenyl. Concentrations of aromatic hydrocarbons in fat samples were an order of magnitude higher than in other tissues. The patterns of distribution of these hydrocarbons suggested crude oil as the source of contamination. However, there was variation among oiled otters in the concentrations of individual hydrocarbons, which may be due to differing proximate causes of mortality and varying lengths of time the sea otters survived following oil exposure. The ability of sea otters and other mammals to metabolize the hydrocarbon compounds found in crude oil probably helped to reduce total concentrations of hydrocarbons and changed the distribution of individual hydrocarbons present in tissues. The concentrations of both aliphatic and aromatic hydrocarbons in the tissues of the ten oiled sea otters generally were higher than in tissues from 7 sea otters with no external oiling that were collected from Prince William Sound in 1989 and 1990, or from 12 sea otters collected from an area in southeast Alaska which had not experienced an oil spill.

Key Words: carcasses, *Enhydra lutris*, *Exxon Valdez*, hydrocarbons, mortality, oil spill, sea otter.

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EXECUTIVE SUMMARY

Ten moderately to heavily oiled sea otters were collected in Prince William Sound early during the *Exxon Valdez* oil spill and up to seven tissues from each were analyzed for hydrocarbons. All of the animals had gross pathological lesions consistent with exposure to crude oil as an ultimate cause of death. Aliphatic and aromatic hydrocarbons were detected in all tissues. The alkane series C20 through C30 frequently was observed at relatively high concentrations in all tissue types, as were the aromatic compounds naphthalene, its alkylated derivatives C1-C4-naphthalene, and biphenyl. Concentrations of aromatic hydrocarbons in fat samples were an order of magnitude higher than in other tissues. The patterns of distribution of these hydrocarbons suggested crude oil as the source of contamination. However, there was variation among oiled otters in the concentrations of individual hydrocarbons, which may be due to differing proximate causes of mortality and varying lengths of time the sea otters survived following oil exposure. The ability of sea otters and other mammals to metabolize the hydrocarbon compounds found in crude oil probably helped to reduce total concentrations of hydrocarbons and changed the distribution of individual hydrocarbons present in tissues. The concentrations of both aliphatic and aromatic hydrocarbons in the tissues of the ten oiled sea otters generally were higher than in tissues from 7 sea otters with no external oiling that were collected from Prince William Sound in 1989 and 1990, or from 12 sea otters collected from an area in southeast Alaska which had not experienced an oil spill.

INTRODUCTION

On March 24, 1989, the T/V *Exxon Valdez* ran aground in Prince William Sound (PWS), eventually releasing 42,000 m^3 (11 million gallons) of Prudhoe Bay crude oil. The oil slick extended from PWS southwest along the Kenai Peninsula, past Kodiak Island to the Alaska Peninsula (Galt and Payton 1990). The spill encompassed extensive areas of sea otter (*Enhydra lutris*) habitat. Acute mortality of sea otters due to the oil spill may have been as high as several thousand animals (Ballachey et al. 1994; Garrott et al. 1993; DeGange et al. 1994), although only 994 carcasses were actually collected (Ballachey et al. 1994). Some sea otters exposed to the oil slick and recovered as carcasses may have died quickly from hypothermia, inhalation, or ingestion of oil, while others may have survived for varying lengths of time before succumbing. An unknown and presumably very small number of animals may have died from causes unrelated to the oil spill and drifted into the oil slick to become coated with oil.

The effects of petroleum exposure on sea otters and other marine mammals have been reviewed (Engelhardt 1983, 1985; Geraci and Smith 1977; Geraci and St. Aubin 1980, 1990; Waldichuk 1990). However, little has been published on the concentrations of hydrocarbons found in marine mammal tissues naturally or in animals exposed to an oil spill (Hellou 1996).

We report the results of hydrocarbon analyses of tissues taken from ten sea otters found dead in western PWS soon after the spill. All of the carcasses were covered with oil when found, and evidence of the involvement of oiling in the deaths of these animals was provided by necropsy observations. In addition, we compare hydrocarbon residues in oiled sea otters to those in unoiled sea otters collected in 1989 and 1990 from PWS ("PWS unoiled" otters), and sea otters ("SE unoiled" otters) collected from an area in southeast Alaska that has not experienced a crude oil spill.

METHODS

Animals

Shortly after the oil spill occurred, sea otter carcasses were recovered mostly from beaches and nearshore areas. They were placed in plastic bags with identifying tags and held on the recovery boats sometimes for up to several days before transfer to collection centers and storage in freezer vans at -20°C. The ten oiled sea otters in this study (Table 1) were recovered dead in western PWS, and frozen between April 5 and April 11, 1989. These otters were selected for study because they were early victims of the spill and they were heavily (greater than 60% of the pelage) or moderately (between 30 and 60% of the pelage) oiled (Williams et al. 1990).

Seven unoiled sea otters from western PWS were included for comparison to the ten oiled animals (Table 2). One was recovered dead on April 29, 1989, two were captured alive (on April 13, 1989 and May 29, 1989) and died within 48 hours at the Valdez Sea Otter Rehabilitation Center, and four were recovered dead between March and August 1990. Additional comparisons of the oiled sea otters are made to 12 unoiled sea otters that were collected from southeast Alaska (Ballachey and Kloecker 1997a).

Samples

The oiled sea otters were necropsied in the summer of 1990, and gross pathological lesions noted (Lipscomb et al. 1993, 1994). At necropsy, the carcasses were weighed and measured, the upper first premolar tooth was removed for age determination, the gender was determined and samples of liver, muscle, kidney, brain, intestine, fat, and testes were taken. Samples were taken using instruments that were cleaned with hot, soapy water and rinsed with acetone and n-hexane. Testes were sampled from only two animals. Fat was obtained from only six animals due to the poor body condition of some of the animals. The abdomen of the animal was opened with care to avoid transferring oil into the body cavity. Jejunum was stripped of obvious amounts of lumenal material before the intestinal sample was obtained. Muscle tissue was taken mostly from the internal obturator muscle. The head was skinned and disarticulated from the body. The calvarium was opened using a reciprocating saw and brain tissue was removed. Bile could not be obtained because generally it was not present in gall bladders of the frozen and thawed animals. The samples were placed in glass jars (Eagle Picher Environmental Services, Miami, Oklahoma) and frozen at -20°C in the dark. Samples were analyzed within 9 months of collection.

The unoiled sea otters that died at the Valdez Otter Rehabilitation Center were necropsied on April 14 and May 31, 1989, and tissue samples collected at that time. The remaining five unoiled sea otters were necropsied in the summer of 1990, following the same protocols used for the oiled sea otters. Liver was the only tissue from the unoiled sea otters that was analyzed for hydrocarbon residues.

The SE unoiled otters were reported on in detail by Ballachey and Kloecker (1997). Liver, kidney and muscle samples were available from this group for comparison with the PWS otters.

Hydrocarbon Analyses

Hydrocarbon analyses were done by the Geochemical and Environmental Research Group (GERG), Texas A&M University, College Station, Texas. The methods used were those initially developed by MacLeod et al. (1985) as modified by Wade et al. (1988, 1993) and Jackson et al. (1994).

Briefly, a tissue sample weighing approximately 0.5 to 1.0 g was used for the analysis. After the addition of internal standards (surrogates) and 50 g of anhydrous sodium sulfate, the tissue was extracted three times with dichloromethane using a tissuemizer. The extract was fractionated by alumina:silica open column chromatography. The extract was sequentially eluted from the column with pentane (aliphatic fraction) and pentane-dichloromethane (aromatic fraction). The aromatic fraction was further purified by HPLC to remove lipids.

Quality assurance for each set of 10 samples included a procedural blank and a sample spiked with all calibration analytes (matrix spike) which were carried through the entire analytical scheme. In addition, a laboratory reference oil from the T/V *Exxon Valdez* was used to confirm the identity of alkylated polyaromatic hydrocarbons when no standards were available, and act as a reference oil. All internal standards (surrogates) were added to the samples prior to extraction and were used for quantification.

Aliphatic hydrocarbons (n-C10 to n-C34 including pristane and phytane) were separated by gas chromatography in the split-less mode using a flame ionization detector. Analyte amounts were calculated using the surrogate standards.

Aromatic hydrocarbons were separated and quantified by gas chromatography-mass spectrometry (GC-MS). The mass spectral data were acquired using selected ions for each of the polyaromatic hydrocarbon analytes. The GC-MS was calibrated by injection of a standard component mixture at five concentrations ranging from 0.01 ng/μl to 1 ng/μl. Sample component concentrations were calculated from the average response factor for each analyte. Analyte identifications were based on correct retention time of the quantitation ion (molecular ion) for the specific analyte and confirmed by the ratio of the confirmation ion.

A calibration check standard was run three times during the sample runs (beginning, middle and end), with no more than 6 h between calibration checks. The calibration check was confirmed to maintain an average response factor within 10% for all analytes, with no one analyte greater than 25% of the known concentration. With each set of samples, a laboratory reference sample (oil spiked solution) was analyzed to confirm GC-MS system performance.

Analytical data are always estimates of the concentrations of the compounds being measured; however, the uncertainties of the estimated concentrations can be assessed. The minimum concentration of a substance that can be measured and reported with a specified statistical confidence that the analyte concentration is greater than zero can be determined and is sometimes termed the method detection limit (MDL). Using spiked oyster (*Crassostrea virginica*) tissue samples (n=7) obtained from the Gulf of Mexico, GERG estimated the MDLs of the hydrocarbon analytes at the 99% confidence level; these MDL estimates are listed in Appendix Table A-1. For analytes where an MDL was not specified, we used the mean value of reported MDLs to assess which concentrations were greater than MDL (i.e., the mean of aliphatic MDLs for aliphatic compounds without a reported MDL; the mean of all reported aromatic MDLs for aromatic compounds without a reported MDL).

GERG reported hydrocarbon concentrations as nanograms of analyte per gram of tissue (wet weight), and included values for individual hydrocarbons lower than the computed MDL. Sample weights and estimated concentrations for individual analytes are presented in Appendix Tables A-2 and A-3 (oiled otters) and Tables A-4 and A-5 (PWS unoiled otters).

Data Analysis

For each sample, MDLs for specific analytes were calculated as the ratio of the absolute weight MDL (ng; Table A-1) to the sample wet weight. Hydrocarbon concentrations that are above the MDL are indicated in bold-face in Tables A-2 through A-5. However, in Figures 1-16, rather than present the exact MDL for each sample, we computed the mean MDL for all samples of that tissue type from oiled otters. For example, the MDLs shown in Figure 1 are the mean MDLs for all kidney samples from the oiled otters with values graphed in that figure. This approach was based on the fact that, within a group and tissue type, sample weights were relatively similar, and was used to simplify presentation of the data in graphic form.

Wilcoxon two sample rank sum tests were used to compare the hydrocarbon data from the oiled otters to data from the SE unoiled otters (Ballachey and Kloecker 1997), within each tissue type. MDLs were computed for each sample, based on its wet weight. All values below

the MDL were treated as tied, the average rank was assigned to ties, and all possible permutations of the ranks were performed to obtain p-values. Aliphatic and aromatic hydrocarbons were analyzed separately. Only the data for kidney, liver, and muscle were included in this analysis because these were the only tissues sampled from both the oiled and SE unoiled sea otters. Hydrocarbon data from the PWS unoiled otters, which died over a two year period, were not included in statistical analyses.

RESULTS

Concentrations of aliphatic and aromatic hydrocarbons in tissue samples are presented by tissue, in Figures 1-7 (aliphatics in PWS oiled otters), Figures 8-14 (aromatics in PWS oiled otters), and Figures 15-16 (aliphatics and aromatics in liver of PWS unoiled otters). Mean hydrocarbon concentrations from SE unoiled otters (kidney, liver and muscle) are included on the graphs for kidney, liver and muscle samples from oiled otters. Values of estimated MDLs, and concentrations of individual hydrocarbon analytes in individual samples are presented in the Appendix (MDLs: Table A-1; PWS oiled: aliphatics, Table A-2; aromatics, Table A-3; PWS unoiled: aliphatics, Table A-4; aromatics, Table A-5).

Statistical Analysis

The exact two-tailed p-values of the Wilcoxon tests between PWS oiled and SE unoiled samples are listed in Table 3. The pattern of compounds for which the P values indicated significant differences was similar in the three tissues, and in general agreement with results presented below for kidney, liver and muscle. C13 differed significantly between areas ($P=0.0000$, 0.0126, 0.0000 for kidney, liver and muscle respectively); SE unoiled samples had higher concentrations. Generally, most P values for the C19 to C28 alkane series were significant in all three tissues ($P<0.01$), reflecting the higher concentrations observed in the oiled samples. C22 was an exception: SE unoiled samples exhibited a C22 peak, which resulted in no significant differences observed between groups for this alkane. For the aromatic hydrocarbons, only the naphthalenes (including alkylated derivatives C1N, C2N and C3N but not C4N) and biphenyl showed significant differences between the oiled and SE unoiled groups, corresponding to higher concentrations observed in the oiled samples. As expected, no differences between groups were detected for any other aromatic compounds, as all values were below MDL.

Hydrocarbon Concentrations

Kidney, Liver and Muscle: Within each group, distributions of aliphatic compounds generally were similar in kidney, liver and muscle samples. Concentrations of the C10 to C14 alkanes were relatively low (frequently reported at 0), with few values detected above the MDL. C13, however, tended to differ among groups. In the PWS unoiled liver samples, C13 was very low, reported at <10 ng/g in all samples, well below MDL. In contrast, in the SE unoiled samples (liver, kidney and muscle), C13 was relatively high, with concentrations ranging from 47 to 143 ng/g, all $>$MDL. In the PWS oiled liver, kidney and muscle, C13

was much more variable: only 8 of the 30 samples had concentrations >47 ng/g, and many were reported at 0.

Concentrations of C15 were elevated in many samples from the oiled group, but were highly variable, ranging from 0 to about 1.7 μg/g, with 40% having concentrations above 200 ng/g, which was >MDL. In contrast, 7 of the 8 PWS unoiled samples were less than 40 ng/g, <MDL, and the other sample was 132 ng/g, and all the SE unoiled samples were less than <200 ng/g, although about one third of them were >MDL. However, these differences in C15 concentrations between the oiled and SE unoiled groups were not significant. Within an individual otter, concentrations of C15 tended to be relatively similar among tissues. For example, VD018 had values of 0 reported for C15 in all tissues except brain, whereas VD141 had relatively high C15 concentrations in all tissues analyzed.

Concentrations of C16 to C19 tended to be relatively low in most groups, although many were >MDL. For the range C20 to C30, a relatively consistent pattern was observed in the oiled samples: concentrations increased, with a peak around C25, and then decreased through C30. A high proportion of these values were >MDL. This was in marked contrast to the PWS unoiled samples, where the C20 to C30 alkanes were generally much lower (most were below MDL), and the SE unoiled samples where concentrations measured also were, on the average, much lower than those observed for oiled samples (although many were >MDL). In the oiled samples and in both unoiled groups, alkanes C31 to C34 were generally low, with most values below MDL. Pristane was frequently present at concentrations >MDL in liver and kidney samples from all three groups; however, the PWS samples (oiled and unoiled) exhibited higher concentrations and greater variability among otters than did the SE unoiled samples. Muscle samples from both PWS oiled and SE unoiled otters had concentrations of pristane that were consistently low and below the MDL. Phytane in kidney and muscle was detected only at low concentrations, below MDL, in all groups. In liver, however, several samples from PWS (5 oiled and and 4 unoiled) had phytane concentrations detected >MDL, and although the concentrations of the oiled group were higher than those of the unoiled, all but a single sample (VD068) were <100ng/g. Differences in both pristane and phytane concentrations in liver samples between the PWS oiled and SE unoiled groups were significant. The UCM fraction was either not detected or present at low concentrations, with only 2 samples (livers from one oiled and one SE unoiled otter) having concentrations greater than 20 μg/g.

The distribution of aromatic hydrocarbons generally was similar among kidney, liver and muscle samples from PWS oiled otters, although concentrations reported for muscle tended to be slightly lower. For many samples of all three tissue types, naphthalene and its alkylated derivatives, and biphenyl were detected at concentrations well above the MDL. With the exception of a single kidney sample (VD028) that had a concentration of phenanthrene slightly >MDL, no other aromatic hydrocarbons were detected at concentrations >MDL in any kidney, liver or muscle samples.

In all 3 tissues, concentrations of C1-naphthalene were higher than the other compounds, and ranged as high as 523 ng/g (kidney), 355 ng/g (liver) and 101 ng/g (muscle). Concentrations of C1-, C2- and C3-naphthalene were generally higher than that of naphthalene, which was reflected in the fact that C1-, C2- and C3-naphthalene were more frequently detected >MDL than were the other compounds (59% of samples were >MDL for these three aromatics). C4-naphthalene was reported at zero in most samples, with only 10%

having concentrations detected >MDL. Tissues from an individual animal tended to be similar in concentrations of aromatics. Fluorene, phenanthrene, dibenzothiophene and their C1 and C2 alkylated derivatives were reported at low concentrations (<30 ng/g) in several samples; however, these concentrations were all <MDL.

In contrast, aromatic concentrations in liver samples from PWS unoiled otters were very low, with all values below 20 ng/g and almost all values <MDL. The SE unoiled kidney, liver and muscle samples were similar to the PWS unoiled livers; however, no aromatic values were >MDL. For naphthalene and C1-naphthalene, concentrations reported for the unoiled samples (40 samples total from both areas) were all <18 ng/g, whereas all but two (both muscle) of the 30 oiled samples had concentrations >18 ng/g. Similarly, for biphenyl, there was no overlap in concentrations reported for the unoiled samples and the oiled samples, with the exception of one muscle sample from the oiled group. Naphthalene, C1-, C2-, and C3-naphthalene, and biphenyl concentrations were significantly higher in kidney and liver from PWS oiled otters than in SE unoiled otters. C1-, C2-, and C3-naphthalene concentrations were also significantly higher in muscle from PWS oiled otters than SE unoiled otters. Samples from the two unoiled groups consistently had zero values reported for all alkylated derivatives other than C1-naphthalene, but this was true for only 2 (VD015 and VD141) otters from the oiled group. These two individuals had consistently low concentrations of aromatic hydrocarbons in all tissues analyzed.

Brain: In brain samples of oiled otters, the pattern and concentrations of aliphatics generally were similar to those seen in kidney, liver and muscle, although somewhat more variable. Remarkably high values were reported for C20 (5606 ng/g), C23 (8748 ng/g) and C25 (14,583 ng/g) in brain from VD028, but were not observed in other tissues from this animal. Pristane and phytane concentrations in brain were generally low, similar to those seen in muscle, with almost all concentrations reported <MDL.

Brain samples from eight of the 10 oiled otters exhibited patterns of naphthalene, alkylated naphthalenes and biphenyl similar in magnitude to those measured in kidney and liver. Only 2 samples (VD015, VD141) had concentrations of these compounds below MDL.

Fat: Fat samples for analysis were available from only six of the oiled otters. The concentrations of shorter chain alkanes (C10 to C17) tended to be more variable, with some higher values than reported for other tissues. However, with a few exceptions, concentrations of alkanes C18 to C34 generally were not elevated, compared to other tissues from the same animals. High concentrations (>1500 ng/g) were measured at C14 in one sample (VD028), and at C23 in two samples (VD059 and VD065). In five samples, pristane was present at much higher concentrations (990 to 3300 ng/g) than seen in other tissues (except intestine), whereas phytane was low (close to or below MDL) in all six samples.

Aromatic patterns seen in other tissues also were observed in fat samples, but compounds were measured at higher concentrations (generally an order of magnitude greater) than in other tissues. In addition to naphthalene and its alkylated derivatives, fluorene, phenanthrene, dibenzothiophene and their corresponding alkylated derivatives were detected >MDL in five of the six fat samples, although concentrations of these compounds were considerably less than those of the naphthalene series. However, a pattern was clearly seen, in that the C1- alkylated derivative (and also the C2- for fluorene) was detected at a higher

concentration than the parent compound. This pattern was also seen in other tissues, where concentrations of these compounds had been < MDL, but was more readily observed in fat due to the higher concentrations.

Intestine: The intestinal sample from one oiled otter (VD074) had extremely high concentrations (approximately an order of magnitude greater) of aliphatic and aromatic hydrocarbons present relative to all other samples of intestine or other tissues, and was the only sample in the study for which the analytical laboratory reported non-zero concentrations for all hydrocarbons measured, including the only occurrence of alkylated chrysenes. Most (80%) of the compounds measured were > MDL. Concentrations of alkylated derivatives of naphthalene, phenanthrene, fluorene, dibenzothiophene, and chrysene were higher than the respective parent compounds. The UCM fraction reported for this sample (905 μg/g) was much higher than the UCM reported in other samples in this study. Concentrations of aliphatic or aromatic hydrocarbons in other tissues from this otter were not markedly different from comparable tissues from other animals, although aromatic concentrations were generally high, and aliphatic concentrations low, relative to other oiled otters.

Aliphatic concentrations were also relatively high for intestinal samples from VD059 and for VD028, compared to other intestine samples and to other tissues. However, for aromatics, VD059 had relatively high concentrations (naphthalene, alkylated derivatives, biphenyl, and C1-, C2- and C3-phenanthrene) compared to intestinal samples from most other otters, but these concentrations were not markedly elevated relative to other tissues. Aromatic concentrations measured for intestine of VD028 were low and almost all were < MDL. One other otter, VD165, had relatively high concentrations of aromatic compounds in the intestine, but aliphatic compounds for this sample were not remarkably high. Phytane was reported at concentrations > MDL for VD074, VD059 and VD028, but in all other samples was low and below MDL.

Testis: Only two samples of testis were analyzed, from oiled otters VD018 and VD056. The pattern and concentrations of both alkanes and aromatics generally were similar to those seen in other tissues from the same animals. One sample (VD056) had concentrations of naphthalene, C1-C4-naphthalene, and C1- and C2-dibenzothiophene higher than MDL, with the remainder of the aromatics reported at low concentrations. The other sample (VD018) had low concentrations reported for all aromatics and, except C1-naphthalene, all were < MDL.

DISCUSSION

Little information has been published specific to the occurrence, both natural or due to petroleum contamination, of hydrocarbons in mammals. Few marine mammals have been directly affected by oil spills in the marine environment, a fact that changed dramatically with the grounding of the T/V *Exxon Valdez*. Historically, when an oil spill has occurred in the marine environment, hydrocarbon studies have concentrated on the oil itself, birds (because of their numbers and wide distribution in the marine environment), and then on oil in sediments, invertebrates, fish, and finally mammals. This evolution of emphasis has influenced the

interpretation of hydrocarbon incidence and concentrations in marine mammals. Unlike most lower animals, marine mammals have the enzyme systems permitting the metabolism and excretion of systemic hydrocarbons (Engelhardt 1982; Addison and Brodie 1984; Addison et al. 1986). However, so little is known about the fate of hydrocarbons in mammals that the same interpretation of specific values of individual hydrocarbons and many of the same sums and ratios of hydrocarbons used in studies of oiled sediments have been used for studies of oiled marine mammals (Hall and Coon 1988).

The presentation and discussion of hydrocarbon data which are quantitatively less than the calculated MDL for each hydrocarbon are controversial (Rhodes 1981, Berthouex 1993). MDLs are statistical values obtained from replicate analyses of samples with known quantities of the compound of interest. In the literature, hydrocarbon concentrations which fall below the MDL are presented in various ways: as "trace", "not detected (ND)", "<MDL", zero, or some incremental number between zero and the MDL. Alternate strategies, which include simply presenting the measured concentration regardless of its relationship to the MDL, presentation of both the measured concentration and the MDL (our choice), or giving the measured concentration followed by a statistical estimate of its precision, are considered superior (Berthouex 1993, Gilbert 1987). These methods prevent the discarding of useful information which occurs with the former methods, all of which censor some of the data.

In this report, we focus on those compounds detected at concentrations above the MDL, which is the most conservative approach to interpretation of the hydrocarbon data. However, the relation of the data to the MDLs is influenced by the fact that the wet weights of samples from oiled otters used for analysis were relatively low, less than 1 g. In contrast, the sample weights of the SE unoiled otters were all at least 1 g, and those of the PWS unoiled otters at least 2 g. Accordingly, the MDLs computed for samples from the oiled otters were higher than those applied to the unoiled groups. Although we are cautious in our discussion of concentrations below the MDL, the observation of patterns of distribution of compounds detected below the MDL, both within tissue types and also among samples from individual otters, and the uniformity of values in the two unoiled groups in contrast to the oiled group, support the opinion that there may be useful data below the MDL which should not be discounted. An example is the detection of alkylated derivatives of fluorene, phenanthrene, and dibenzothiophene, detected at concentrations below MDL in many tissues from oiled otters, in sharp contrast to the consistent zero values reported for these compounds in all samples from both unoiled groups. Furthermore, these alkylated derivatives, when present, generally show the pattern expected of oil contamination, in that the parent compound tends to be present at a lower concentration than the alkylated derivatives.

Mulcahy and Ballachey (1994) presented a principal components analysis of the hydrocarbon concentrations in kidney, liver, and muscle samples from the oiled and SE unoiled otters, using all concentrations as reported by GERG, including those below the MDL. They found that the two groups separated on the basis of either aliphatic or aromatic tissue concentrations. Results of the Wilcoxon analysis, with all concentrations below MDL treated as ties, concur with the principal components analysis, with about 10 specific hydrocarbons consistently showing significant differences (at $P < .01$) between groups for the three tissue types.

An additional concern when comparing hydrocarbon concentrations between groups was the possibility of a batch effect. However, the oiled samples were analyzed as one catalog

(batch), the SE unoiled as another, and the PWS unoiled samples were part of two additional catalogs. Our confidence in discussing differences in hydrocarbon concentrations is enhanced by having two unoiled groups analyzed as part of three separate catalogs for comparison. This decreases the likelihood that differences observed between the oiled and unoiled samples could be attributed to a batch effect.

Aromatic hydrocarbons have received more consideration in studies of hydrocarbon contamination of tissues than have alkanes. One factor is that aromatics are more toxic. Additionally, aromatics rarely result from biogenic sources, whereas alkanes do (NRC 1985), and differentiation of biogenic vs. petrogenic sources of alkanes can be difficult. Generally, biogenic alkanes show a high preference for odd-carbon n-alkanes (NRC 1985).

In this study, concentrations of C15, C17 and pristane were relatively high in some samples from all three groups of sea otters, and in the SE group, concentrations of C13 were also high. It is likely that these alkanes originated from a biogenic source (Ballachey and Kloecker 1997a). The variation seen in biogenic hydrocarbon concentrations in sea otter tissues is not surprising, given that individual sea otters select variable diets and that these hydrocarbons may originate from several sources and their availability may fluctuate. Unlike C15, C17 and pristane, the relatively higher concentrations of the C20 to C30 series seen in the oiled samples were not observed in either of the unoiled groups, nor were they observed in liver samples from sea otters with light external oiling collected in PWS several weeks later than the sea otters included in this study (Ballachey and Kloecker 1997b). Thus, it appears that the presence of these compounds is associated with the relatively heavy external oiling of the animals. For aromatics, the distinct difference between oiled and unoiled groups in the concentrations of naphthalene, C1-naphthalene and bipehnyl, and the presence of C2-C4-naphthalenes, demonstrates that these compounds in tissues are markers of oil exposure.

A clear correspondence between total aromatic and total aliphatic concentrations in tissues samples was not observed. For example, VD141 had high concentrations of alkanes but low concentrations of aromatics, whereas VD074 (in tissues other than intestine) had low concentrations of aliphatics and high concentrations of aromatics. In contrast,VD015 had low concentrations of both aliphatics and aromatics in all tissues, and VD065 tended to have high concentrations of both aromatic and aliphatic compounds. Why concentrations of total alkanes and total aromatics are both increased in oiled otters relative to unoiled groups, but nevertheless do not appear to show a consistent association within samples, is not known.

The presence of observable oil, such as could be found in the gastrointestinal tract, should produce elevated concentrations of all hydrocarbons when that tissue is analyzed, presuming an oiled area of the tissue was actually taken for the sample and that the oil was unweathered. The sea otter necropsy reports indicated that, when present, oil existed as patches in the gastrointestinal tract, and sometimes required the use of ultraviolet light for visualization. Thus, it might be anticipated that the concentrations of hydrocarbons found in the intestinal samples would vary greatly. The sample from VD074, which had concentrations an order of magnitude higher than other samples, and was the only sample in which all aromatic analytes were detected (including alkylated derivatives of chrysene), likely represents a situation where the tissue sample was contaminated with an "external" patch of unweathered oil. Two other samples (VD 059 and VD165) were also relatively high in concentrations of aromatics in the intestine; however, concentrations in those samples were not atypical of concentrations seen in other tissues, and so external contamination of these samples does not

seem apparent. The remainder of the intestinal samples had quite low concentrations of hydrocarbons, perhaps reflecting capability of this tissue to metabolize hydrocarbons relatively rapidly.

A sea otter with external oiling could have accumulated internal hydrocarbon contamination by several possible routes of exposure: inhalation, ingestion, and dermal absorption. It is likely that at least the first two of these three routes were important in otters. Certainly, if the fur was contaminated with unweathered oil, inhalation of volatile components of the oil would have occurred. However, oiled otters brought to the rehabilitation centers were observed to be frantically grooming, and thus it seems that ingestion also would have been unavoidable. The aromatic compounds observed in tissues at concentrations above the MDL were the most volatile compounds, suggesting inhalation as a route. These lower molecular weight compounds, however, are also somewhat more water soluble than the heavier aromatic components of oil (T. Wade, pers. comm.), and thus their prevalence in the tissues also could have occurred via ingestion and absorption in the digestive tract.

The pathologies found in sea otters killed by the spill are described by Lipscomb et al. (1993, 1994). Pulmonary emphysema, gastrointestinal hemorrhage, gastric ulceration, and the presence of oil in the gastrointestinal tract are characteristic in sea otters that died as a result of the spill. All oiled otters in this study except VD015 had either pulmonary emphysema or gastric ulcerations, or both. All oiled otters, including VD015, had gastrointestinal hemorrhages present. The presence of these lesions suggests that oil exposure was the cause of death in these otters. Similar lesions were not observed in the unoiled sea otters from southeastern Alaska nor in the two PWS unoiled sea otters that were examined.

The rather large differences were observed in tissue hydrocarbons among oiled sea otters in this study, all of which had substantial amounts of external oil, suggest varying circumstances at the time of death. However, although all the oiled carcasses were collected soon after the spill occurred, and were in good condition and coated with moderate to heavy amounts of oil, no factual information is known about how long the otters lived following exposure. We also lack information on how rapidly various tissues take up hydrocarbons, and on efficiency of metabolic processes in clearing these compounds. Hypothermia is thought to have been a major factor leading to the demise of the oiled otters, but the importance of hydrocarbon toxicity as a contributing factor in the deaths remains unknown. Additional variation in exposure of individual otters in different locations may have resulted from evaporation and dissolution of the low-molecular weight components as the oil spread into PWS.

Given our lack of information on exposure histories of individual otters, it is difficult to speculate further as to relations among specific circumstances of death and tissue hydrocarbon burdens. Controlled studies of oil exposure in sea otters and other marine mammals are required to define the relations among the exposure of sea otters to crude oil by different routes with the occurrence and concentration of specific hydrocarbons in tissues. Such studies should include effect of metabolism on the patterns of hydrocarbons in mammalian tissues at various times after exposure.

Frost et al. (1994) published total aromatic concentrations (including only values $>$MDL in the summation) in tissues of harbor seals that were collected with external oiling after the spill, similar to the sea otters. Blubber concentrations averaged 191 ng/g (range non-detect-800; $n=17$), which is much lower than the average of 6163 ng/g in sea otter fat samples

(range of 1752-12,694 ng/g, or, if only values >MDL are included, range of 1691-12,626). A similar difference, approximately an order of magnitude, was seen for total aromatics in liver samples (mean 45 ng/g in seals and 444 ng/g in sea otters). This difference between the species could arise from two factors: (1) harbor seals have a far greater total body lipid content than sea otters, and thus have a much larger reservoir for absorption of the lipophilic hydrocarbons, and (2) unlike sea otters, harbor seals do not groom, and thus ingestion was unlikely to be an important route of exposure for them. Additionally, differences in extent of external oiling, survivability subsequent to oiling, and ability to metabolize hydrocarbons absorbed into the body, may have influenced concentrations. Computation and comparison of total body burdens for individual seals and otters may provide insight into these observed species differences.

Another major difference observed between sea otters and harbor seals was in phytane concentrations in brain samples. High concentrations (>1000 ng/g) of phytane were reported for brain samples of seven harbor seals collected from PWS (Frost et al. 1994). Seventeen additional seals, however, had low or zero concentrations reported for phytane. The 10 brain samples collected from oiled sea otters had consistently low phytane concentrations, ranging from 0-62 ng/g. Other tissues from sea otters also had low phytane concentrations. Sampling procedures for the two species varied, and may have been a factor in the observed differences: seals with high phytane concentrations were shot, and samples collected within minutes of death, whereas sea otters were recovered as carcasses, and thus samples from otters would have been collected much longer after death of the animal.

CONCLUSIONS

All of the sea otters in this study were early victims of the oil spill, all were moderately to heavily covered with oil, and all had gross lesions consistent with exposure to crude oil. Analysis of tissues collected from oiled sea otters for the hydrocarbons found in crude oil revealed elevated concentrations of several aliphatic and aromatic compounds in all tissues sampled, relative to unoiled otters from both PWS and SE Alaska. However, considerable variation existed in hydrocarbon concentrations among individual otters. The freshness and toxicity of the oil when encountered, extent of oil on the pelage, length of time between oiling and death, and differences in extent and routes of exposure associated with varying otter behavior prior to death may all have contributed to variation in tissue hydrocarbon concentrations. Measurement of metabolites of oil hydrocarbons may provide additional insight into the relation between oil exposure and tissue burdens. The difficulty of interpretation and lack of consistency among oiled otters highlights that necropsies and histopathology of affected carcasses must be considered a primary part of damage assessment following an oil spill.

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Table 1. Histories of oiled sea otters from Prince William Sound sampled for hydrocarbons. All animals were dead when discovered and all had moderate to heavy oiling of their pelage. Ages were determined by counting dental annuli.

Otter number	Sex	Recovery location	Age (y)	Weight (kg)	Length (cm)
VD015	M	Smith I.	9	24.5	122
VD018	M	Unknown	1	11.8	104
VD028	M	Eleanor I.	6	22.7	127
VD056	M	Unknown	5	20.7	119
VD059	F[a]	Knight I.	6	21.8	127
VD065	F	Knight I.	5	18.1	124
VD068	M	Knight I.	4	21.8	122
VD074	M	Knight I.	1	9.9	97
VD141	F	Knight I.	1	8.3	99
VD165	F[a]	Disk I.	9	22.8	119

[a] Pregnant.

Table 2. Histories of unoiled sea otters from western Prince William Sound, sampled for hydrocarbons. No animals had discernable oiling of their pelage as determined by visual inspection and UV testing. Ages were determined by counting dental annuli.

Otter number	Sex	Recovery location	Collection date	Age (y)	Weight (kg)	Length (cm)
VD407	M	Perry I.	4/29/89	10	20.9	125
VZ121	M	Ingot I.	4/13/89	NA[a]	12.5	106
VZ156	F	Knight I.	5/29/89	NA	20.0	132
Y2D028	M	Knight I.	3/23/90	6	16.4	132
Y2D031	F	Unknown	Unknown[b]	3	14.6	119
Y2D050	F	BM003	6/14/90	7	18.6	117
Y2D058	M	Knight I.	5/9/90	3	20.5	109

[a] NA = Age not available
[b] Necropsied August 1, 1990.

Table 3. Results of statistical analysis comparing aliphatic and aromatic hydrocarbon concentrations in kidney, liver, and muscle samples from sea otters that were heavily oiled after the T/V *Exxon Valdez* oil spill to samples from sea otters from a pristine area of southeast Alaska. The regular Wilcoxon two sample rank sum test was performed. All values below MDL were treated as tied and assigned the average rank. All possible permutations of the ranks were performed to obtain p-values. P-values < 0.05 are boldfaced.

	Kidney		Liver		Muscle	
n, oiled	10		10		10	
n, southeast	10		11		12	
Aliphatic[a]	**p**[b]	**n**[c]	**p**	**n**	**p**	**n**
C10	0.4737	3	1	1	0.4545	2
C11	0.3034	6	[illegible]	4	0.4805	3
C12	0.7214	5	0.4762	2	1	1
C13	**0.0000**	10	**0.0126**	13	**0.0000**	12
C14	0.3731	6	0.0902	4	0.3233	6
C15	0.3219	11	0.3432	6	0.5449	10
C16	**0.0325**	7	0.4762	2	1	6
C17	0.6111	15	**0.0054**	15	0.0816	11
C18	1	4	0.0902	4	0.3377	4
C19	0.0587	17	**0.0013**	15	**0.0053**	12
C20	0.0851	8	**0.0039**	7	0.6617	5
C21	**0.0067**	10	**0.0004**	10	0.1053	9
C22	0.9118	19	0.4566	19	0.5697	20
C23	**0.0001**	19	**0.0002**	20	**0.0020**	21
C24	**0.0073**	19	**0.0293**	19	0.0801	20
C25	**0.0029**	17	**0.0089**	15	**0.0153**	16
C26	**0.0085**	13	**0.0054**	15	**0.0071**	15
C27	**0.0029**	18	**0.0005**	16	**0.0018**	15
C28	**0.0014**	16	**0.0035**	14	**0.0033**	14
C29	0.6656	7	0.1818	10	0.0604	8
C30	0.9814	8	0.4588	9	0.5907	10
C31	0.3034	6	0.7381	3	0.5940	5

Table 3 continued.

	Kidney		Liver		Muscle	
C32	1	4	0.7381	3	0.5940	5
C33	1	2	1	2	1	2
C34	1	1	1	1	1	1
Pristane	0.5791	13	**0.0233**	13	0.4545	2
Phytane	1	1	**0.0124**	6	1	1
UCM	0.1103	11	0.3044	10	0.3893	9
N, oiled	10		10		10	
N, southeast	10		11		12	
Aromatic Analyte[d]	**p**	**n**	**p**	**n**	**p**	**n**
NAP	**0.0108**	7	**0.0039**	7	0.4545	2
C1N	**0.0007**	9	**0.001**	8	**0.0028**	7
C2N	**0.0031**	8	**0.001**	8	**0.0096**	6
C3N	**0.0108**	7	**0.0351**	5	**0.0287**	5
C4N	0.4737	3	0.4762	2	1	1
BIP	**0.0325**	6	**0.0124**	6	0.1948	3
ANP	1	1	1	1	1	1
ANH	1	1	1	1	1	1
FLU	1	1	1	1	1	1
C1F	1	1	1	1	1	1
C2F	1	1	1	1	1	1
C3F	1	1	1	1	1	1
PHE	1	2	1	1	1	1
ANT	1	1	1	1	1	1
C1P	1	1	1	1	1	1
C2P	1	1	1	1	1	1
C3P	1	1	1	1	1	1
C4P	1	1	1	1	1	1
DIB	1	1	1	1	1	1
C1D	1	1	1	1	1	1
C2D	1	1	1	1	1	1

Table 3 continued.

	Kidney		Liver		Muscle	
C3D	1	1	1	1	1	1
FLA	1	1	1	1	1	1
PYR	1	1	1	1	1	1
CFP	1	1	1	1	1	1
BAA	1	1	1	1	1	1
CHR	1	1	1	1	1	1
C1C	1	1	1	1	1	1
C2C	1	1	1	1	1	1
C3C	1	1	1	1	1	1
C4C	1	1	1	1	1	1
BBF	1	1	1	1	1	1
BKF	1	1	1	1	1	1
BEP	1	1	1	1	1	1
BAP	1	1	1	1	1	1
PER	1	1	1	1	1	1
IDE	1	1	1	1	1	1
DBN	1	1	1	1	1	1
BEQ	1	1	1	1	1	1

[a] Abbreviations: C10-C34: n-alkanes; UCM: unresolved complex mixture.

[b] The exact two-tailed p-value from the Wilcoxon two sample rank sum test.

[c] *n refers to the number of non-tied* observations in the Wilcoxon test.

[d] Abbreviations: NAP: naphthalene; C1N: C1-naphthalene; C2N: C2-naphthalene; C3N: C3-naphthalene; C4N: C4-naphthalene; BIP: biphenyl; ANP: acenaphthylene; ANH: acenaphthene; FLU: fluorene; C1F: C1-fluorene; C2F: C2-fluorene; C3F: C3-fluorene; ANT: anthracene; PHE: phenanthrene; C1P: C1-phenanthrene; C2P: C2-phenanthrene; C3P: C3--phenanthrene; C4P: C4-phenanthrene; DIB: dibenzothiophene; C1D: C1-dibenzothiophene; C2D: C2-dibenzothiophene; C3D: C3-dibenzothiophene; FLA: fluoranthene; PYR: pyrene; CFP: methyl fluoranthene-pyrene; BAA: benz(a)anthracene; CHR: chrysene; C1C: C1-chrysene; C2C: C2-chrysene; C3C: C3-chrysene; C4C: C4-chrysene; BBF: benzo(b)fluoranthene; BKF: benzo(k)fluoranthene; BEP: benzo(e)pyrene; BAP: benzo(a)pyrene; PER: perylene; IDE: ideno(1,2,3-cd)pyrene; DBN: dibenzo(a,h)anthracene; BEQ: benzo(g,h,i)perylene.

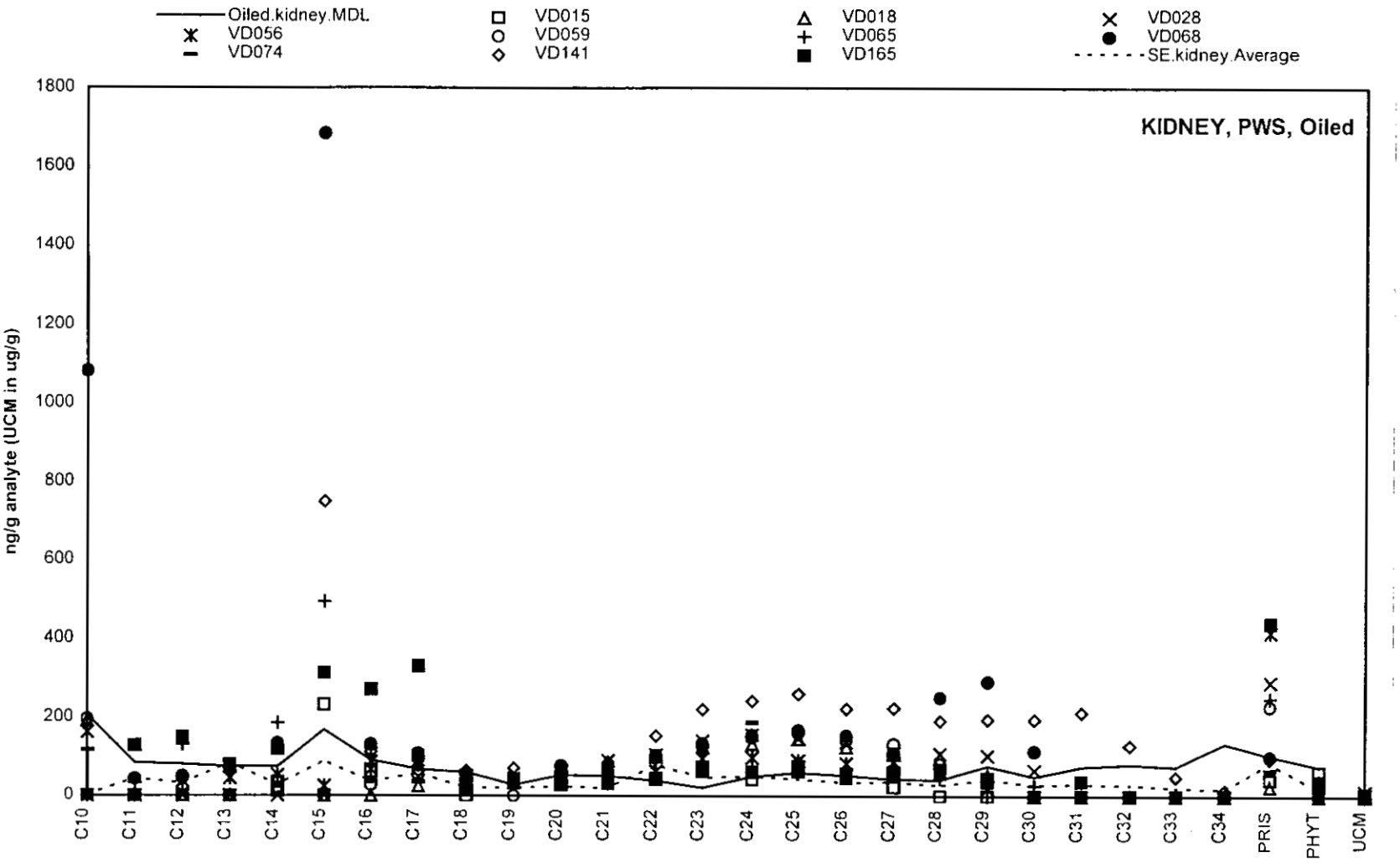

Figure 1. Aliphatic hydrocarbon concentrations present in kidney samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram except UCM which is in micrograms per gram. The solid line indicates the mean MDL for oiled kidney samples, and the dashed line indicates the mean hydrocarbon concentration of the SE unoiled kidney samples. Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture.

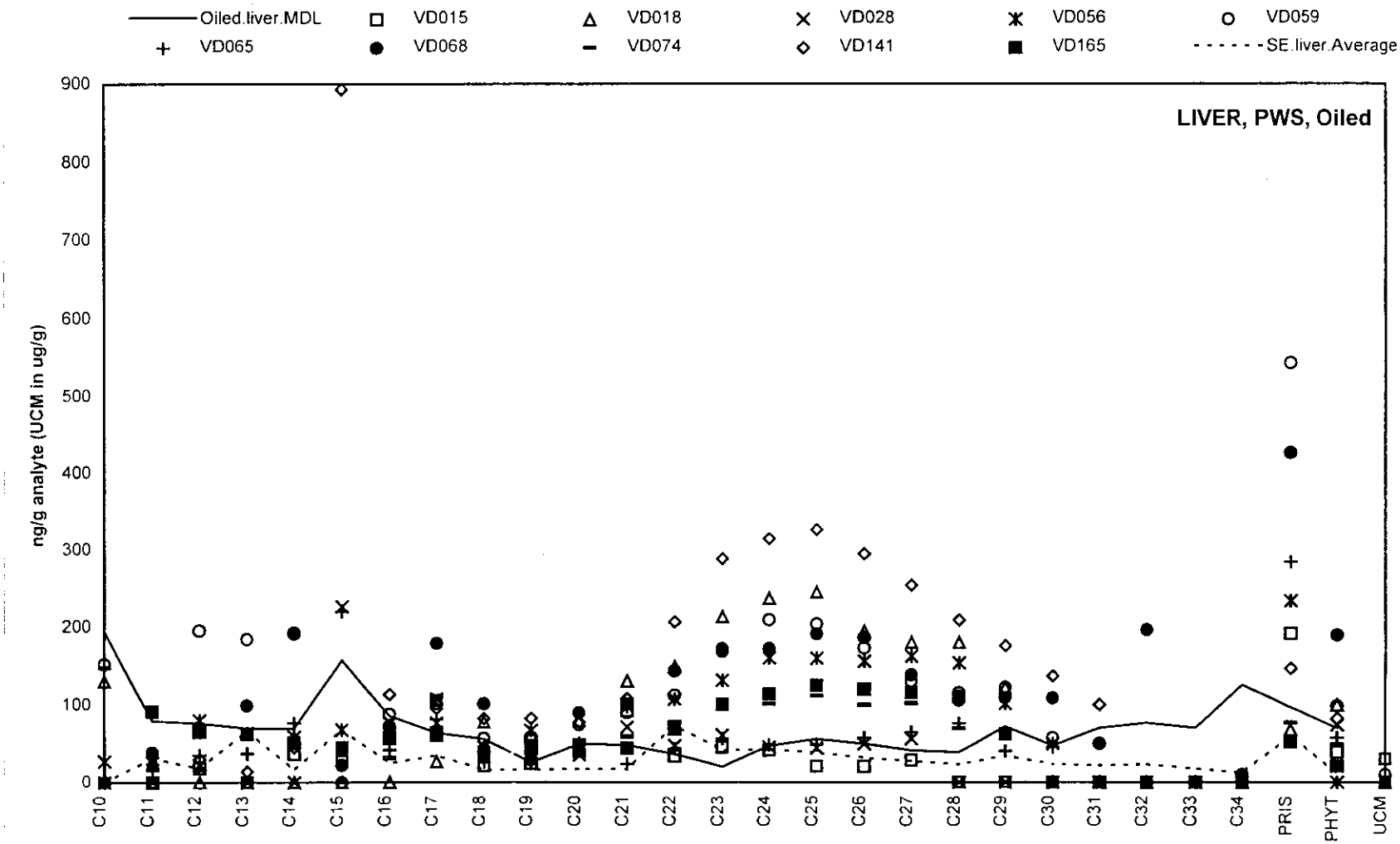

Figure 2. Aliphatic hydrocarbon concentrations present in liver samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram except UCM which is in micrograms per gram. The solid line indicates the mean MDL for oiled liver samples, and the dashed line indicates the mean hydrocarbon concentration of the SE unoiled liver samples. Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture.

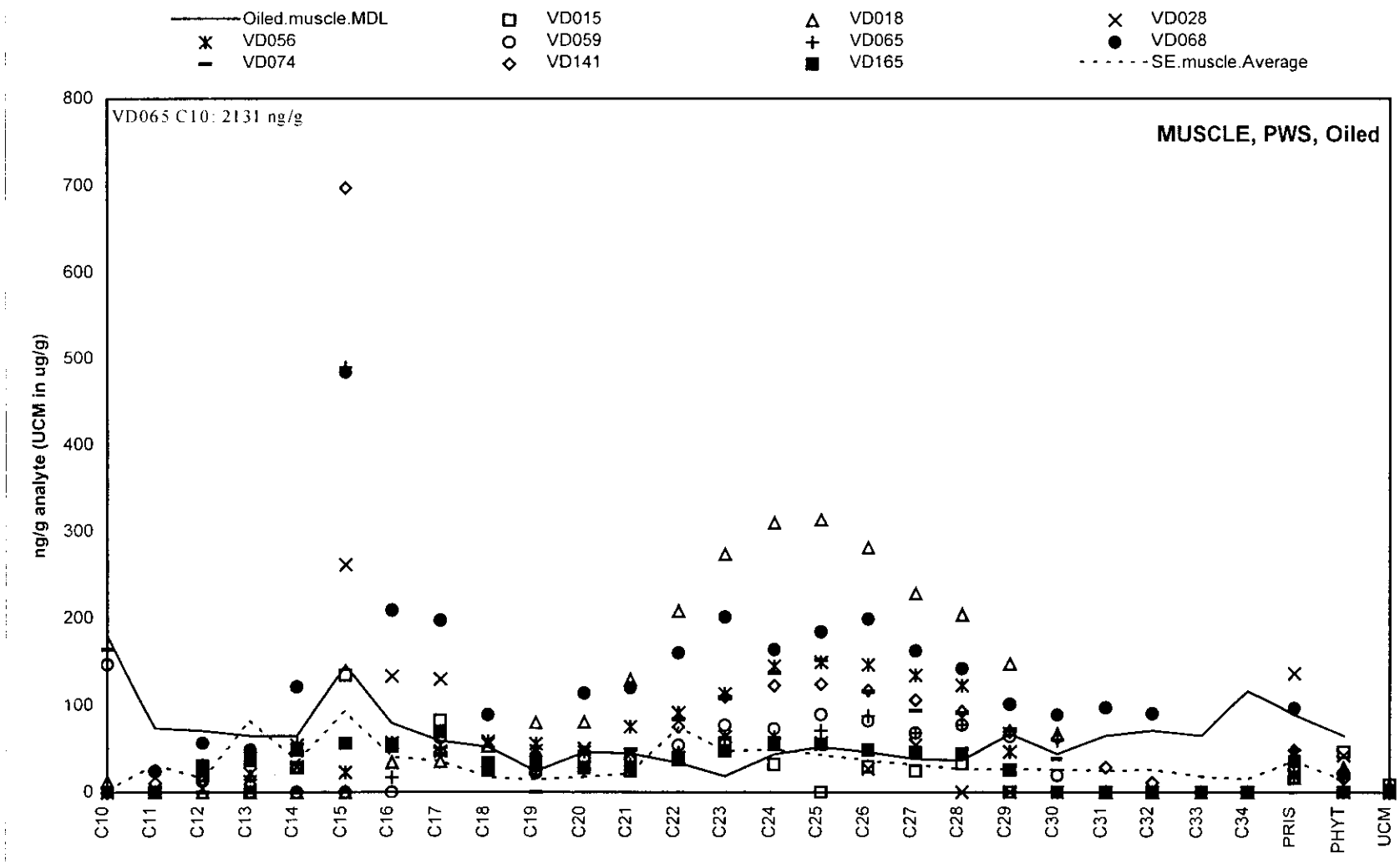

Figure 3. Aliphatic hydrocarbon concentrations present in muscle samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram except UCM which is in micrograms per gram. The solid line indicates the mean MDL for oiled kidney samples, and the dashed line indicates the mean hyddrocarbon concentrations of the SE unoiled kidney samples. Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture.

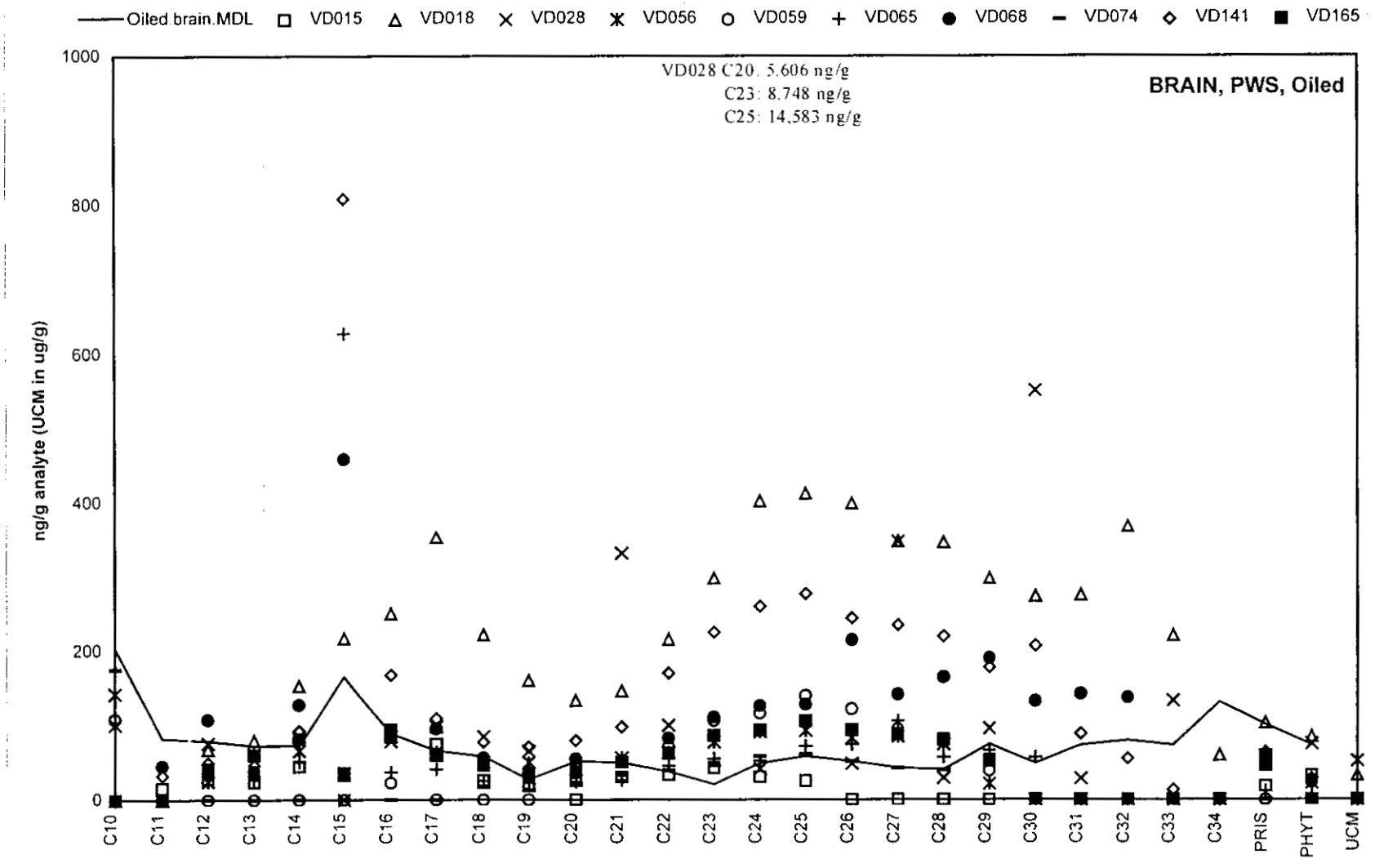

Figure 4. Aliphatic hydrocarbon concentrations present in brain samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram except UCM which is in micrograms per gram. The solid line indicates the mean MDL for brain samples. Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture.

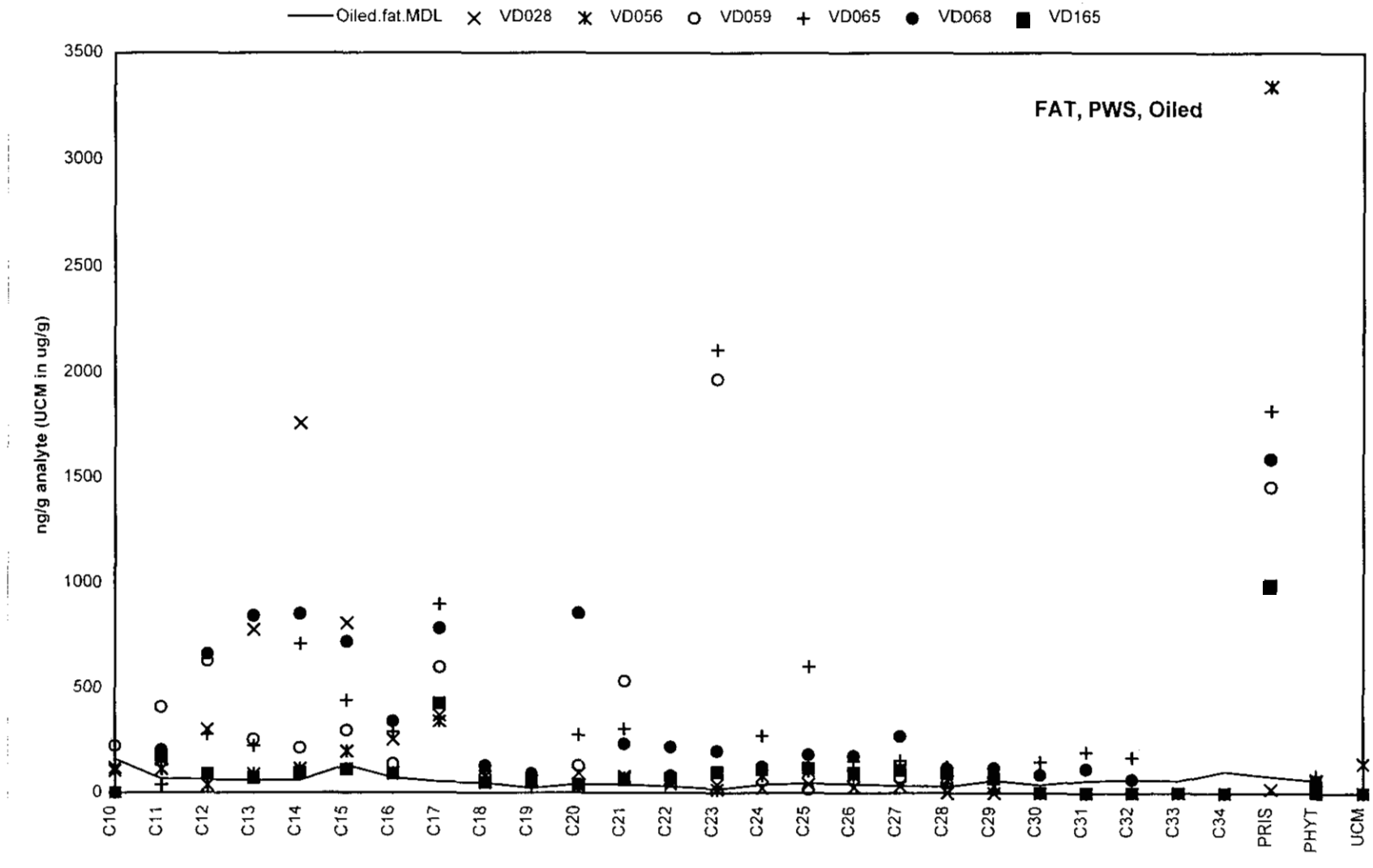

Figure 5. Aliphatic hydrocarbon concentrations present in fat samples from sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram except UCM which is in micrograms per gram. The solid line indicates the mean MDL for fat samples. Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture.

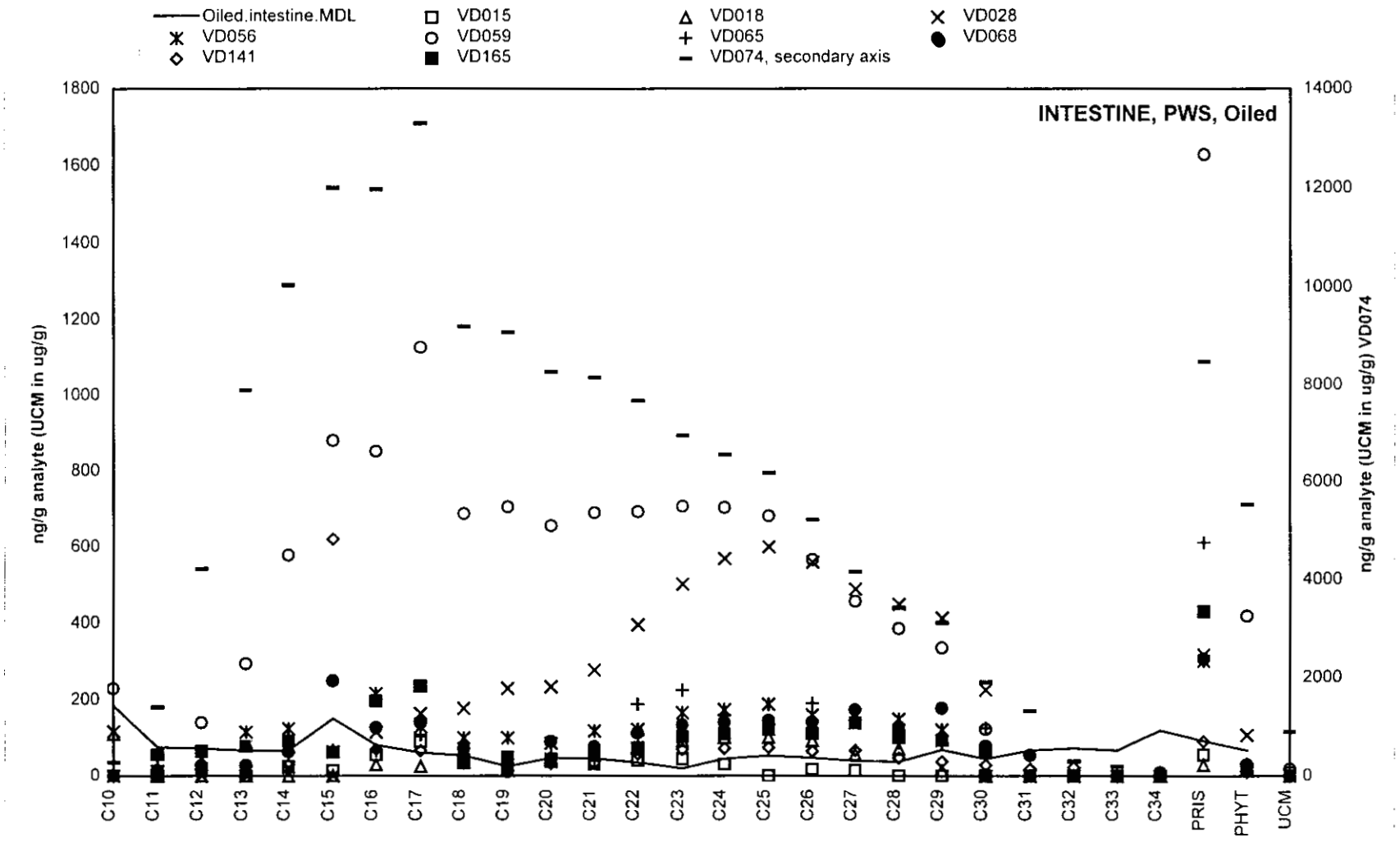

Figure 6. Aliphatic hydrocarbon concentrations present in intestine samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. VD074 is on the secondary axis. Units are in nanograms per gram except UCM which is in micrograms per gram. The solid line indicates the mean MDL for intestine samples. Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture.

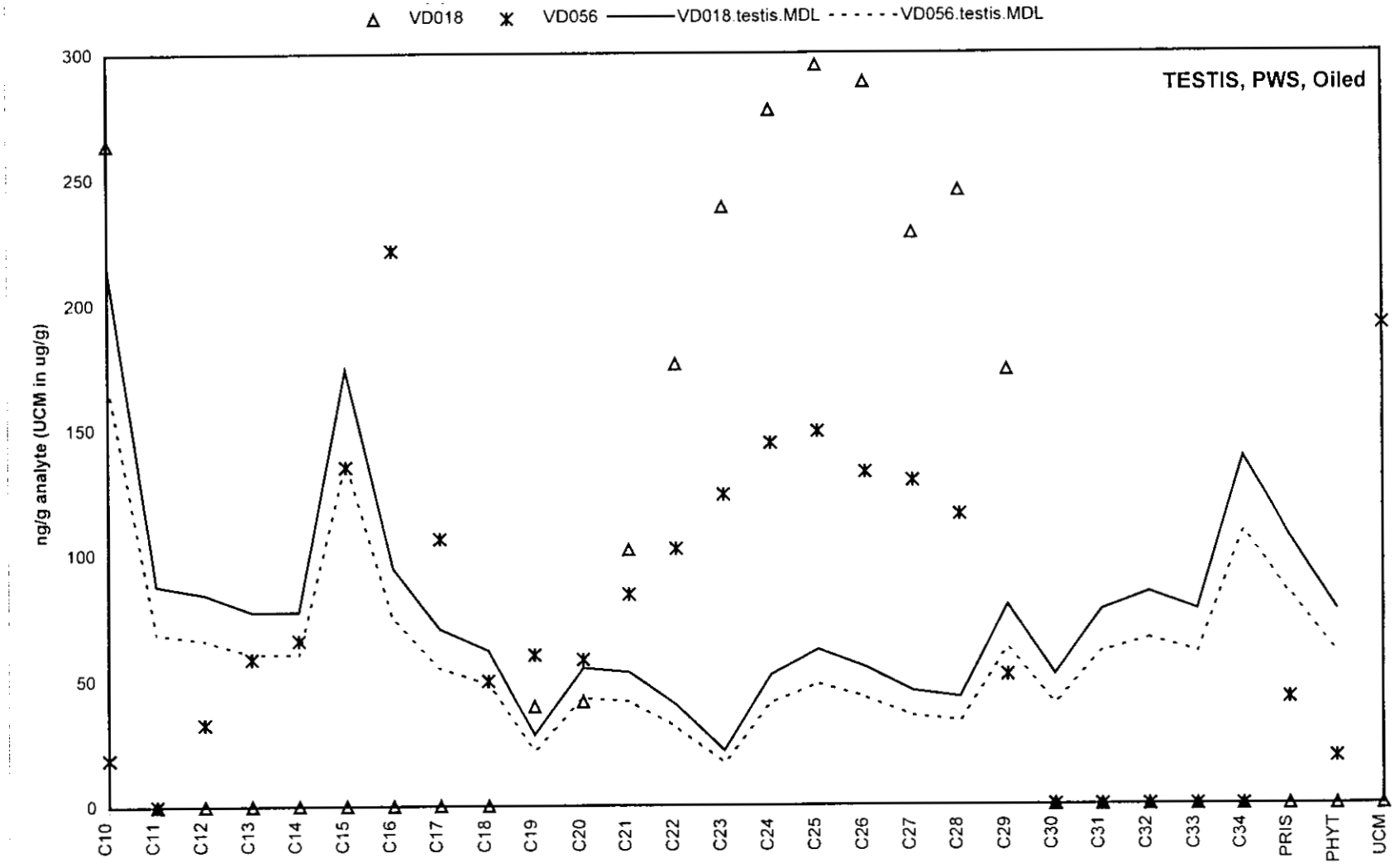

Figure 7. Aliphatic hydrocarbon concentrations present in testis samples from sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram except UCM which is in micrograms per gram. The lines indicate the MDLs for the samples. Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture.

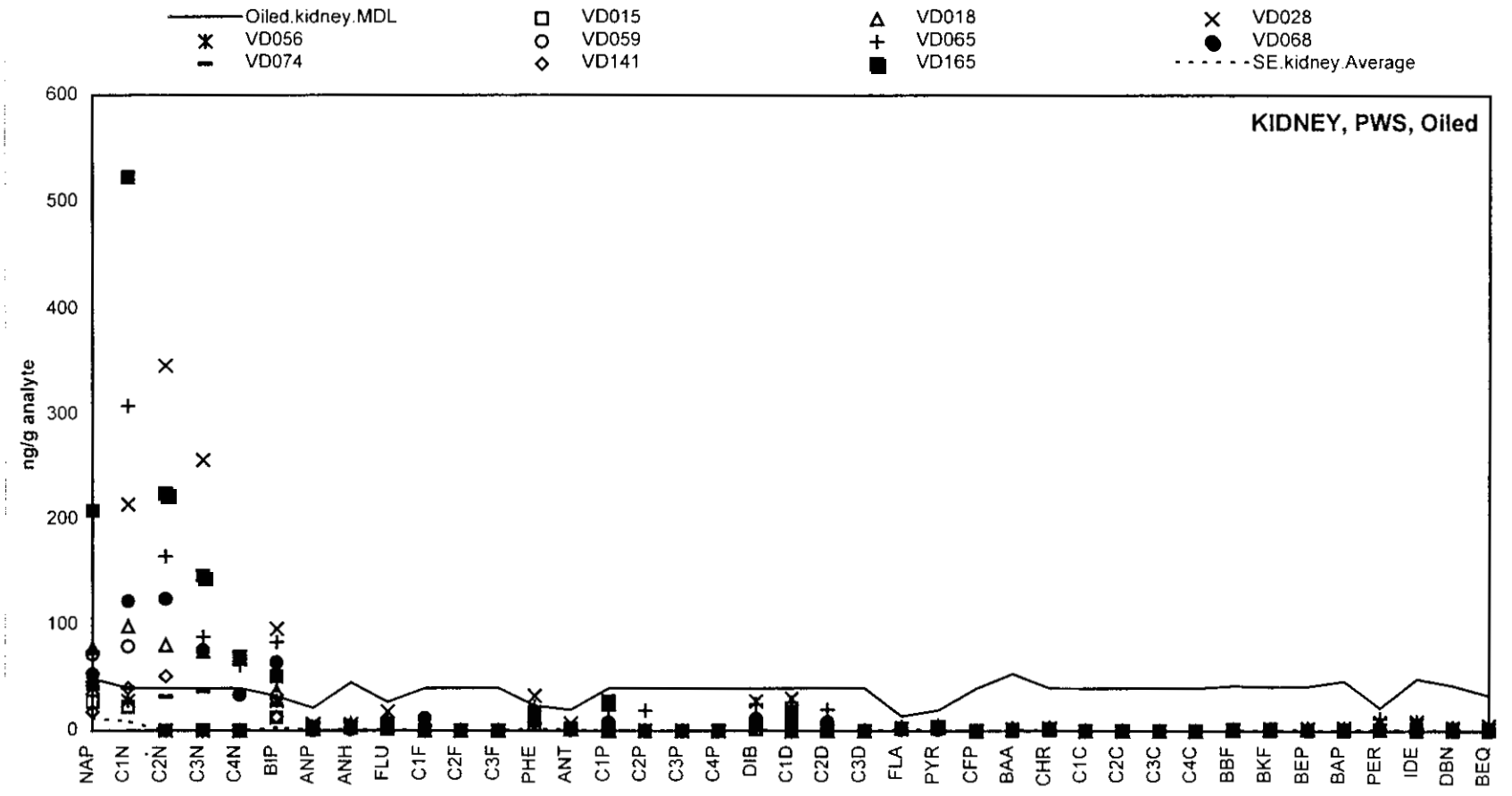

Figure 8. Aromatic hydrocarbon concentrations in kidney samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram. The solid line indicates the mean MDL for oiled kidney samples, and the dashed line indicates the mean hydrocarbon concentrations of the SE unoiled kidney samples. Abbreviations: NAP: naphthalene; C1N-C4N: C1-C4-methylated naphthalenes; BIP: biphenyl; ANP: acenaphthalene; ANH: acenapthene; FLU: fluorene; C1F-C3F: C1-C3-methylated fluorenes; PHE: phenanthrene; ANT: anthracene; C1P-C4P: C1-C4-phenanthrenes/anthracenes; DIB: dibenzothiophene; C1D-C3D: C1-C3-dibenzothiophenes; FLA: fluoranthene; PYR: pyrene; CFP: C1-fluoranthenes/pyrenes; BAA: benzo[a]anthracene; CHR: chrysene; C1C-C4C: C1-C4-chrysenes; BBF: benzo[b]fluoranthene; BKF: benzo[k]fluoranthene; BEP: benzo[e]pyrene; BAP: benzo[a]pyrene; PER: perylene; IDE: indeno[1,2,3-c,d]pyrene; DBN: dibenzo[a,h]anthracene; BEQ: benzo[g,h,i]perylene.

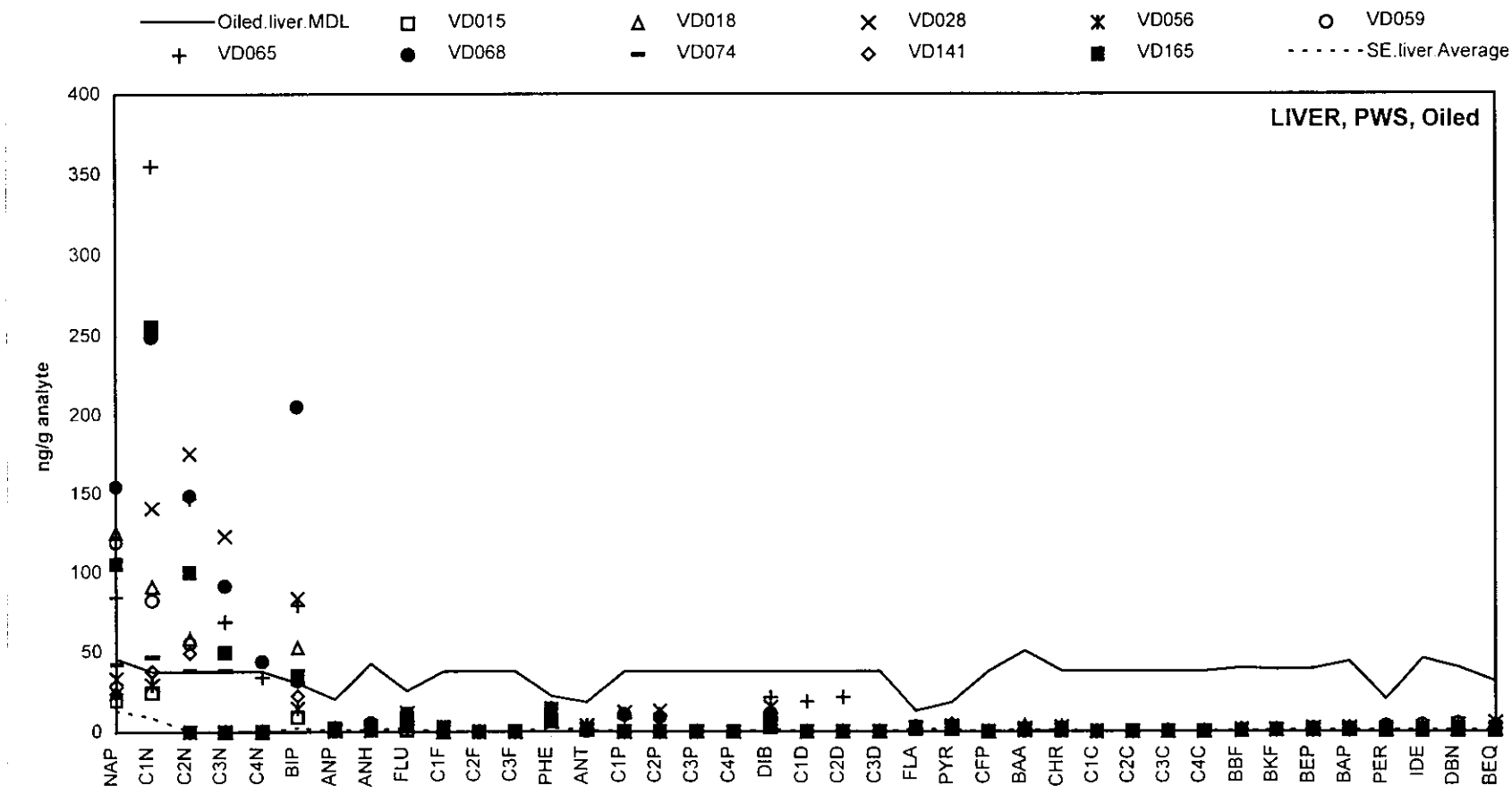

Figure 9. Aromatic hydrocarbon concentrations in liver samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram. The solid line indicates the mean MDL for oiled liver samples, and the dashed line indicates the mean hydrocarbon concentrations of the SE unoiled liver samples. Abbreviations: NAP: naphthalene; C1N-C4N: C1-C4-methylated naphthalenes; BIP: biphenyl; ANP: acenaphthalene; ANH: acenapthene; FLU: fluorene; C1F-C3F: C1-C3-methylated fluorenes; PHE: phenanthrene; ANT: anthracene; C1P-C4P: C1-C4-phenanthrenes/anthracenes; DIB: dibenzothiophene; C1D-C3D: C1-C3-dibenzothiophenes; FLA: fluoranthene; PYR: pyrene; CFP: C1-fluoranthenes/pyrenes; BAA: benzo[a]anthracene; CHR: chrysene; C1C-C4C: C1-C4-chrysenes; BBF: benzo[b]fluoranthene; BKF: benzo[k]fluoranthene; BEP: benzo[e]pyrene; BAP: benzo[a]pyrene; PER: perylene; IDE: indeno[1,2,3-c,d]pyrene; DBN: dibenzo[a,h]anthracene; BEQ: benzo[g,h,i]perylene.

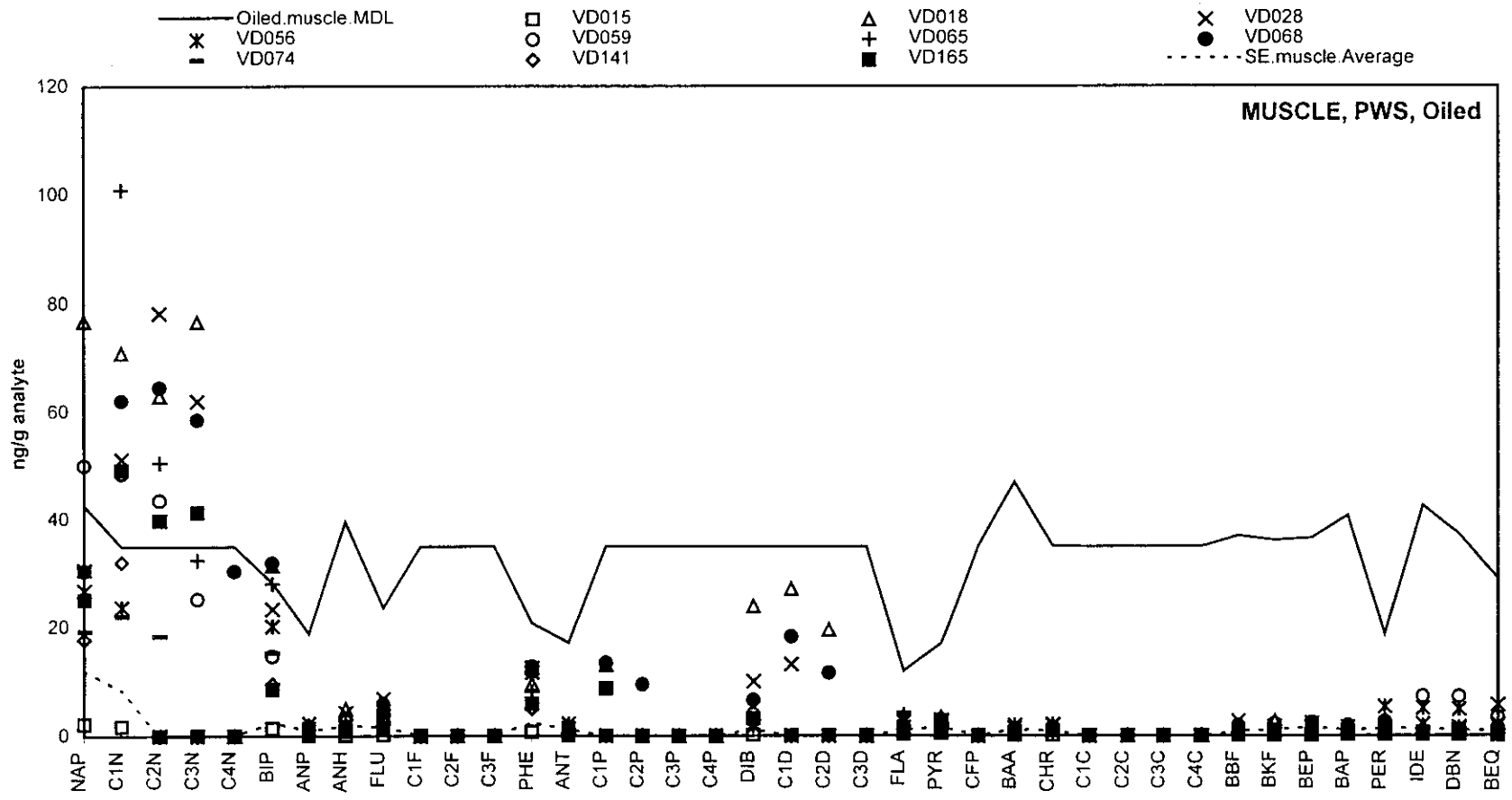

Figure 10. Aromatic hydrocarbon concentrations in muscle samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram. The solid line indicates the mean MDL for oiled muscle samples, and the dashed line indicates the mean hydrocarbon concentrations of the SE unoiled muscle samples. Abbreviations: NAP: naphthalene; C1N-C4N: C1-C4-methylated naphthalenes; BIP: biphenyl; ANP: acenaphthalene; ANH: acenapthene; FLU: fluorene; C1F-C3F: C1-C3-methylated fluorenes; PHE: phenanthrene; ANT: anthracene; C1P-C4P: C1-C4-phenanthrenes/anthracenes; DIB: dibenzothiophene; C1D-C3D: C1-C3-dibenzothiophenes; FLA: fluoranthene; PYR: pyrene; CFP: C1-fluoranthenes/pyrenes; BAA: benzo[a]anthracene; CHR: chrysene; C1C-C4C: C1-C4-chrysenes; BBF: benzo[b]fluoranthene; BKF: benzo[k]fluoranthene; BEP: benzo[e]pyrene; BAP: benzo[a]pyrene; PER: perylene; IDE: indeno[1,2,3-c,d]pyrene; DBN: dibenzo[a,h]anthracene; BEQ: benzo[g,h,i]perylene.

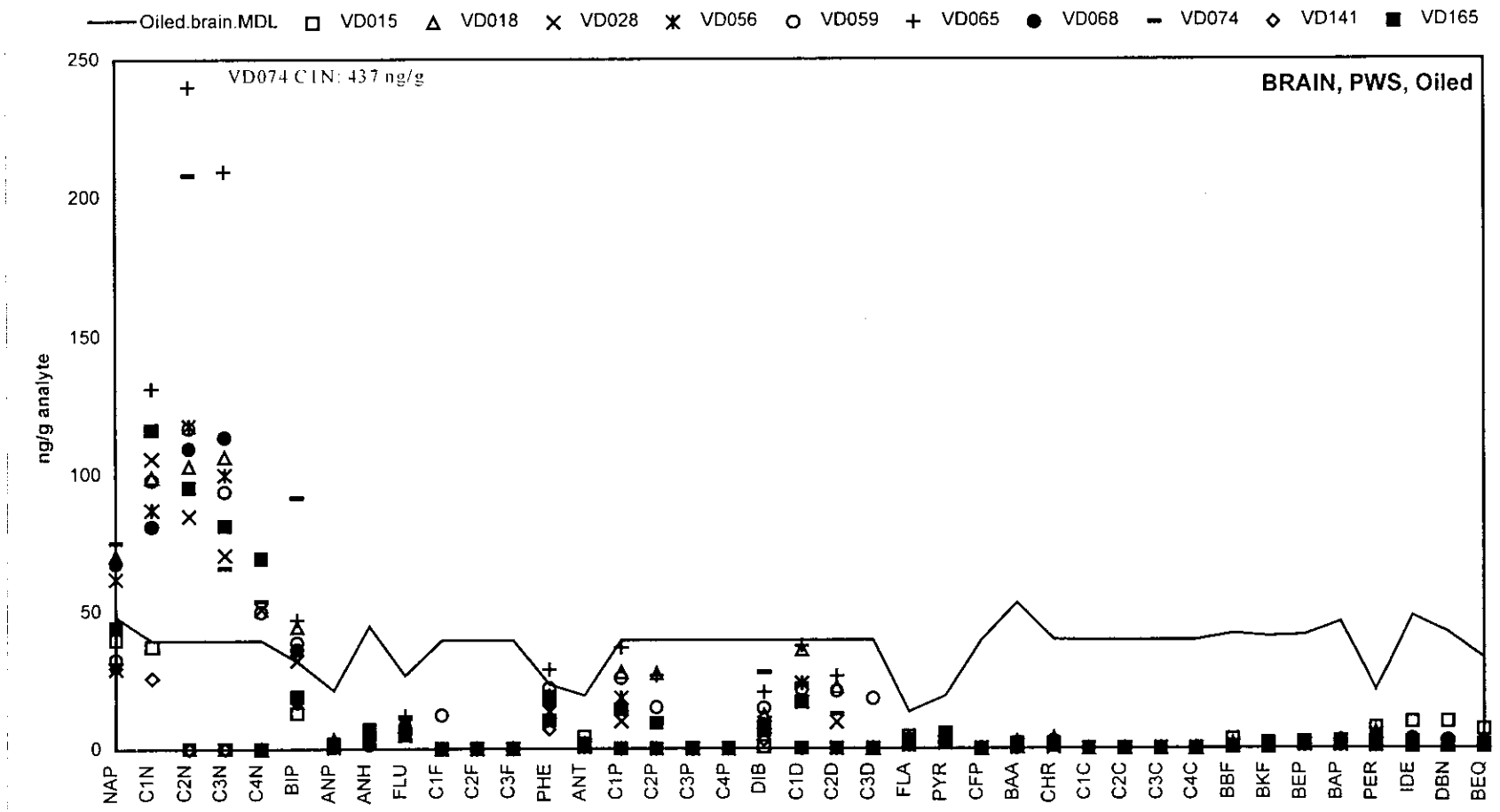

Figure 11. Aromatic hydrocarbon concentrations in brain samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram. The solid line indicates the mean MDL for oiled brain samples. Abbreviations: NAP: naphthalene; C1N-C4N: C1-C4-methylated naphthalenes; BIP: biphenyl; ANP: acenaphthalene; ANH: acenapthene; FLU: fluorene; C1F-C3F: C1-C3-methylated fluorenes; PHE: phenanthrene; ANT: anthracene; C1P-C4P: C1-C4-phenanthrenes/anthracenes; DIB: dibenzothiophene; C1D-C3D: C1-C3-dibenzothiophenes; FLA: fluoranthene; PYR: pyrene; CFP: C1-fluoranthenes/pyrenes; BAA: benzo[a]anthracene; CHR: chrysene; C1C-C4C: C1-C4-chrysenes; BBF: benzo[b]fluoranthene; BKF: benzo[k]fluoranthene; BEP: benzo[e]pyrene; BAP: benzo[a]pyrene; PER: perylene; IDE: indeno[1.2.3-c.d]pyrene; DBN: dibenzo[a.h]anthracene; BEQ: benzo[g.h.i]perylene.

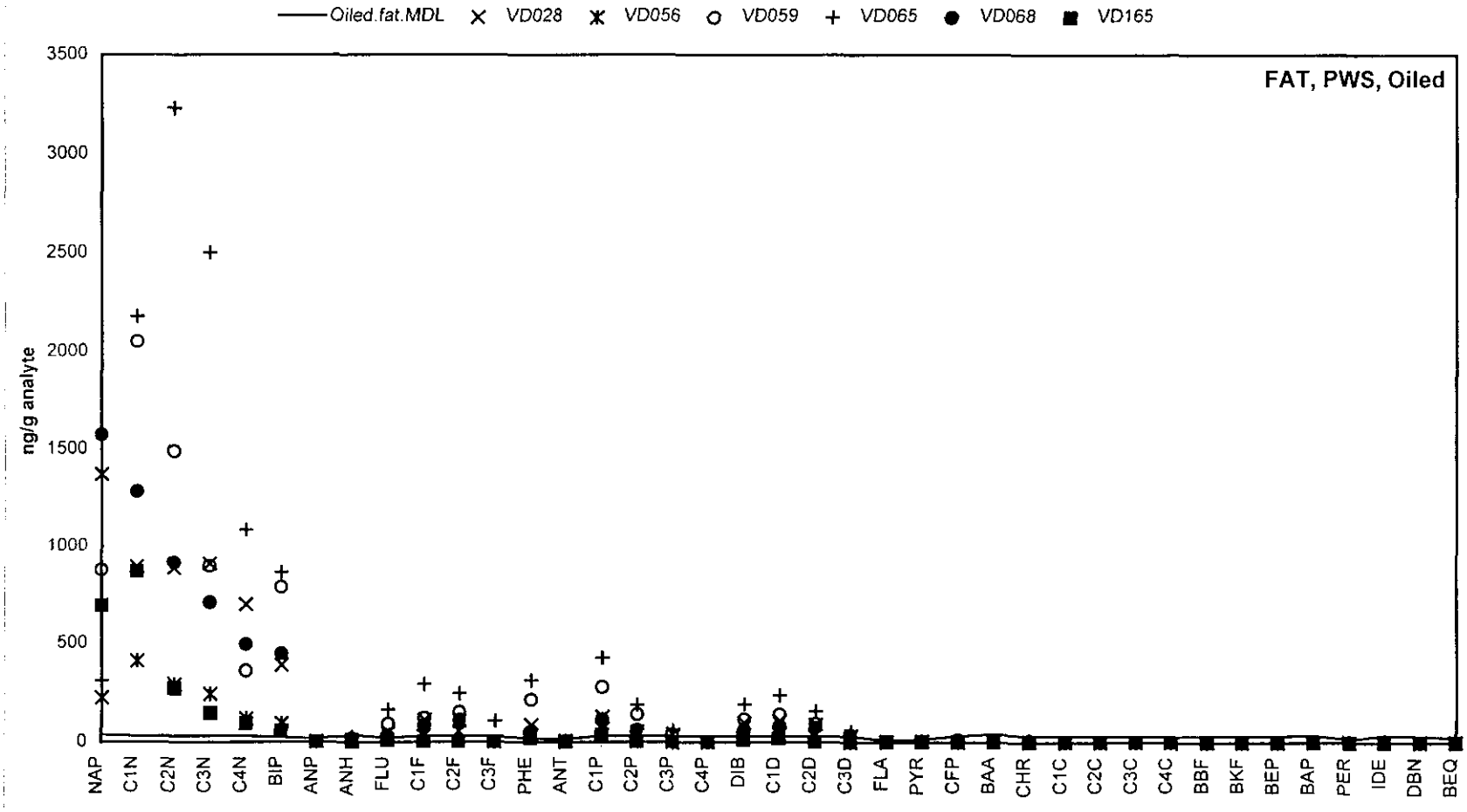

Figure 12. Aromatic hydrocarbon concentrations in fat samples from sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram. The solid line indicates the mean MDL for fat samples. Abbreviations: NAP: naphthalene; C1N-C4N: C1-C4-methylated naphthalenes; BIP: biphenyl; ANP: acenaphthalene; ANH: acenapthene; FLU: fluorene; C1F-C3F: C1-C3-methylated fluorenes; PHE: phenanthrene; ANT: anthracene; C1P-C4P: C1-C4-phenanthrenes/anthracenes; DIB: dibenzothiophene; C1D-C3D: C1-C3-dibenzothiophenes; FLA: fluoranthene; PYR: pyrene; CFP: C1-fluoranthenes/pyrenes; BAA: benzo[a]anthracene; CHR: chrysene; C1C-C4C: C1-C4-chrysenes; BBF: benzo[b]fluoranthene; BKF: benzo[k]fluoranthene; BEP: benzo[e]pyrene; BAP: benzo[a]pyrene; PER: perylene; IDE: indeno[1.2.3-c.d]pyrene; DBN: dibenzo[a.h]anthracene; BEQ: benzo[g.h.i]perylene.

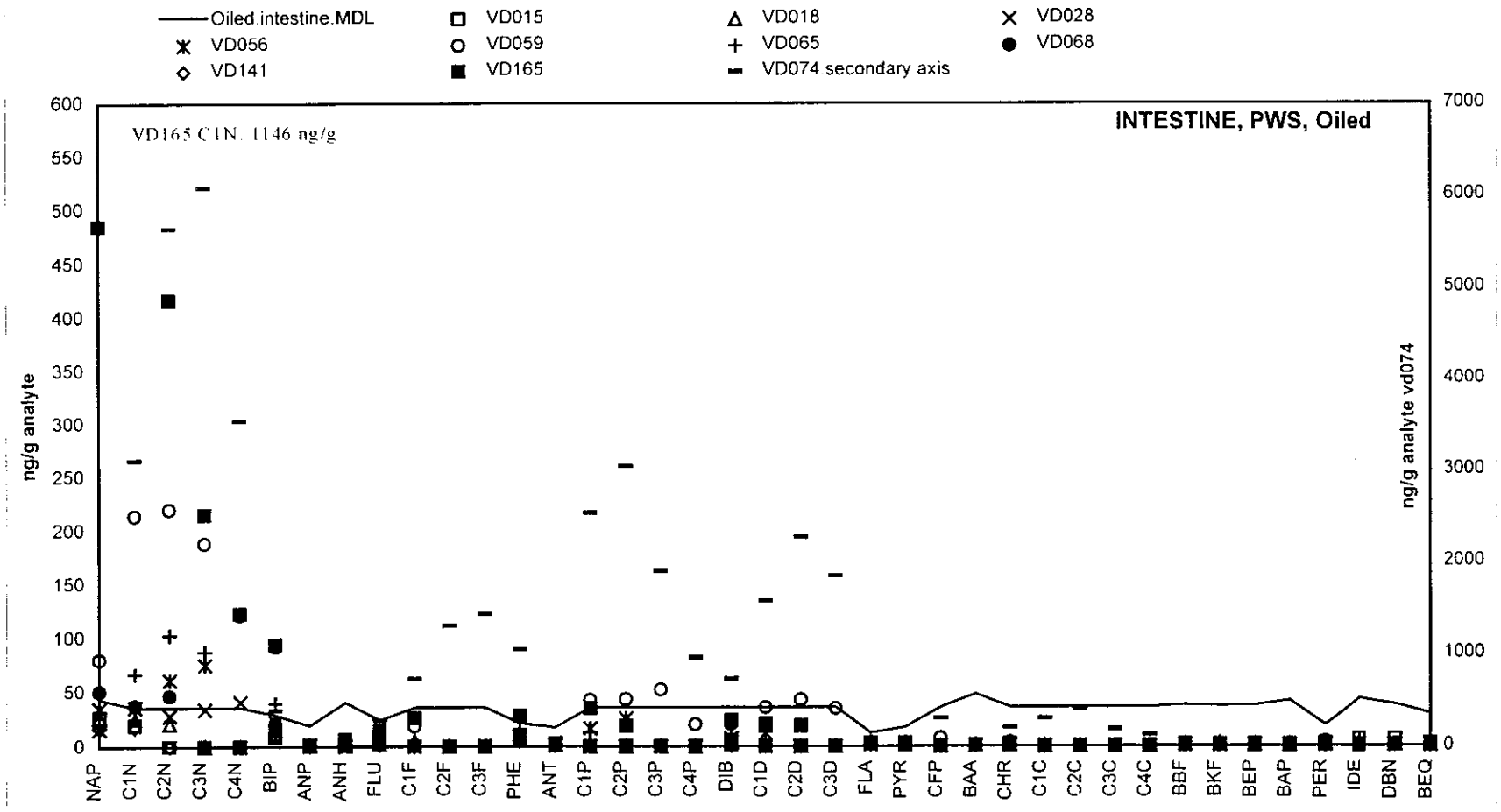

Figure 13. Aromatic hydrocarbon concentrations in intestine samples from 10 sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram. VD074 is on the secondary axis. The solid line indicates the mean MDL for intestine samples. Abbreviations: NAP: naphthalene; C1N-C4N: C1-C4-methylated naphthalenes; BIP: biphenyl; ANP: acenaphthalene; ANH: acenapthene; FLU: fluorene; C1F-C3F: C1-C3-methylated fluorenes; PHE: phenanthrene; ANT: anthracene; C1P-C4P: C1-C4-phenanthrenes/anthracenes; DIB: dibenzothiophene; C1D-C3D: C1-C3-dibenzothiophenes; FLA: fluoranthene; PYR: pyrene; CFP: C1-fluoranthenes/pyrenes; BAA: benzo[a]anthracene; CHR: chrysene; C1C-C4C: C1-C4-chrysenes; BBF: benzo[b]fluoranthene; BKF: benzo[k]fluoranthene; BEP: benzo[e]pyrene; BAP: benzo[a]pyrene; PER: perylene; IDE: indeno[1,2,3-c,d]pyrene; DBN: dibenzo[a,h]anthracene; BEQ: benzo[g,h,i]perylene.

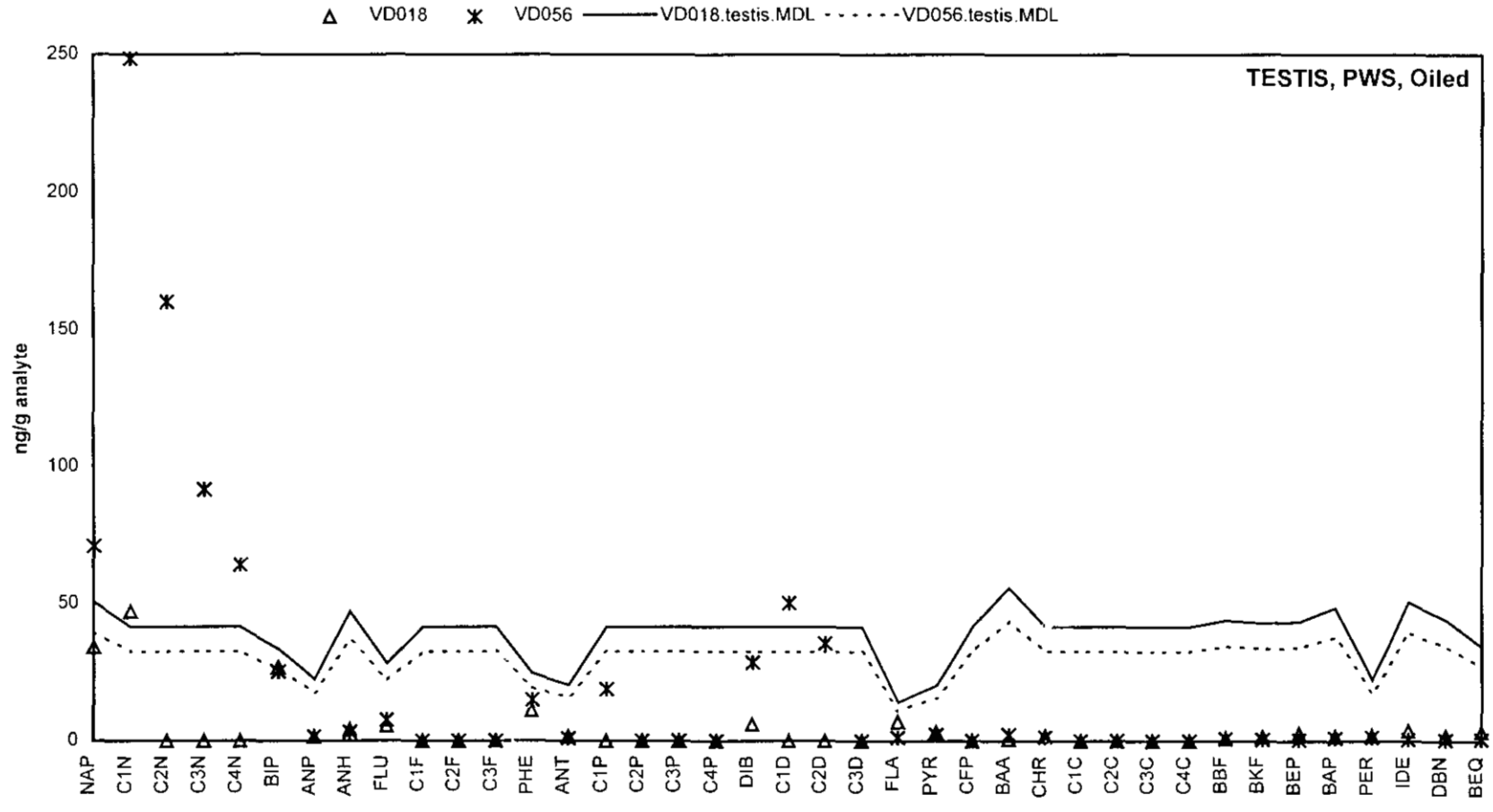

Figure 14. Aromatic hydrocarbon concentrations in testis samples from sea otters oiled following the *Exxon Valdez* oil spill. Units are in nanograms per gram. The solid and dashed lines indicate the MDLs. Abbreviations: NAP: naphthalene; C1N-C4N: C1-C4-methylated naphthalenes; BIP: biphenyl; ANP: acenaphthalene; ANH: acenapthene; FLU: fluorene; C1F-C3F: C1-C3-methylated fluorenes; PHE: phenanthrene; ANT: anthracene; C1P-C4P: C1-C4-phenanthrenes/anthracenes; DIB: dibenzothiophene; C1D-C3D: C1-C3-dibenzothiophenes; FLA: fluoranthene; PYR: pyrene; CFP: C1-fluoranthenes/pyrenes; BAA: benzo[a]anthracene; CHR: chrysene; C1C-C4C: C1-C4-chrysenes; BBF: benzo[b]fluoranthene; BKF: benzo[k]fluoranthene; BEP: benzo[e]pyrene; BAP: benzo[a]pyrene; PER: perylene; IDE: indeno[1,2,3-c,d]pyrene; DBN: dibenzo[a,h]anthracene; BEQ: benzo[g,h,i]perylene.

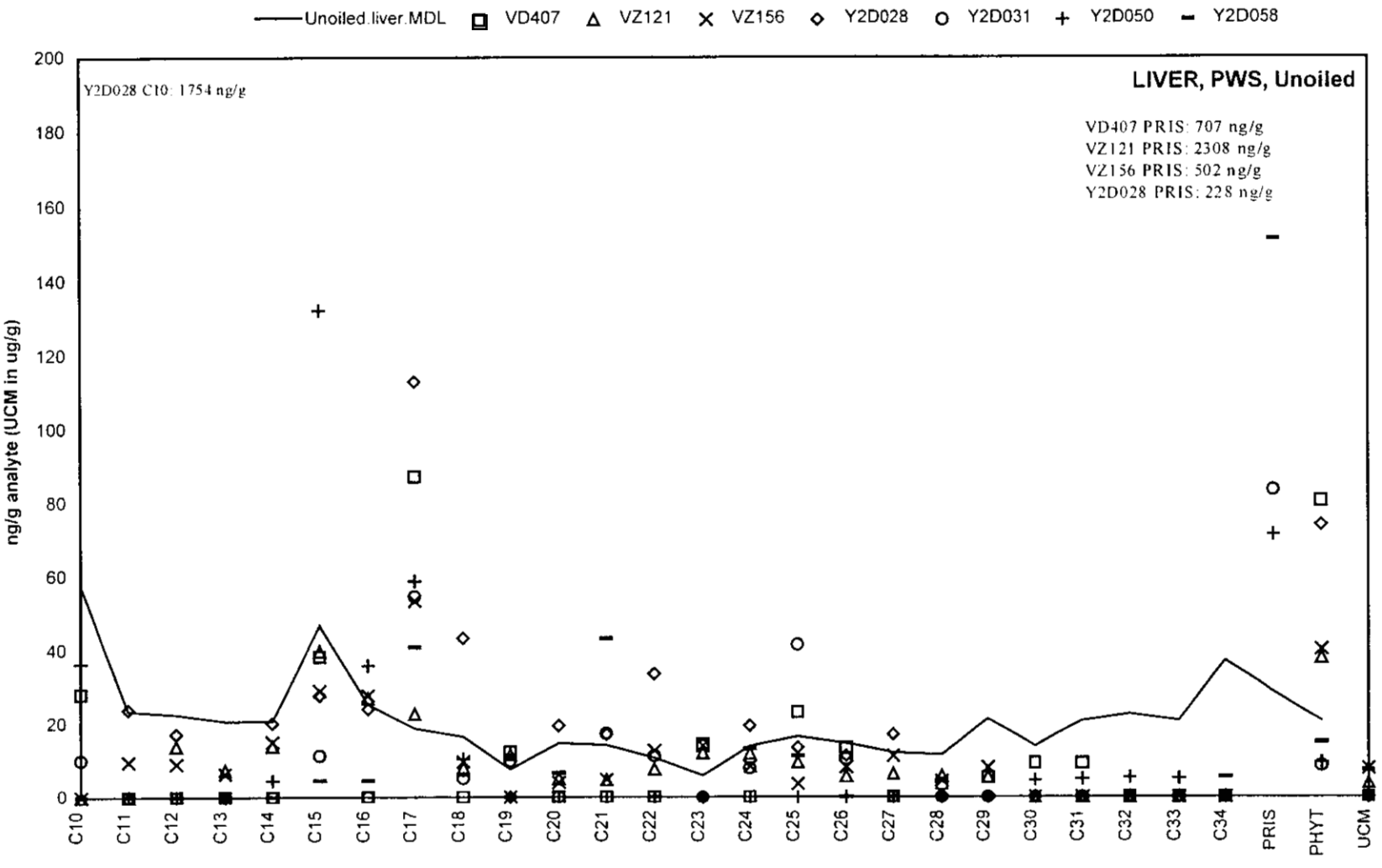

Figure 15. Aliphatic hydrocarbon concentrations in liver samples from 7 non-oiled sea otters from Prince William Sound, Alaska. Note that units are in nanograms per gram except UCM which is in micrograms per gram. The area under the curve is not a significant factor, rather the points are connected to highlight distribution patterns. Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture.

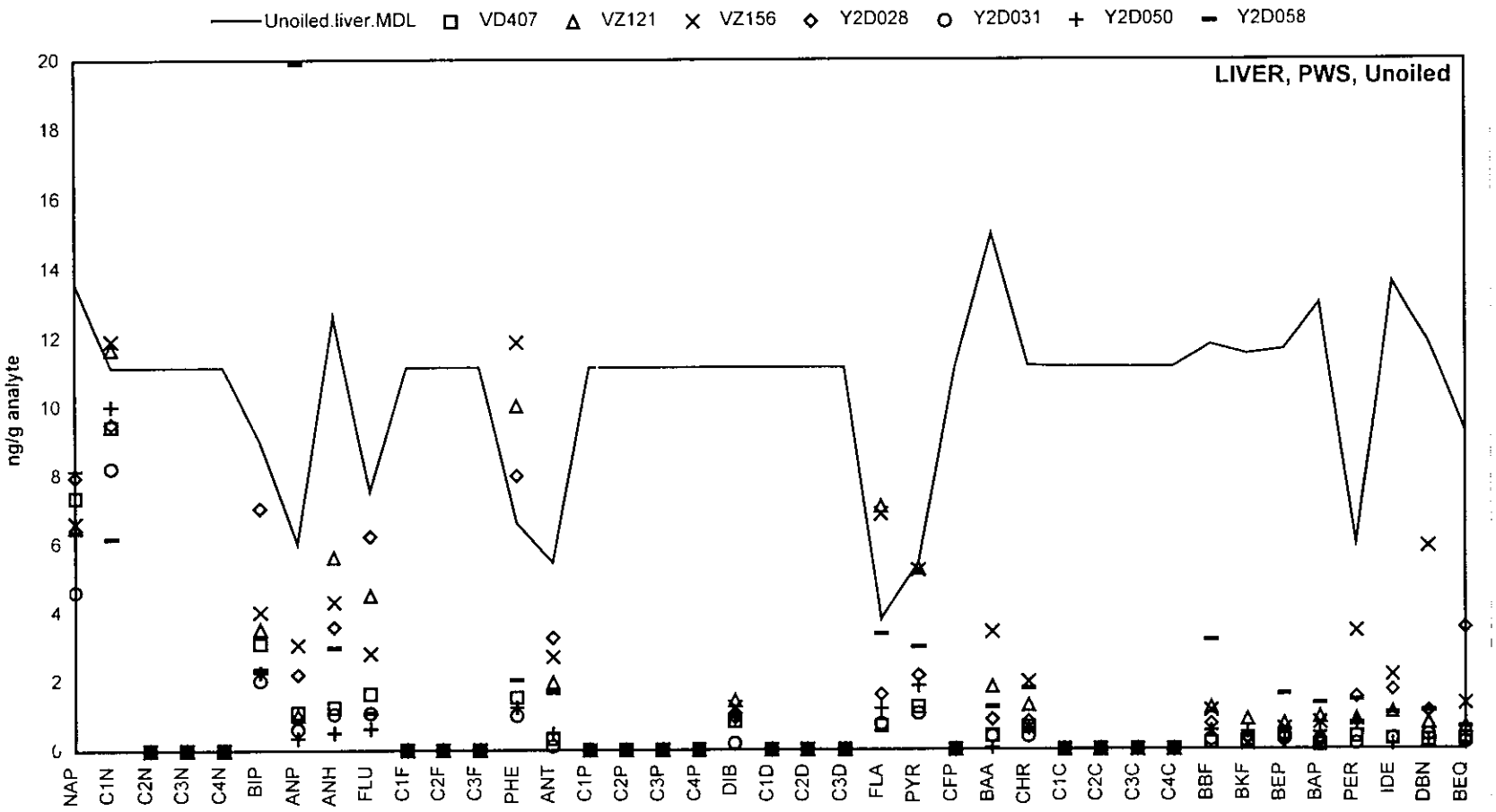

Figure 16. Aromatic hydrocarbon concentrations in liver samples from 7 non-oiled sea otters collected in 1989 and 1990 from PWS, Alaska. Units are in nanograms per gram. The solid line indicates the mean MDL for liver samples from this group. Abbreviations: NAP: naphthalene; C1N-C4N: C1-C4-methylated naphthalenes; BIP: biphenyl; ANP: acenaphthalene; ANH: acenapthene; FLU: fluorene; C1F-C3F: C1-C3-methylated fluorenes; PHE: phenanthrene; ANT: anthracene; C1P-C4P: C1-C4-phenanthrenes/anthracenes; DIB: dibenzothiophene; C1D-C3D: C1-C3-dibenzothiophenes; FLA: fluoranthene; PYR: pyrene; CFP: C1-fluoranthenes/pyrenes; BAA: benzo[a]anthracene; CHR: chrysene; C1C-C4C: C1-C4-chrysenes; BBF: benzo[b]fluoranthene; BKF: benzo[k]fluoranthene; BEP: benzo[e]pyrene; BAP: benzo[a]pyrene; PER: perylene; IDE: indeno[1,2,3-c,d]pyrene; DBN: dibenzo[a,h]anthracene; BEQ: benzo[g,h,i]perylene.

APPENDICES

Table A-1. Method detection limits (MDLs) in ng and ng/g for aliphatic and aromatic hydrocarbons analyzed by GERG.[a, b]

Aliphatic hydrocarbons	MDL		Aromatic hydrocarbons	MDL			MDL	
	ng	ng/g		ng	ng/g		ng	ng/g
C10	124.6	95.9	NAP	29.4	22.6	1MP	37.7	29.0
C11	50.9	39.1	C1N	--	--	DIB	--	--
C12	48.9	37.6	C2N	--	--	C1D	--	--
C13	--	--	C3N	--	--	C2D	--	--
C14	--	--	C4N	-	--	C3D	--	--
C15	101.0	77.7	1MN	32.8	25.2	FLA	8.2	6.3
C16	54.8	42.1	2MN	46.5	35.	PYR	11.7	9.0
C17	40.8	31.4	2,6MN	33.4	25.7	CFP	--	--
C18	35.9	27.6	2,3,5MN	28.6	22.0	BAA	32.4	24.9
C19	16.6	12.8	BIP	19.5	15.0	CHR	24.2	18.6
C20	31.9	24.5	ANP	13.0	10.0	C1C	--	--
C21	30.9	23.8	ANH	27.3	21.0	C2C	--	--
C22	23.3	17.9	FLU	16.3	12.5	C3C	--	--
C23	12.8	9.9	C1F	--	--	C4C	--	--
C24	30.2	23.2	C2F	--	--	BBF	25.5	19.6
C25	35.9	27.6	C3F	--	--	BKF	24.9	19.1
C26	31.8	24.5	ANT	11.8	9.1	BEF	25.2	19.4
C27	26.4	20.3	PHE	14.3	11.0	BAP	28.1	21.6
C28	25.0	19.2	C1P	--	--	PER	12.9	9.9
C29	46.1	35.5	C2P	--	--	IDE	29.4	22.6
C30	30.1	23.1	C3P	--	--	DBN	25.7	19.8
C31	--	--	C4P	--	--	BEQ	20.0	15.4
C32	48.9	37.6						
C33	44.9	34.6						
C34	80.2	61.7						
PRIS	61.7	47.5						
PHYT	--	--						
UCM	--	--						

[a] ng/g are on a dry weight basis.

[b] Abbreviations: C10 through C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture; NAP: naphthalene; C1N: C1-naphthalene; C2N: C2-naphthalene; C3N: C3-naphthalene; C4N: C4-naphthalene; 1MN: 1-methylnaphthalene; 2MN: 2-methylnaphthalene; 2,6MN: 2,6-dimethylnaphthalene; 2,3,5MN: 2,3,5-trimethylnaphthalene; BIP: biphenyl; ANP: acenaphthylene; ANH: acenaphthene; FLU: fluorene; C1F: C1-fluorene; C2F: C2-fluorene; C3F: C3-fluorene; ANT: anthracene; PHE: phenanthrene; C1P: C1-phenanthrene; C2P: C2-phenanthrene; C3P: C3-phenanthrene; C4P: C4-phenanthrene; 1MP: 1-methylphenanthrene; DIB: dibenzothiophene; C1D: C1-dibenzothiophene; C2D: C2-dibenzothiophene; C3D: C3-dibenzothiophene; FLA: fluoranthene; PYR: pyrene; CFP: methyl fluoranthene-pyrene; BAA: benz(a)anthracene; CHR: chrysene; C1C: C1-chrysene; C2C: C2-chrysene; C3C: C3-chrysene; C4C: C4-chrysene; BBF: benzo(b)fluoranthene; BKF: benzo(k)fluoranthene; BEP: benzo(e)pyrene; BAP: benzo(a)pyrene; PER: perylene; IDE: ideno(1,2,3-cd)pyrene; DBN: dibenzo(a,h)anthracene; BEQ: benzo(g,h,i)perylene.

Table A-2. Aliphatic hydrocarbon concentrations (ng/g) in tissue samples collected from oiled sea otter carcasses recovered in Prince Willima Sound, Alaska, in spring 1989.[a, b] Values in boldface are greater than MDL.

Lab ID	Tissue[c]	Sample wt.[d]	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
Otter # VD015																
23273	B	0.68	0.	15.63	28.54	24.10	45.28	33.08	**85.41**	**76.**	26.4	18.9	0.	31.	33.7	**43.61**
23263	I	0.65	0.	0.	15.3	0.	24.3	13.6	55.2	**89.8**	34.5	**27.8**	44.2	31.5	**40.7**	**44.40**
23264	K	0.57	0.	0.	0.	0.	35.81	**232.95**	61.09	**101.5**	0.	**33.7**	50.3	42.4	**41.6**	**72.55**
23262	L	0.57	0.	0.	18.35	0.	36.91	27.63	57.98	**105.4**	21.	23.9	39.5	**92.6**	33.8	**45.27**
23261	M	0.56	0.	0.	19.53	0.	28.26	134.86	55.03	**82.8**	25.3	26.1	41.2	24.5	37.5	**56.96**
Otter # VD018																
23484	B	0.65	0.	0.	68.9	**80.9**	**153.5**	**217.5**	**250.**	**353.7**	**221.8**	**160.3**	**133.9**	**146.5**	**215.5**	**297.67**
23471	I	0.71	110.51	0.	0.	0.	0.	0.	28.53	24.8	36.5	**28.3**	44.1	**54.1**	**76.7**	**91.65**
23472	K	0.75	**192.61**	0.	0.	0.	23.06	0.	0.	24.6	30.	**34.5**	**48.7**	**55.2**	**100.2**	**124.8**
23470	L	0.53	130.66	0.	0.	0.	0.	0.	0.	27.	**77.7**	**61.8**	**79.7**	**130.9**	**149.3**	**213.22**
23476	M	0.59	12.31	0.	0.	0.	0.	0.	34.26	35.	52.8	**80.5**	**80.6**	**130.1**	**208.**	**273.62**
23482	T	0.58	**263.76**	0.	0.	0.	0.	0.	0.	0.	0.	**39.8**	41.7	**101.8**	**176.**	**238.61**
Otter # VD028																
23292	B	0.78	143.24	0.	**76.76**	54.26	**86.43**	0.	**79.41**	**99.**	**85.6**	**66.3**	**5606.1**	**331.9**	**100.6**	**8747.58**
23279	F	0.75	105.67	**156.48**	**303.29**	**780.09**	**1758.01**	**810.14**	**254.79**	**370.3**	**78.7**	**58.4**	**94.4**	**80.2**	**41.9**	**37.92**
23286	I	0.62	117.21	0.	0.	0.	22.15	0.	**115.13**	**164.2**	**178.**	**229.6**	**233.7**	**277.5**	**395.7**	**501.85**
23285	K	0.63	162.21	0.	0.	0.	0.	0.	**87.37**	48.7	51.2	**34.1**	**66.2**	**89.9**	**105.**	**140.79**
23283	L	0.56	0.	0.	23.21	0.	0.	**226.47**	76.54	**107.5**	33.2	**29.8**	35.4	**71.2**	**47.4**	**60.73**
23280	M	0.51	0.	0.	26.68	20.93	29.36	**261.52**	**133.49**	**130.3**	55.8	**47.7**	50.1	44.1	40.1	**64.14**
Otter # VD056																
23503	B	0.52	102.01	0.	24.99	62.62	66.86	37.01	85.58	65.1	51.2	**51.**	41.	56.9	**64.4**	**78.22**
23492	F	0.84	118.54	**113.34**	35.83	**88.76**	**114.38**	**196.91**	**93.96**	**341.8**	**51.5**	**55.6**	37.7	**72.9**	**66.8**	14.56
23499	I	0.55	0.	0.	45.86	**115.85**	**125.12**	63.84	**215.56**	**128.8**	**100.3**	**100.2**	**86.1**	**118.2**	**122.1**	**165.94**
23498	K	0.65	0.	0.	36.79	45.03	53.47	24.93	67.92	**79.8**	38.9	**45.4**	38.7	**66.1**	**63.7**	**96.06**
23497	L	0.6	27.68	26.06	80.09	63.73	59.07	67.82	63.07	**76.6**	44.9	**66.8**	46.2	**97.3**	**107.3**	**131.60**
23494	M	0.62	0.	0.	25.63	39.37	54.04	22.84	56.92	47.	**58.6**	**55.8**	46.3	**75.3**	**91.6**	**113.23**
23493	T	0.74	19.08	0.	32.98	58.73	**66.05**	134.96	**221.57**	**106.3**	**49.9**	**60.1**	**58.2**	**84.**	**102.2**	**123.74**

Lab ID	Tissue[c]	Sample wt.[d]	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
Otter # VD059																
23408	B	0.67	109.50	0.	0.	0.	0.	0.	23.12	0.	0.	0.	25.6	**51.8**	**71.9**	**106.99**
23389	F	0.72	**225.29**	**412.11**	**630.75**	**255.73**	**215.08**	**298.57**	**138.63**	**600.7**	**82.**	**91.4**	**129.8**	**535.2**	**82.7**	**1968.89**
23397	I	0.58	**230.29**	0.	**141.65**	**295.35**	**578.96**	**880.77**	**852.2**	**1127.8**	**687.6**	**705.5**	**656.4**	**690.7**	**693.5**	**707.45**
23398	K	0.59	196.70	0.	47.39	0.	20.28	0.	27.75	53.8	40.6	0.	49.9	**54.7**	**98.1**	**134.13**
23396	L	0.61	153.11	0.	**195.72**	**184.62**	**192.87**	0.	88.19	**101.9**	57.1	**58.3**	**74.4**	**89.9**	**112.4**	**172.21**
23393	M	0.77	147.8	0.	12.8	0.	0.	0.	0.	**62.8**	28.	**22.2**	28.1	**40.3**	**54.2**	**77.29**
Otter # VD065																
23195	B	0.57	**4355.73**	0.	31.71	27.28	51.50	**628.30**	37.52	41.9	25.8	22.9	24.1	26.8	**46.**	**55.98**
23182	F	0.82	0.	39.57	**277.35**	**224.08**	**712.62**	**444.29**	**291.16**	**898.6**	**69.1**	**39.9**	**277.2**	**307.5**	**71.2**	**2108.82**
23185	I	0.64	0.	27.71	34.26	25.06	62.34	67.13	67.01	**108.7**	44.7	**43.4**	**53.8**	40.2	**187.9**	**224.21**
23186	K	0.56	0.	33.20	**130.87**	63.78	**186.20**	**492.09**	**121.41**	**100.5**	46.	**34.8**	40.2	31.4	**59.6**	**76.45**
23183	L	0.98	0.	15.86	35.67	37.59	**76.89**	**220.16**	42.13	**81.3**	25.8	**24.1**	**50.5**	23.6	**43.6**	**56.30**
23188	M	0.77	**2131.02**	0.	31.59	18.74	55.90	**490.14**	17.03	51.2	29.4	**24.4**	25.8	32.1	**45.5**	**61.30**
Otter # VD068																
23179	B	0.57	0.	46.40	**108.97**	39.42	**128.59**	**459.24**	92.29	**96.5**	57.2	**36.6**	55.7	51.3	**84.**	**111.81**
23172	F	0.76	0.	**204.80**	**664.88**	**845.79**	**854.53**	**723.36**	**342.95**	**785.7**	**130.3**	**84.5**	**858.3**	**235.4**	**219.7**	**199.33**
23175	I	0.66	0.	14.32	27.88	28.85	64.16	**250.16**	**127.77**	**140.8**	**72.1**	11.3	**91.2**	**77.5**	**113.1**	**134.24**
23176	K	0.51	**1082.07**	43.75	50.4	66.	**134.29**	**1683.82**	**131.89**	**108.6**	57.6	**39.7**	**77.2**	**64.7**	**103.7**	**129.12**
23174	L	0.58	0.	38.80	71.49	**99.36**	**191.52**	22.65	72.87	**179.3**	**101.3**	**29.2**	**89.9**	**101.2**	**143.7**	**168.61**
23173	M	0.62	0.	24.19	57.04	48.94	**121.73**	**484.82**	**209.17**	**197.7**	**89.3**	**41.4**	**114.1**	**120.4**	**160.7**	**201.37**
Otter # VD074																
23310	B	0.54	175.85	0.	0.	0.	0.	0.	0.	0.	17.3	13.2	19.8	33.6	40.1	**46.28**
23299	I	0.6	**279.37**	**1406.06**	**4215.88**	**7886.28**	**10037.16**	**11992.15**	**11961.96**	**13296.6**	**9201.8**	**9075.**	**8263.8**	**8145.5**	**7665.9**	**6959.37**
23301	K	0.61	117.27	0.	0.	0.	0.	0.	36.46	36.4	41.9	21.	**60.7**	**57.6**	**53.3**	**85.45**
23298	L	0.68	148.35	0.	16.69	0.	50.08	0.	31.80	54.6	42.8	**50.1**	**53.8**	**59.**	**78.**	**97.48**
23304	M	0.61	164.64	0.	0.	0.	0.	0.	57.19	42.9	32.1	0.	34.	49.1	**84.**	**109.69**

Lab ID	Tissue[c]	Sample wt.[d]	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
Otter # VD141																
21809	B	0.55	0.	33.21	50.66	34.05	**93.54**	**808.92**	**168.15**	**109.8**	**78.5**	**71.9**	**80.3**	**98.8**	**170.8**	**225.08**
21805	I	1.11	0.	16.08	20.08	9.70	29.66	**620.84**	**70.03**	**66.7**	**33.7**	**33.4**	**33.2**	**33.8**	**57.4**	**69.83**
21803	K	0.57	0.	0.	21.72	0.	41.75	**749.78**	**112.95**	**77.**	**64.9**	**71.6**	**76.1**	**86.7**	**153.6**	**220.97**
21804	L	0.56	0.	23.96	30.12	14.31	45.53	**893.48**	**113.82**	**95.1**	**82.2**	**82.5**	**78.**	**107.9**	**206.7**	**288.44**
21806	M	0.93	0.	10.78	13.82	9.47	28.63	**697.90**	56.05	**46.6**	29.2	**23.3**	28.2	**38.**	**75.5**	**109.79**
Otter # VD165																
23554	B	0.55	0.	0.	42.31	60.81	**82.94**	36.17	95.03	60.5	46.9	**34.5**	36.9	50.8	**63.3**	**86.75**
23543	F	0.7	0.	**176.72**	**87.90**	**70.99**	**94.06**	111.25	**90.88**	**427.9**	47.8	**49.7**	39.	**62.**	**70.4**	**97.48**
23547	I	0.61	0.	56.28	65.55	**78.07**	**91.73**	62.49	**196.65**	**235.**	43.1	**48.5**	36.6	**57.1**	**73.9**	**103.84**
23546	K	0.55	0.	**128.07**	**150.15**	79.46	**119.30**	**313.23**	**271.82**	**330.7**	14.2	**40.5**	28.3	31.2	**42.9**	**62.89**
23545	L	0.69	0.	**91.44**	65.06	62.33	51.82	45.53	56.61	**64.4**	38.9	**46.**	41.1	44.2	**68.7**	**100.27**
23544	M	0.87	0.	0.	30.27	36.38	47.97	56.23	52.64	**69.5**	33.2	**34.6**	27.8	28.3	**39.2**	**47.7**

Table A-2. Continued.

Lab ID	Tissue[c]	Sample wt.[d]	C24	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	PRIS	PHYT	Total	UCM[e]
Otter # VD015																	
23273	B	0.68	30.96	25.39	0.	0.	0.	0.	0.	0.	0.	0.	0.	18.3	32.4	568.70	0.
23263	I	0.65	31.22	0.	17.50	13.50	0.	0.	0.	0.	0.	0.	0.	55.3	17.7	556.53	8.1
23264	K	0.57	43.14	62.78	47.54	23.40	0.	0.	0.	0.	0.	0.	0.	42.	61.8	952.55	5.7
23262	L	0.57	41.27	20.96	20.42	28.63	0.	0.	0.	0.	0.	0.	0.	**191.1**	39.	843.71	30.3
23261	M	0.56	31.97	0.	29.39	24.24	32.93	0.	0.	0.	0.	0.	0.	17.2	46.2	713.98	8.8
Otter # VD018																	
23484	B	0.65	**402.56**	**412.44**	**398.90**	**348.29**	**346.67**	**297.67**	**273.48**	**274.91**	**367.97**	**220.17**	60.34	**103.5**	**84.9**	5891.97	33.2
23471	I	0.71	**101.09**	**101.61**	**92.38**	**57.23**	**70.50**	13.06	0.	0.	0.	0.	0.	28.7	29.2	988.97	1.3
23472	K	0.75	**133.07**	**146.14**	**126.54**	**107.34**	**98.14**	53.21	0.	0.	0.	0.	0.	25.6	0.	1323.72	0.
23470	L	0.53	**236.55**	**244.95**	**194.41**	**180.22**	**179.91**	**121.79**	0.	0.	0.	0.	0.	67.6	**99.3**	2195.00	0.
23476	M	0.59	**310.12**	**313.85**	**281.31**	**228.24**	**203.88**	**147.80**	**67.26**	0.	0.	0.	0.	16.5	28.4	2504.57	7.7
23482	T	0.58	**277.3**	**295.01**	**288.45**	**228.44**	**245.06**	**173.46**	0.	0.	0.	0.	0.	0.	0.	2369.38	0.
Otter # VD028																	
23282	B	0.78	**41.62**	**14582.79**	**48.65**	**347.54**	29.63	**96.19**	**551.53**	28.48	0.	**133.12**	0.	49.5	**75.5**	31461.71	52.7
23279	F	0.75	22.75	40.34	27.26	32.86	0.	0.	0.	0.	0.	0.	0.	18.3	**65.5**	5137.3	141.3
23286	I	0.62	**569.04**	**599.84**	**559.36**	**488.49**	**449.14**	**412.43**	**225.18**	0.	0.	0.	0.	**317.**	**107.4**	5962.92	1.8
23285	K	0.63	**156.10**	**147.83**	**138.42**	**111.62**	**108.41**	**103.56**	**66.17**	0.	0.	0.	0.	**290.5**	0.	1908.08	13.5
23283	L	0.56	45.28	44.32	49.65	**56.25**	0.	0.	0.	0.	0.	0.	0.	**233.2**	73.7	1213.86	2.7
23280	M	0.51	55.54	56.92	26.87	**54.27**	0.	0.	0.	0.	0.	0.	0.	**136.7**	42.2	1276.7	0.
Otter # VD056																	
23503	B	0.52	**91.61**	**93.56**	**83.08**	**85.24**	**75.30**	21.50	0.	0.	0.	0.	0.	59.1	22.1	1318.39	0.
23492	F	0.84	**82.24**	**102.58**	**80.42**	**116.93**	**59.86**	34.69	0.	0.	0.	0.	0.	**3341.4**	14.3	5235.01	0.
23499	I	0.55	**173.82**	**187.86**	**159.68**	**161.52**	**149.10**	**121.03**	0.	0.	0.	0.	0.	**301.2**	18.3	2660.39	0.
23498	K	0.65	**98.53**	**91.33**	**84.24**	**88.43**	**58.88**	19.34	0.	0.	0.	0.	0.	**415.9**	0.	1513.44	5.
23497	L	0.6	**160.15**	**159.83**	**156.18**	**162.62**	**153.50**	**101.54**	49.73	0.	0.	0.	0.	**233.4**	0.	2135.17	0.
23494	M	0.62	**145.28**	**149.95**	**146.87**	**134.46**	**122.78**	46.59	0.	0.	0.	0.	0.	20.9	0.	1453.47	3.5
23493	T	0.74	**144.28**	**148.84**	**132.54**	**129.18**	**115.70**	51.82	0.	0.	0.	0.	0.	42.5	19.1	1901.78	191.5

Lab ID	Tissue[c]	Sample wt.[d]	C24	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	PRIS	PHYT	Total	UCM[e]
Otter # VD059																	
23408	B	0.67	**117.07**	**140.22**	**122.32**	**95.37**	**82.1**	39.3	0.	0.	0.	0.	0.	0.	0.	985.29	0.
23389	F	0.72	**123.95**	17.55	**59.91**	**75.14**	**48.41**	**76.04**	0.	0.	0.	0.	0.	**1458.7**	40.2	7566.74	0.
23397	I	0.58	**704.41**	**682.16**	**566.65**	**457.35**	**385.52**	**335.64**	**123.22**	0.	0.	0.	0.	**1629.5**	**418.7**	13551.33	19.
23398	K	0.59	**155.81**	**168.25**	**143.27**	**133.41**	**82.12**	43.78	0.	0.	0.	0.	0.	**228.8**	0.	1678.79	0.9
23396	L	0.61	**209.23**	**203.88**	**173.15**	**130.36**	**115.26**	**122.29**	**57.28**	0.	0.	0.	0.	**543.2**	**98.3**	3133.66	10.5
23393	M	0.77	**73.26**	**89.69**	**82.25**	**68.41**	**77.5**	**64.38**	19.27	0.	0.	0.	0.	25.3	0.	973.56	0.
Otter # VD065																	
23195	B	0.57	**53.05**	72.79	**74.67**	**106.52**	**57.54**	67.05	**57.09**	0.	0.	0.	0.	11.7	7.2	5883.14	0.
23182	F	0.82	**273.95**	**602.69**	**151.91**	**152.66**	**123.91**	**116.98**	**147.55**	**194.4**	**169.36**	0.	0.	**1820.7**	**83.2**	9598.70	0.
23185	I	0.64	**160.08**	**135.76**	**190.93**	**148.26**	**86.68**	**86.90**	**125.87**	0.	0.	0.	0.	**611.6**	10.2	2542.69	0.
23186	K	0.56	**67.90**	**71.55**	**60.80**	**70.09**	**45.37**	0.	27.63	0.	0.	0.	0.	**249.**	40.6	2049.42	0.
23183	L	0.98	**47.91**	**48.75**	**57.66**	**64.90**	**76.11**	40.15	**45.46**	0.	0.	0.	0.	**284.1**	**57.6**	1456.14	0.
23188	M	0.77	**63.82**	**71.14**	**87.77**	**68.42**	**77.62**	**70.62**	**59.42**	0.	0.	0.	0.	48.2	17.6	3578.72	0.
Otter # VD068																	
23179	B	0.57	**126.59**	**128.39**	**214.59**	**141.68**	**164.96**	**190.25**	**132.59**	**142.36**	**137.37**	0.	0.	60.5	23.5	2830.79	0.
23172	F	0.76	**125.12**	**182.43**	**176.55**	**271.73**	**117.74**	**119.77**	**87.44**	**114.82**	**65.01**	0.	0.	**1591.6**	58.8	9060.55	0.
23175	I	0.66	**141.47**	**146.25**	**141.79**	**173.78**	**121.28**	**177.61**	**78.65**	54.74	0.	0.	9.67	**306.7**	30.5	2535.83	0.
23176	K	0.51	**150.67**	**162.82**	**155.32**	**109.78**	**251.15**	**291.73**	**114.96**	0.	0.	0.	0.	101.	21.8	5132.08	0.
23174	L	0.58	**172.32**	**191.30**	**186.53**	**138.60**	**105.83**	**109.12**	**108.56**	50.35	**196.46**	0.	10.17	**426.9**	**189.4**	3195.44	0.
23173	M	0.62	**164.34**	**184.9**	**199.27**	**162.98**	**142.53**	**101.42**	**89.08**	**97.25**	**90.67**	0.	0.	96.8	21.8	3221.90	0.
Otter # VD074																	
23310	B	0.54	58.94	61.11	52.09	43.27	40.36	45.97	0.	0.	0.	0.	0.	0.	0.	647.85	0.
23299	I	0.6	**6559.05**	**6182.52**	**5226.80**	**4156.24**	**3420.80**	**3110.55**	**1903.89**	**1323.66**	**300.56**	**193.59**	16.30	**8473.3**	**5536.5**	156790.6	904.9
23301	K	0.61	**187.72**	**88.75**	**68.63**	**60.58**	**65.12**	57.59	0.	0.	0.	0.	0.	66.6	49.	1154.07	0.
23298	L	0.68	**101.01**	**111.58**	**99.76**	**102.04**	**69.69**	60.04	0.	0.	0.	0.	0.	76.7	48.6	1352.14	0.
23304	M	0.61	**137.32**	**152.30**	**115.70**	**93.89**	**91.14**	72.68	38.33	0.	0.	0.	0.	31.6	0.	1306.58	0.

Lab ID	Tissue[c]	Sample wt.[d]	C24	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	PRIS	PHYT	Total	UCM[e]
Otter # VD141																	
21809	B	0.55	**259.33**	**276.66**	**243.66**	**234.53**	**219.48**	**178.18**	**206.84**	**89.21**	55.89	13.31	0.	64.3	28.8	3893.89	0.
21805	I	1.11	**73.10**	**74.84**	**65.44**	**67.28**	**47.27**	37.78	**28.98**	18.74	22.66	0.	0.	**90.4**	26.3	1647.22	0.
21803	K	0.57	**242.38**	**261.**	**223.24**	**225.**	**191.59**	**195.62**	**194.90**	**213.23**	**129.27**	50.10	15.21	96.6	39.1	3754.30	0.
21804	L	0.56	**314.79**	**326.66**	**294.95**	**253.10**	**208.95**	**175.67**	**136.75**	**99.90**	0.	0.	0.	**146.6**	**82.4**	4102.72	0.
21806	M	0.93	**122.74**	**124.74**	**117.26**	**106.21**	**92.84**	**69.37**	**61.78**	28.67	11.	0.	0.	48.7	15.8	1966.35	0.
Otter # VD165																	
23554	B	0.55	**94.21**	**106.43**	**93.89**	**88.37**	**81.01**	53.8?	0.	0.	0.	0.	0.	46.3	0.	1260.98	0.
23543	F	0.7	**109.96**	**118.25**	**95.33**	**108.46**	**95.54**	**69.08**	0.	0.	0.	0.	0.	**992.5**	0.	3015.2	0.
23547	I	0.61	**110.34**	**122.4**	**111.41**	**139.13**	**105.44**	**93.5**	**63.35**	0.	0.	0.	0.	**429.8**	18.2	2342.39	0.
23546	K	0.55	**61.71**	**66.34**	51.15	**61.38**	**63.**	36.94	0.	37.41	0.	0.	0.	**438.7**	25.8	2455.15	0.
23545	L	0.69	**113.63**	**124.74**	**119.78**	**115.58**	**110.18**	62.21	0.	0.	0.	0.	0.	51.8	20.8	1495.07	0.
23544	M	0.87	**55.16**	**55.38**	**48.67**	**45.97**	**44.35**	25.63	0.	0.	0.	0.	0.	35.8	0.	814.77	0.

[a] Reported by GERG, NRDA Catalog 6540.

[b] Abbreviations: C10 through C34: n-alkanes; PRIS: pristane; PHYT: phytane; UCM: unresolved complex mixture; Total: total aliphatic (not including the UCM).

[c] Tissue: B = brain, F = fat, I = intestine, K = kidney, L = liver, M = muscle, T = testis.

[d] Sample wet weight in grams.

[e] μg/g.

Table A-3. *Aromatic hydrocarbon concentrations (ng/g) in tissue samples collected from oiled sea otter carcasses recovered in Prince William Sound, Alaska, in spring 1989.*[a, b] Values in boldface are greater than MDL.

Lab ID	Tissue[c]	Sample wt.[d]	NAP	C1N	C2N	C3N	C4N	BIP	ANP	ANH	FLU	C1F	C2F	C3F	PHE	ANT	C1P	C2P	C3P	C4P	DIB
Otter # VD015																					
23273	B	0.68	39.81	**37.18**	0.	0.	0.	13.04	1.39	5.51	4.99	0.	0.	0.	18.88	4.28	0.	0.	0.	0.	0.6
23263	I	0.65	27.04	19.87	0.	0.	0.	8.63	1.68	1.25	2.46	0.	0.	0.	9.66	2.97	0.	0.	0.	0.	1.61
23264	K	0.57	40.52	28.34	0.	0.	0.	28.12	1.39	2.8	3.79	0.	0.	0.	12.99	1.99	0.	0.	0.	0.	3.03
23262	L	0.57	24.24	29.39	0.	0.	0.	14.64	1.35	0.92	2.92	0.	0.	0.	12.95	3.75	0.	0.	0.	0.	3.75
23261	M	0.56	30.7	23.73	0.	0.	0.	20.21	1.37	1.9	3.83	0.	0.	0.	12.43	2.22	0.	0.	0.	0.	1.77
Otter # VD018																					
23484	B	0.65	70.34	**99.01**	**103.1**	**106.42**	0.	**44.43**	3.55	2.85	8.91	0.	0.	0.	19.33	1.83	27.81	27.42	0.	0.	12.14
23471	I	0.71	26.8	25.65	20.84	0.	0.	15.57	0.79	1.03	2.55	5.28	0.	0.	6.84	1.14	0.	0.	0.	0.	2.76
23472	K	0.75	**39.71**	**40.19**	**32.41**	**37.33**	0.	24.61	0.5	0.84	2.34	4.33	0.	0.	6.26	0.63	6.99	0.	0.	0.	4.83
23470	L	0.53	42.27	**46.79**	38.4	38.07	0.	30.17	0.81	2.11	4.53	5.83	0.	0.	7.38	1.13	0.	0.	0.	0.	7.27
23476	M	0.59	19.27	22.04	18.35	0.	0.	15.24	0.84	1.93	3.94	0.	0.	0.	5.75	0.78	0.	0.	0.	0.	2.96
23482	T	0.58	34.01	**47.08**	0.	0.	0.	26.9	1.59	4.19	5.56	0.	0.	0.	11.12	1.69	0.	0.	0.	0.	6.08
Otter # VD028																					
23292	B	0.78	61.9	**105.83**	**34.83**	**70.55**	**50.83**	**32.21**	0.64	3.16	4.9	0.	0.	0.	13.59	0.49	10.	0.	0.	0.	9.24
23279	F	0.75	**1370.81**	**894.91**	**886.44**	**911.18**	**700.69**	**388.69**	3.08	11.79	**43.6**	**113.53**	**105.95**	0.	**86.9**	5.96	**127.19**	**52.02**	**41.77**	0.	**99.14**
23286	I	0.62	35.33	36.33	28.46	34.11	**41.**	22.24	0.75	0.65	4.29	0.	0.	0.	8.51	1.02	0.	0.	0.	0.	3.46
23285	K	0.63	**72.18**	**79.5**	0.	0.	0.	**31.75**	0.23	1.46	2.75	0.	0.	0.	8.81	0.94	0.	0.	0.	0.	5.77
23283	L	0.56	**119.15**	**82.52**	**55.64**	0.	0.	32.03	0.52	0.91	4.55	0.	0.	0.	14.65	0.69	0.	0.	0.	0.	4.19
23280	M	0.51	50.11	**48.55**	43.52	25.23	0.	14.66	1.07	3.3	3.67	0.	0.	0.	11.81	1.1	0.	0.	0.	0.	3.97
Otter # VD056																					
23503	B	0.52	29.28	**87.08**	**117.68**	**99.88**	0.	17.03	1.43	4.17	8.74	0.	0.	0.	13.41	1.33	18.58	0.	0.	0.	7.7
23492	F	0.84	**226.28**	**409.4**	**293.36**	**244.02**	**119.09**	**94.82**	2.53	4.24	13.5	**31.14**	**55.93**	0.	**38.92**	1.45	**67.28**	**36.05**	0.	0.	24.51
23499	I	0.55	16.16	36.42	**61.24**	**75.43**	0.	13.44	2.2	2.64	4.05	0.	0.	0.	9.68	1.59	16.46	25.63	0.	0.	7.29
23498	K	0.65	17.73	**40.08**	**51.41**	0.	0.	12.87	1.91	3.61	5.09	0.	0.	0.	7.92	0.94	0.	0.	0.	0.	5.35
23497	L	0.6	24.13	37.85	**49.51**	0.	0.	22.45	1.51	2.79	5.07	0.	0.	0.	9.13	1.37	0.	0.	0.	0.	4.53
23494	M	0.62	17.75	32.06	0.	0.	0.	9.58	2.07	1.38	4.33	0.	0.	0.	4.99	1.24	0.	0.	0.	0.	2.37
23493	T	0.74	**71.02**	**248.55**	**160.22**	**91.67**	**64.18**	25.24	1.61	3.27	7.63	0.	0.	0.	14.99	0.96	18.81	0.	0.	0.	28.66

Lab ID	Tissue	Sample wt.[d]	NAP	C1N	C2N	C3N	C4N	BIP	ANP	ANH	FLU	C1F	C2F	C3F	PHE	ANT	C1P	C2P	C3P	C4P	DIB
Otter # VD059																					
23408	B	0.67	32.65	97.96	116.82	93.78	49.88	38.76	0.62	1.58	7.65	12.34	0.	0.	22.08	0.58	25.76	15.13	0.	0.	14.8
23389	F	0.72	879.27	2052.58	1490.1	900.14	360.6	789.64	1.19	19.3	93.29	123.1	153.78	0.	216.42	3.85	279.54	141.8	39.9	0.	117.6
23397	I	0.58	80.6	214.16	220.27	188.47	121.78	92.4	1.54	3.31	13.35	18.74	0.	0.	28.5	0.74	42.77	43.47	52.37	20.39	20.7
23398	K	0.59	53.2	122.68	124.84	76.12	34.07	64.58	0.31	2.57	6.27	11.77	0.	0.	14.68	1.55	7.93	0.	0.	0.	11.59
23396	L	0.61	154.65	249.42	148.85	91.6	43.98	205.19	0.89	5.61	11.54	0.	0.	0.	13.55	0.54	10.73	9.17	0.	0.	11.41
23393	M	0.77	30.47	62.16	64.62	58.59	30.42	31.93	0.68	1.38	5.98	0.	0.	0.	12.73	0.66	13.46	9.49	0.	0.	6.57
Otter # VD065																					
23195	B	0.57	31.5	131.22	240.07	209.44	0.	46.98	2.07	3.65	12.21	0.	0.	0.	28.81	1.81	36.93	26.73	0.	0.	20.64
23182	F	0.82	312.28	2180.21	3230.58	2501.33	1085.56	866.82	0.73	27.65	165.61	294.09	246.79	107.79	312.6	7.21	425.12	188.71	59.92	0.	194.65
23185	I	0.64	32.03	67.1	103.04	87.56	0.	39.9	1.42	3.94	8.64	0.	0.	0.	16.15	0.84	12.91	0.	0.	0.	10.36
23186	K	0.56	48.25	214.19	346.14	256.81	0.	96.13	6.17	6.17	18.09	0.	0.	0.	33.02	6.73	0.	0.	0.	0.	28.
23183	L	0.98	33.39	140.8	175.67	122.84	0.	83.78	0.53	3.41	12.04	0.	0.	0.	14.45	1.43	12.21	12.97	0.	0.	15.44
23188	M	0.77	26.84	51.22	78.33	62.03	0.	23.42	2.34	4.31	6.82	0.	0.	0.	11.67	1.39	0.	0.	0.	0.	10.02
Otter # VD068																					
23179	B	0.57	67.56	81.07	109.56	113.58	0.	36.3	2.18	3.92	8.09	0.	0.	0.	16.92	2.05	0.	0.	0.	0.	8.73
23172	F	0.76	1576.13	1283.08	916.77	711.74	496.53	448.	0.92	6.61	30.66	85.74	113.68	0.	56.	3.08	116.5	62.07	0.	0.	63.68
23175	I	0.66	51.16	37.79	46.95	0	0.	21.02	1.23	1.42	3.57	0.	0.	0.	9.13	1.81	0.	0.	0.	0.	3.09
23176	K	0.51	77.94	98.37	80.95	74.64	0.	37.46	1.86	6.51	6.28	0.	0.	0.	13.02	1.36	0.	0.	0.	0.	8.04
23174	L	0.58	125.32	91.32	58.38	0.	0.	52.69	2.57	1.47	5.26	0.	0.	0.	7.91	1.6	0.	0.	0.	0.	4.48
23173	M	0.62	76.88	71.	63.	76.71	0.	31.48	1.51	5.02	3.39	0.	0.	0.	9.52	1.75	13.1	0.	0.	0.	23.93
Otter # VD074																					
23310	B	0.54	75.1	437.04	208.16	65.8	53.8	91.53	3.5	4.59	11.42	0.	0.	0.	20.64	1.24	13.46	9.89	0.	0.	27.68
23299	I	0.6	222.34	3104.18	5641.07	6079.22	3538.76	390.35	3.15	45.86	279.46	727.54	1303.71	1430.82	1048.57	16.03	2531.44	3037.92	1894.19	956.87	728.68
23301	K	0.61	74.57	307.9	165.06	88.36	62.04	83.64	0.33	4.25	11.06	0.	0.	0.	22.68	0.86	19.44	19.11	0.	0.	25.15
23298	L	0.68	84.44	355.18	146.88	69.	34.07	79.36	0.9	3.34	9.8	0.	0.	0.	14.18	1.87	10.	10.74	0.	0.	21.3
23304	M	0.61	31.37	100.92	50.58	32.42	0.	28.06	0.7	2.87	4.81	0.	0.	0.	8.08	1.49	0.	0.	0.	0.	6.46

Lab ID	Tissue	Sample wt.[d]	NAP	C1N	C2N	C3N	C4N	BIP	ANP	ANH	FLU	C1F	C2F	C3F	PHE	ANT	C1P	C2P	C3P	C4P	DIB
Otter # VD141																					
21809	B	0.55	29.67	25.83	0.	0.	0.	17.33	1.81	2.03	6.08	0.	0.	0.	7.1	0.96	0.	0.	0.	0.	3.05
21805	I	1.11	17.25	18.06	0.	0.	0.	9.29	0.57	1.71	1.64	0.	0.	0.	5.23	1.1	0.	0.	0.	0.	0.84
21803	K	0.57	27.18	22.62	0.	0.	0.	12.38	2.98	4.13	1.53	0.	0.	0.	5.67	1.71	0.	0.	0.	0.	1.51
21804	L	0.56	19.68	24.52	0.	0.	0.	9.13	2.39	3.54	1.08	0.	0.	0.	6.32	1.43	0.	0.	0.	0.	2.58
21806	M	0.93	2.2	1.77	0.	0.	0.	1.36	0.14	0.14	0.23	0.	0.	0.	0.71	0.12	0.	0.	0.	0.	0.15
Otter # VD165																					
23554	B	0.55	44.28	**116.23**	**95.34**	**81.28**	**69.37**	19.08	1.84	7.12	5.97	0.	0.	0.	10.26	0.8	14.37	9.4	0.	0.	6.56
23543	F	0.7	**695.19**	**869.13**	**271.67**	**147.47**	**95.7**	**57.76**	1.66	2.72	9.8	0.	0.	0.	20.02	1.01	**38.5**	0.	0.	0.	13.52
23547	I	0.61	**485.78**	**1145.76**	**416.78**	**215.37**	**122.95**	**94.38**	0.83	6.63	14.52	26.18	0.	0.	**28.06**	1.09	35.35	18.95	0.	0.	23.94
23546	K	0.55	**207.82**	**522.75**	**224.67**	**146.84**	**69.76**	**51.33**	3.47	4.12	6.41	0.	0.	0.	17.42	1.54	27.71	0.	0.	0.	5.69
23545	L	0.69	**105.56**	**255.89**	**100.3**	**49.7**	0.	**34.99**	1.51	3.74	5.11	0.	0.	0.	7.47	1.09	0.	0.	0.	0.	7.74
23544	M	0.87	25.13	**49.18**	**39.77**	**41.25**	0.	8.54	0.85	0.9	1.41	0.	0.	0.	5.89	1.4	8.71	0.	0.	0.	3.18

Table A-3. Continued.

Lab ID	Tissue[c]	Sample wt.[d]	C1D	C2D	C3D	FLA	PYR	CFP	BAA	CHR	C1C	C2C	C3C	C4C	BBF	BKF	BEP	BAP	PER	IDE	DBN	BEQ	Total
Otter # VD015																							
23273	B	0.68	0.	0.	0.	4.42	5.42	0.	1.85	1.27	0.	0.	0.	0.	3.44	2.	2.23	2.61	7.47	9.52	9.56	6.78	182.25
23263	I	0.65	0.	0.	0.	2.19	2.84	0.	0.88	2.23	0.	0.	0.	0.	0.75	1.1	1.9	1.29	0.99	6.57	6.16	2.63	104.7
23264	K	0.57	0.	0.	0.	2.68	3.67	0.	1.46	2.78	0.	0.	0.	0.	1.56	1.95	2.54	2.73	8.49	8.88	3.36	5.16	168.23
23262	L	0.57	0.	0.	0.	2.29	3.42	0.	1.91	2.9	0.	0.	0.	0.	1.24	0.76	2.16	2.29	0.89	2.42	4.07	5.52	123.78
23261	M	0.56	0.	0.	0.	2.54	2.87	0.	1.95	2.07	0.	0.	0.	0.	1.12	0.77	2.29	1.6	5.33	5.03	4.84	5.66	134.23
Otter # VD018																							
23484	B	0.65	35.92	22.46	0.	3.73	4.13	0.	2.63	3.88	0.	0.	0.	0.	1.81	0.99	2.06	2.71	5.92	1.59	1.82	2.38	619.17
23471	I	0.71	0.	0.	0.	2.93	1.59	0.	0.71	1.	0.	0.	0.	0.	1.74	2.29	1.3	1.28	1.26	1.33	1.1	1.06	126.84
23472	K	0.75	9.25	0.	0.	1.82	1.48	0.	0.87	0.94	0.	0.	0.	0.	0.43	0.58	1.52	0.68	0.95	1.46	1.24	0.61	222.8
23470	L	0.53	0.	0.	0.	1.69	2.98	0.	0.39	1.29	0.	0.	0.	0.	0.85	0.83	1.65	2.7	0.68	2.11	2.87	1.58	244.38
23476	M	0.59	0.	0.	0.	4.13	1.56	0.	0.5	1.08	0.	0.	0.	0.	0.63	1.65	0.91	1.11	2.38	1.51	1.	0.97	108.53
23482	T	0.58	0.	0.	0.	7.04	3.27	0.	0.68	2.03	0.	0.	0.	0.	1.03	1.6	2.82	1.76	2.05	3.88	2.12	3.45	169.95
Otter # VD028																							
23292	B	0.78	16.86	9.57	0.	1.97	1.99	0.	0.29	0.3	0.	0.	0.	0.	0.55	0.6	1.11	0.93	0.87	1.25	0.69	1.13	486.28
23279	F	0.75	**108.87**	**89.5**	**34.68**	3.56	5.22	0.	0.74	4.05	0.	0.	0.	0.	0.88	0.84	1.71	2.13	2.28	3.52	4.64	3.75	6110.02
23286	I	0.62	0.	0.	0.	2.85	2.8	0.	0.98	0.68	0.	0.	0.	0.	0.96	0.78	0.94	0.93	1.03	1.56	1.31	1.39	232.36
23285	K	0.63	0.	0.	0.	2.24	1.49	0.	0.48	1.14	0.	0.	0.	0.	0.53	0.85	1.35	1.14	3.3	1.38	0.52	1.36	219.17
23283	L	0.56	0.	0.	0.	1.59	2.47	0.	1.17	1.12	0.	0.	0.	0.	0.82	1.13	1.89	1.58	3.66	4.05	4.95	2.43	341.71
23280	M	0.51	0.	0.	0.	1.76	3.02	0.	1.03	1.62	0.	0.	0.	0.	1.91	2.23	2.42	1.05	2.61	7.22	7.17	3.36	242.39
Otter # VD056																							
23503	B	0.52	23.75	0.	0.	1.28	2.31	0.	1.28	1.85	0.	0.	0.	0.	1.33	1.23	0.98	0.91	4.85	2.2	1.26	1.11	450.65
23492	F	0.84	**40.3**	**34.67**	0.	1.42	2.53	0.	2.5	1.94	0.	0.	0.	0.	0.79	0.35	0.52	0.97	1.27	1.42	0.67	0.57	1752.44
23499	I	0.55	12.01	0.	0.	1.6	2.88	0.	1.07	1.32	0.	0.	0.	0.	0.86	0.5	1.59	0.91	2.38	1.87	1.14	0.76	301.12
23498	K	0.65	0.	0.	0.	1.22	2.25	0.	1.6	1.01	0.	0.	0.	0.	0.98	0.96	0.67	1.08	1.64	0.56	0.98	1.02	160.88
23497	L	0.6	0.	0.	0.	1.52	4.66	0.	1.29	1.65	0.	0.	0.	0.	0.98	0.81	0.49	0.57	0.49	0.81	0.87	1.79	174.27
23494	M	0.62	0.	0.	0.	1.91	2.43	0.	0.71	0.85	0.	0.	0.	0.	0.91	0.87	0.44	0.99	2.27	1.24	0.63	0.89	89.91
23493	T	0.74	**50.26**	**35.47**	0.	1.21	2.29	0.	2.43	1.47	0.	0.	0.	0.	0.8	0.57	0.49	1.02	1.37	0.67	0.56	0.77	836.19

Lab ID	Tissue	Sample wt.[d]	C1D	C2D	C3D	FLA	PYR	CFP	BAA	CHR	C1C	C2C	C3C	C4C	BBF	BKF	BEP	BAP	PER	IDE	DBN	BEQ	Total
Otter # VD059																							
23408	B	0.67	21.59	20.9	18.24	2.22	2.47	0.	0.19	2.58	0.	0.	0.	0.	0.45	0.92	1.09	0.99	0.99	0.74	1.16	0.79	605.71
23389	F	0 72	**142.2**	**95.32**	**37.33**	4.05	4.47	12.21	1.42	8.63	0.	0.	0.	0.	0.82	0.8	0.63	0.85	5.53	0.43	0.61	0.42	7977.82
23397	I	0.58	36.13	43.18	**34.96**	3.43	2.85	7.44	0.61	3.76	0.	0.	0.	0.	0.91	0.5	2.17	1.41	4.05	0.49	1.71	1.35	1308.51
23398	K	0.59	11.7	8.42	0.	2.81	1.48	0.	1.17	1.21	0.	0.	0.	0.	0.57	1.3	0.36	0.96	1.28	0.95	1.5	0.91	566.78
23396	L	0.61	0.	0.	0.	2.15	2.75	0.	0.39	0.65	0.	0.	0.	0.	1.15	0.74	1.36	1.57	1.27	1.06	1.32	1.92	973.46
23393	M	0.77	18.31	11.61	0.	1.82	1.33	0.	0.26	1.08	0.	0.	0.	0.	0.34	0.95	1.06	1.9	1.21	0.69	0.58	1.42	371.7
Otter # VD065																							
23195	B	0.57	37.45	26.42	0.	2.05	2.9	0.	0.75	1.25	0.	0.	0.	0.	0.82	0.94	1.19	1.54	1.31	2.29	2.07	2.02	875.06
23182	F	0.82	**239.36**	**158.92**	**55.87**	4.8	6.86	0.	3.23	11.19	0.	0.	0.	0.	0.53	0.56	1.09	0.31	1.41	0.88	0.83	1.03	12694.42
23185	I	0.64	13.36	0.	0.	3.04	3.64	0.	1.41	1.03	0.	0.	0.	0.	0.94	1.24	1.16	0.87	0.53	3.68	1.17	1.27	417.23
23186	K	0.56	30.44	0.	0.	2.5	3.65	0.	1.67	1.24	0.	0.	0.	0.	1.45	1.83	2.17	2.88	1.35	5.9	2.03	1.96	1118.77
23183	L	0.98	0.	0.	0.	1.83	1.84	0.	0.42	0.64	0.	0.	0.	0.	0.31	0.82	0.46	1.38	0.65	0.73	0.81	0.83	639.68
23188	M	0.77	13.13	0.	0.	1.58	2.64	0.	1.44	1.98	0.	0.	0.	0.	2.66	1.71	1.78	0.63	1.16	2.07	1.55	2.12	312.84
Otter # VD068																							
23179	B	0.57	0.	0.	0.	3.34	4.74	0.	1.08	2.75	0.	0.	0.	0.	0.87	1.25	2.42	2.74	3.91	3.35	2.82	1.55	480.78
23172	F	0.76	**83.88**	**72.28**	**37.11**	2.71	4.4	0.	1.16	4.92	0.	0.	0.	0.	0.41	0.72	0.63	0.83	0.9	0.78	1.95	0.77	6184.64
23175	I	0.66	0.	0.	0.	1.88	2.46	0.	1.05	1.08	0.	0.	0.	0.	0.56	0.47	0.65	1.81	1.01	1.67	1.69	1.94	193.44
23176	K	0.51	0.	0.	0.	2.99	4.67	0.	2.28	2.25	0.	0.	0.	0.	1.33	1.93	2.06	1.07	1.14	4.39	1.6	1.05	433.19
23174	L	0.58	0.	0.	0.	2.54	1.67	0.	3.58	3.01	0.	0.	0.	0.	1.07	1.03	1.66	1.16	1.13	2.22	1.61	1.27	372.95
23173	M	0.62	27.11	19.52	0.	2.43	3.42	0.	1.21	1.18	0.	0.	0.	0.	1.85	2.66	0.64	1.68	0.79	1.73	1.31	1.52	444.34
Otter # VD074																							
23310	B	0.54	23.41	12.59	0.	4.73	1.88	0.	1.57	0.89	0.	0.	0.	0.	2.14	1.46	1.48	2.07	4.2	1.2	1.45	0.83	1083.75
23299	I	0.6	**1572.35**	**2261.5**	**1841.54**	9.14	**56.13**	**301.34**	21.22	**202.17**	**298.52**	**392.13**	**180.8**	**119.66**	20.83	5.03	56.03	11.35	9.89	3.88	5.13	16.34	40365.14
23301	K	0.61	27.04	20.03	0.	4.06	3.14	0.	2.78	3.32	0.	0.	0.	0.	1.04	0.56	1.2	1.19	11.88	1.27	2.98	2.05	966.99
23298	L	0.68	18.62	21.45	0.	2.86	1.72	0.	1.62	1.58	0.	0.	0.	0.	0.93	1.3	1.27	0.87	0.67	1.03	0.67	0.82	896.47
23304	M	0.61	0.	0.	0.	3.81	2.44	0.	1.35	1.38	0.	0.	0.	0.	0.73	1.02	0.72	0.62	0.92	1.1	1.31	0.92	284.08

Lab ID	Tissue[c]	Sample wt.[d]	C1D	C2D	C3D	FLA	PYR	CFP	BAA	CHR	C1C	C2C	C3C	C4C	BBF	BKF	BEP	BAP	PER	IDE	DBN	BEQ	Total
Otter # VD141																							
21809	B	0.55	0.	0.	0.	2.85	2.65	0.	2.58	1.76	0.	0.	0.	0.	0.94	0.98	1.29	1.97	0.83	2.23	2.14	2.98	117.06
21805	I	1.11	0.	0.	0.	1.43	1.53	0.	0.59	0.93	0.	0.	0.	0.	0.54	0.99	0.54	0.67	0.76	0.98	1.12	0.42	66.19
21803	K	0.57	0.	0.	0.	2.32	3.82	0.	1.4	1.8	0.	0.	0.	0.	1.27	1.89	0.85	1.11	1.15	2.08	2.29	1.89	101.58
21804	L	0.56	0.	0.	0.	2.74	2.68	0.	1.13	1.54	0.	0.	0.	0.	0.5	0.96	0.88	1.4	0.41	1.32	1.62	2.09	87.94
21806	M	0.93	0.	0.	0.	0.28	0.46	0.	0.12	0.17	0.	0.	0.	0.	0.16	0.12	0.12	0.21	0.2	0.17	0.2	0.12	9.15
Otter # VD165																							
23554	B	0.55	16.85	0.	0.	1.23	1.85	0.	0.79	0.8	0.	0.	0.	0.	0.44	0.45	1.11	1.39	0.72	0.51	0.43	0.52	508.99
23543	F	0.7	19.38	0.	0.	1.63	1.95	0.	1.14	1.13	0.	0.	0.	0.	0.48	0.83	0.85	0.79	0.9	0.8	0.66	0.95	2255.64
23547	I	0.61	21.14	18.75	0.	2.61	2.79	0.	0.73	1.85	0.	0.	0.	0.	1.57	1.35	0.29	0.53	0.75	0.62	1.01	0.75	2691.31
23546	K	0.55	17.67	0.	0.	1.69	2.3	0.	0.4	1.13	0.	0.	0.	0.	0.62	0.69	0.81	0.65	0.72	0.37	0.45	0.63	1317.66
23545	L	0.69	0.	0.	0.	1.26	2.71	0.	0.95	0.43	0.	0.	0.	0.	0.57	1.03	0.76	0.74	2.02	0.4	0.4	0.4	584.81
23544	M	0.87	0.	0.	0.	0.59	1.34	0.	0.68	0.91	0.	0.	0.	0.	0.52	0.69	0.98	0.41	0.71	0.37	1.07	0.47	194.95

[a] Reported by GERG, NRDA Catalog 6540.

[b] Abbreviations: NAP: naphthalene; C1N: C1-naphthalene; C2N: C2-naphthalene; C3N: C3-naphthalene; C4N: C4-naphthalene; BIP: biphenyl; ANP: acenaphthylene; ANH: acenaphthene; FLU: fluorene; C1F: C1-fluorene; C2F: C2-fluorene; C3F: C3-fluorene; ANT: anthracene; PHE: phenanthrene; C1P: C1-phenanthrene; C2P: C2-phenanthrene; C3P: C3-phenanthrene; C4P: C4-phenanthrene; DIB: dibenzothiophene; C1D: C1-dibenzothiophene; C2D: C2-dibenzothiophene; C3D: C3-dibenzothiophene; FLA: fluoranthene; PYR: pyrene; CFP: methyl fluoranthene-pyrene; BAA: benz(a)anthracene; CHR: chrysene; C1C: C1-chrysene; C2C: C2-chrysene; C3C: C3-chrysene; C4C: C4-chrysene; BBF: benzo(b)fluoranthene; BKF: benzo(k)fluoranthene; BEP: benzo(e)pyrene; BAP: benzo(a)pyrene; PER: perylene; IDE: ideno(1,2,3-cd)pyrene; DBN: dibenzo(a,h)anthracene; BEQ: benzo(g,h,i)perylene.

[c] Tissue: B = brain, F = fat, I = intestine, K = kidney, L = liver, M = muscle, T = testis.

[d] Sample wet weight, in grams.

Table A-4. Aliphatic hydrocarbon concentrations (ng/g except UCM in μg/g) measured in liver samples collected from non-oiled sea otters in Prince William Sound, Alaska[a, b]. Values in boldface are greater than MDL.

Otter#	Lab ID	wt[c]	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
VD407	21938	2.03	28.2	0	0	0	0	38.4	0	**87.2**	0	**12.4**	0	0	0	**14.4**	0
VZ121	27798	2.12	0	0	14	7.5	14	39.9	**27.1**	**22.8**	8.1	**11.7**	5.1	4.7	7.7	**12.2**	12
VZ156	29189	2.14	0.	9.7	9.2	6.5	15.2	29.1	**27.8**	**53.5**	9.8	0.	4.	4.8	**12.8**	**14.1**	8.4
Y2D028	22916	2	**1754**	24	17.3	0	20.3	27.9	24.1	**113**	**43.4**	0	**19.6**	**17.3**	**33.7**	0	**19.6**
Y2D031	22866	2.1	10.3	0	0	0	0	11.5	0	**54.7**	5.2	**10.1**	0	**17.5**	**11.4**	0	8
Y2D050	21895	2.28	36.5	0	0	0	4.5	132	**36**	**58.8**	10.5	0	0	0	0	0	0
Y2D058	21277b	2.44	0	0	0	0	0	4.5	4.5	**40.9**	6.2	0	6.7	**43.2**	0	**15.8**	**13.3**

Otter#	Lab ID	wt	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	PRIS	PHYT	Total	UCM
VD407	21938	2.03	**23.2**	13.5	0	3.6	5.4	9.4	9.3	0	0	0	**707**	**80.5**	1032.2	0
VZ121	27798	2.12	9.6	5.6	6.4	5.8	5.5	0	0	0	0	0	**2308**	**37.9**	2565.7	3.9
VZ156	29189	2.14	3.6	8.[illegible]	11.3	4.4	8.1	0.	0.	0.	0.	0.	**502.4**	**40.2**	783.0	7.8
Y2D028	22916	2	13.6	11.3	**17.2**	0	0	0	0	0	0	0	**228**	**74.1**	2458.7	0
Y2D031	22866	2.1	**41.6**	10.4	0	0	0	0	0	0	0	0	**83.5**	8.6	272.7	0
Y2D050	21895	2.28	0	0	0	0	0	4.7	4.9	5.4	5	0	**71.4**	9.5	379.6	0
Y2D058	21277	2.44	11.3	0	0	0	0	0	0	0	0	5.5	**151**	15	318.3	7.4

[a] Reported by GERG, NRDA Catalog 6556 and 6641.

[b] Abbreviations: C10-C34: n-alkanes; PRIS: pristane; PHYT: phytane; Total: total aliphatic (not including the UCM); UCM: unresolved complex mixture.

[c] Sample wet weight in grams.

Table A-5. Aromatic hydrocarbon concentrations (ng/g wet weight) measured in liver samples collected from non-oiled sea otters in Prince William Sound, Alaska[a, b]. Values in boldface are greater than MDL.

Otter #	Lab ID	wt.[c]	NAP	C1N	C2N	C3N	C4N	BIP	ANP	ANH	FLU	C1F	C2F	C3F	PHE	ANT	C1P	C2P
VD407	21938	2.03	7.36	9.44	0	0	0	3.1	1.09	1.23	1.63	0	0	0	1.52	0.33	0	0
VZ121	27798	2.12	6.52	**11.69**	0	0	0	3.52	1.01	5.62	4.5	0	0	0	**10.03**	1.96	0	0
VZ156	29189	2.14	6.62	**11.93**	0	0	0	4.02	3.06	4.31	2.81	0	0	0	**11.88**	2.71	0	0
Y2D028	22916	2	7.97	9.52	0	0	0	7.05	2.2	3.59	6.23	0	0	0	**8**	3.27	0	0
Y2D031	22866	2.1	4.62	8.23	0	0	0	2.02	0.61	1.05	1.07	0	0	0	1	0.12	0	0
Y2D050	21895	2.28	8.16	10.03	0	0	0	2.26	0.35	0.51	0.62	0	0	0	1.24	0.47	0	0
Y2D058	21277	2.44	6.35	6.17	0	0	0	2.34	**19.9**	2.98	1.07	0	0	0	2.03	1.66	0	0

Otter #	Lab ID	wt.	C3P	C4P	DIB	C1D	C2D	C3D	FLA	PYR	CFP	BAA	CHR	C1C	C2C	C3C	C4C	BBF
VD407	21938	2.03	0	0	0.82	0	0	0	0.68	1.23	0	0.4	0.65	0	0	0	0	0.18
VZ121	27798	2.12	0	0	1.43	0	0	0	**7.09**	5.27	0	1.82	1.28	0	0	0	0	1.21
VZ156	29189	2.14	0	0	1.23	0	0	0	**6.86**	5.22	0	3.42	1.96	0	0	0	0	1.12
Y2D028	22916	2	0	0	0.93	0	0	0	1.59	2.15	0	0.87	0.81	0	0	0	0	0.74
Y2D031	22866	2.1	0	0	0.19	0	0	0	0.75	1.05	0	0.38	0.38	0	0	0	0	0.28
Y2D050	21895	2.28	0	0	1.04	0	0	0	1.19	1.84	0	0.06	0.61	0	0	0	0	0.54
Y2D058	21277	2.44	0	0	0.96	0	0	0	**3.37**	2.98	0	1.23	1.77	0	0	0	0	3.18

Table A-5. Continued.

Otter #	Lab ID	wt.	BKF	BEP	BAP	PER	IDE	DBN	BEQ	Total
VD407	21938	2.03	0.2	0.4	0.12	0.35	0.28	0.23	0.27	31.5
VZ121	27798	2.12	0.87	0.74	0.94	0.86	1.06	0.75	0.64	68.8
VZ156	29189	2.14	0.16	0.59	0.76	3.43	2.14	5.9	1.3	81.4
Y2D028	22916	2	0.32	0.36	0.3	1.5	1.71	1.09	3.53	63.7
Y2D031	22866	2.1	0.18	0.28	0.25	0.15	0.29	0.4	0.18	23.5
Y2D050	21895	2.28	0.5	0.26	0.47	0.77	0.14	0.25	0.16	31.5
Y2D058	21277	2.44	0.37	1.59	1.32	1.41	1.03	1.1	0.63	63.4

[a] Reported by GERG, NRDA Catalog 6556 and 6641.

[b] Abbreviations: NAP: naphthalene; C1N: C1-naphthalene; C2N: C2-naphthalene; C3N: C3-naphthalene; C4N: C4-naphthalene; BIP: biphenyl; ANP: acenaphthylene; ANH: acenaphthene; FLU: fluorene; C1F: C1-fluorene; C2F: C2-fluorene; C3F: C3-fluorene; ANT: anthracene; PHF: phenanthrene; C1P: C1-phenanthrene; C2P: C2-phenanthrene; C3P: C3-phenanthrene; C4P: C4-phenanthrene; DIB: dibenzothiophene; C1D: C1-dibenzothiophene; C2D: C2-dibenzothiophene; C3D: C3-dibenzothiophene; FLA: fluoranthene; PYR: pyrene; CFP: methyl fluoranthene-pyrene; BAA: benz(a)anthracene; CHR: chrysene; C1C: C1-chrysene; C2C: C2-chrysene; C3C: C3-chrysene; C4C: C4-chrysene; BBF: benzo(b)fluoranthene; BKF: benzo(k)fluoranthene; BEP: benzo(e)pyrene; BAP: benzo(a)pyrene; PER: perylene; IDE: ideno(1,2,3-cd)pyrene; DBN: dibenzo(a,h)anthracene; BEQ: benzo(g,h,i)perylene.

[c] Sample wet weight in grams.