Exxon Valdez Oil Spill
Restoration Project Annual Report

Recovery Monitoring and Restoration of Oiled Mussel Beds in Prince William Sound, Alaska

Restoration Project 93036
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: This project was initiated under Restoration Project 103A. An annual report was issued in 1994 by Babcock et al., under the title of "Recovery Monitoring and Restoration of Intertidal Oiled Mussel (*Mytilus trossulus*) Beds in Prince William Sound Impacted by the *Exxon Valdez* Oil Spill". An Alaska Fisheries Science Center Processed Report (94-02) was prepared covering the same material. Two papers have been accepted for the *Exxon Valdez* Symposium proceedings, "Persistence of Oiling in Mussel Beds Three and Four Years after the *Exxon Valdez* Oil Spill" and "Within Bed Distribution of *Exxon Valdez* Crude Oil in Prince William Sound Blue Mussels and Underlying Sediments". Numerous verbal presentations have been made on this project to Trustee-sponsored workshops and other scientific meetings. The project has continued under Restoration 93036, the subject of this annual report.

Abstract: Dense mussel (*Mytilus trossulus*) beds impacted by *Exxon Valdez* crude oil in Prince William Sound were intentionally left untreated during shoreline cleanup activities, 1989-1991. In 1992 and 1993, mussels and sediments from a total of 70 mussel beds in the Sound were sampled to establish the geographical extent and intensity of *Exxon Valdez* oil persisting in mussel beds. Sediments collected in 1992 and 1993 from 31 of the oiled beds in the Sound had total petroleum hydrocarbon concentrations greater than 10,000 μg/g wet weight. The highest concentrations were in sediments collected from Foul Bay (62,258 ± 1,272 μg/g total polynuclear hydrocarbons). The mean concentration of total polynuclear aromatic hydrocarbons in mussels ranged up to 8.30 ± 0.26 μg/g (Squirrel Island). Polynuclear aromatic hydrocarbon fingerprints of mussel tissue collected from surveyed sites indicated contaminantion from *Exxon Valdez* oil.

In 1993, total polynuclear hydrocarbons concentrations in sediments and total polynuclear aromatic hydrocarbons concentrations in mussels were generally lower than in 1992. Many beds, especially in protected, low-energy areas, showed little reduction, probably due to remobilization of residual oil underlying the beds. The substantial residual oil persisting under beds in the spill area is a source of chronic contamination of mussels and their predators.

Key Words: *Exxon Valdez*, hydrocarbons, mussels, *Mytilus trossulus*, oiling, persistence, petroleum hydrocarbons, sediments

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EXECUTIVE SUMMARY

Sediments collected in 1992 and 1993 from 31 of the oiled mussel beds in Prince William Sound had total petroleum hydrocarbon concentrations greater than 10,000 μg/g wet weight. The highest concentrations were in sediments collected from Foul Bay (62,258 ± 1,272 μg/g total petroleum hydrocarbon). The mean concentration of total polynuclear aromatic hydrocarbons in mussels ranged up to 8.30 $\pm$ 0.26 μg/g (Squirrel Island). Polynuclear aromatic hydrocarbon fingerprints of mussel tissue collected from surveyed sites indicated the contaminant source was *Exxon Valdez* crude oil.

In 1993, mean TPH concentration in sediments and mean total polynuclear aromatic hydrocarbon concentration in mussels were lower by over 50% than in 1992. Some beds showed little reduction in oil. Almost all the beds showing only small decreases in hydrocarbons were in protected, low-energy areas, probably resulting little remobilization of residual oil underlying the beds.

This study has produced analytical evidence showing that substantial residual *Exxon Valdez* oil persists in sediments underlying mussel beds in the area impacted by the spill. Residual crude oil is a source of chronic contamination of mussels and their predators. In the more protected intertidal areas, natural flushing and remobilization of *Exxon Valdez* oil will be slow; some of these mussel beds can potentially be manually cleaned.

INTRODUCTION

Based on the importance of dense mussel (*Mytilus trossulus*) beds (on finer, unconsolidated substrates) as food for higher consumers and as a community and physically stabilizing influence in the intertidal area, the *Exxon Valdez* oil spill Interagency Shoreline Cleanup Committee intentionally avoided cleaning and other treatment of these beds after the *Exxon Valdez* oil spill (EVOS) on 23 March 1989. It was hoped that natural processes would clean the beds in reasonable time.

In the spring of 1991, the persistence of crude oil in sediments underneath some dense mussel beds in Prince William Sound (PWS) was apparent and began to cause concern among scientists from federal and state agencies. Because these beds were left intact and uncleaned, as an unanticipated consequence they could be a source of chronic hydrocarbon (HC) exposure to organisms inhabiting the near surface and surface areas, thus providing a possible pathway for petroleum HCs to enter the food web for higher consumers. Persistent, high concentrations of HCs in mussels were identified as a possible source of impacts in several consumer species. These contaminated beds could also impact human subsistence users. Pilot surveys and collections of sediments and mussels in 1991 did indeed confirm the existence of substantial amounts of residual *Exxon Valdez* crude oil (EVO) in sediments immediately underlying dense mussel beds, and also in mussels (Babcock et al. 1994). This crude oil was mobile and odorous, and concentrations within these sediments and mussels were the highest found in 1991.

Extensive surveys were conducted in 1992 under Restoration Project 103A to determine the extent of mussel bed contamination and to assess the magnitude of the problem (Babcock et al. 1994). We documented 27 mussel beds with HC levels in excess of 10,000 μg/g total petroleum hydrocarbons (TPH) in sediments underlying these beds in 1992. The highest oil concentrations found in animals or sediments in 1991 and 1992 were in mussels and underlying substrates from oiled mussel beds (Babcock, 1991; Babcock et al. 1994).

In 1993, under Project 93036, we resampled many of the sites identified in 1992 and allowing calculations of changes between 1992 and 1993, and sampled five additional oiled beds; conducted an additional minimally intrusive test to accelerate flushing within the beds; and conducted tests of biological impact to the mussels themselves. All work was been completed, and the HC data has been received, on schedule. Data and results from the manipulation tests and biological tests is still being analyzed and will be discussed fully in the four-year Final Report due September 1996.

These data on oiled mussel beds will allow monitoring of natural recovery and provide information for decisions on assisted recovery in areas with residual HCs in future years.

OBJECTIVES

A. To monitor natural recovery in levels of petroleum hydrocarbons in oiled mussel beds, including beds identified and ampled in 1991 and 1992, and additional beds identified by other agency field investigators.

B. To monitor recovery in levels of petroleum hydrocarbons in experimentally manipulated mussel beds. Note: This objective will be discussed fully in the Final Report on this four-year project--due September 1996.

C. To measure physiological injury caused to mussels by chronic expsure to petroleum hydrocarbons. Note: This objective will be discussed fully in the Final Report on this four-year project--due September 1996.

METHODS

Potentially oiled mussel beds within PWS were tentatively identified through several sources: 1) Alaska Department of Environmental Conservation's (ADEC) extensive Shoreline Assessment records, 2) Alaska Department of Fish and Game researchers on harlequin ducks, and 3) U.S. Fish and Wildlife personnel working on black oystercatchers. Mussel beds were visited, and mussels and underlying sediments were sampled if oil was present in both 1992 and 1993. Twenty six of the sites sampled in 1992 were resampled in 1993.

Sampled mussel beds ranged in size from approximately 20 m^2 for a small bed on Disk Island to 700 m^2 for the large bed on the tombolo adjacent to Eleanor Island. Density of mussels ranged from thinly interspersed mussels (288/m^2) at Aguliak Island to multiple layers of mussels (5,000/m^2) at Eleanor Island.

Most mussel beds were situated on mixed sand and gravel substrates, and mussels were usually relatively evenly dispersed throughout the sampling area; however, the presence of large cobble and boulders created heterogeneity in some beds.

Sampling Procedures

The primary criteria for sampling mussels and sediments were the presence of moderately to densely packed mussels on sand and gravel-sized sediments (i.e., <1 cm diameter) and the detection of crude oil by visual or olfactory means. Mussel and sediment sampling was modified from methods developed by Auke Bay Laboratory (ABL) in previous years (Karinen et al. 1993; Babcock et al. 1994). A transect line, usually 30 m long and parallel to the water line (as topography allowed), was established through the middle of a mussel bed. The length of the transect line varied according to size and topography and ranged from 10 m at a Disk

Island site to 50 m at the Foul Bay site. At 8 to 10 places along the transect line, and within 1 m above and below the transect line, a small portion of mussels was overturned. Triplicate pooled subsamples of sediment were collected (0-2 cm deep) by scooping sediment from each exposed location with a hydrocarbon-free stainless steel spoon into each of three 118-ml, HC-free glass jars. Similarly, triplicate pooled samples of 20-25 mussels (ranging from 25-40 mm in length) each were collected from the overturned portions and placed in three HC-free jars. All samples were immediately cooled, and frozen within 2-4 h.

Chemistry

All sediment samples collected were analyzed by ultraviolet fluorescence (UVF), as adapted from Krahn et al. (1991, 1993). For UVF screening, wet sediment samples were extracted twice with methylene chloride, then concentrated or diluted to match a calibration curve based on an EVO oil standard. These extracts were read with a high-performance liquid chromatograph equipped with a fluorescence detector. Excitation/emission spectra of the extracts were read at the phenanthrene wavelengths (260 nm/ 380 nm), and values were calculated to estimate TPH based on the amount of phenanthrene in EVO. Data are reported as μg/g wet weight TPH. All data have an N of three unless otherwise noted.

This procedure allowed economical screening of many samples and produced semi-quantitative data, which were then used to select mussel samples for analyses by gas chromatography/mass spectroscopy (GC/MS). All mussel samples were analyzed by GC/MS as described by Short et al. (In press). Units presented in this paper are μg/g dry weight total polynuclear aromatic hydrocarbons (TPAH), which represents the sum of all measured aromatic hydrocarbons except perylene (produced by biogenic sources). Mussel data presented have an N of three unless otherwise noted.

RESULTS

Geographic extent and intensity of oil

Sediments (Table 1) and mussels (Table 2) from visibly oiled intertidal areas of PWS had substantial amounts of oil in 1992 and 1993; data from both years are presented below. Sediments were visibly oiled and odorous, and the oil was easily detected. Often, sheening was visible without any manual disturbance. Sites examined and sampled for sediments and mussels ranged through the entire spill impact area in PWS (Fig. 1).

Sediments from 31 of the 70 mussel beds sampled in 1992 and 1993 showed HCs greater than 10,000 μg/g wet weight TPH (measured by UVF), and sediments from 13 beds were between 5,000 and 10,000 μg/g TPH. The highest mean concentrations of oil were in sediments from Foul Bay in PWS (62,258 ± 1,558 μg/g, $N = 4$), a small islet in Herring Bay

Table 1. TPHs in sediments sampled under oiled mussel beds in PWS, 1992 and 1993. Segment # is the beach designation assigned during the *Exxon Valdez* cleanup process. Numbers following the segment # indicate multiple mussel beds sampled within that segment. Units are μg/g TPH as measured by ultraviolet fluorescence. * indicates that no evidence of oiling was observed at the site in 1993 and bed was not sampled for chemical analysis.

		1992			1993		
Location	Segment #	N	Mean	SE	N	Mean	SE
Aguliak Island, n	AG001A	3	9972	1110			
Aguliak Island, s	AG009A	6	11002	1150			
Applegate Island, e	AE005A	3	8766	2381			
Applegate Island, e	AE005B	6	26867	2107	3	1326	302
Barnes Cove (Control)	KN575A	6	1	1			
Bay of Isles	KN004A-1	3	18653	4644			
Bay of Isles	KN004A-2	3	1764	1013			
Bay of Isles	KN136A-1	1	3525		3	24323	3623
Bay of Isles	KN136A-2	3	18673	1814	3	10108	4382
Bay of Isles, Islet	KN016A	3	4699	1130			
Bay of Isles, se	KN207B	3	21934	2311			
Bay of Isles, S.Arm	KN205B	3	9	1	6	12	3
Bay of Isles, w	KN005A	3	1664	240	3	421	97
Bay of Isles, w	KN203A	3	6436	821			
Block Island, nw	EL011A-1	3	2118	281	3	206	40
Block Island, nw	EL011A-2				3	2339	484
Chenega Island, n	CH009A-1	3	26	4			
Chenega Island, n	CH009A-2	3	11507	1858		*	
Chenega Island, n	CH009A-3	6	20482	1726	3	8543	1815
Chenega Island, n	CH010B-2	12	27871	4359	11	27643	4879
Chenega Island, n	CH010B-3	3	26572	8578	3	4893	2025
Chenega Island, n	CH011A	3	7900	956			
Crab Bay, Evans Isl.	EV500A	3	0	0			
Crafton Island	CR004A	3	3361	1063			
Crafton Island	CR005A	3	3067	634			
Disk Island, n	DI059A	6	8249	1352	3	65	16
Disk Island, nw	DI067A-2	3	14020	1496	3	6921	2274
Disk Island, nw	DI067A-3	10	15071	2634	5	8041	2634
Disk Island, nw	DI067A-4	3	6324	653			
Disk Island, nw	DI067A-5	3	4979	1329			
Disk Island, nw	DI067A-6	3	22600	3950	3	12756	1860
Disk Island, nw	DI067A-7				3	17524	3839
Disk Island, w	DI066A	6	11942	2775	3	678	313

Table 1. Continued.

Eleanor Isl., NW Bay	EL052A-1	3	3266	1035		*	
Eleanor Isl., NW Bay	EL052A-2	3	198	40		*	
Eleanor Isl., NW Bay	EL052B	3	9868	1421			
Eleanor Island, NW Bay	EL054A	3	307	78			
Eleanor Island, sw	EL013A	8	10071	3821	5	21208	9436
Eleanor Island, sw	EL015A-1	3	11871	1809		*	
Eleanor Island, sw	EL015A-2	3	17179	489		*	
Eleanor Island, sw	EL015A-3	3	3149	277	3	6253	1851
Elrington Island, Fox Farm	ER007A	3	37	1			
Elrington Island, n	ER020B	3	954	138			
Evans Island, ne	EV036A	3	10725	2016			
Fleming Island, nw	FL004A	3	1787	254			
Foul Bay	MA002C	3	62258	1558	4	11934	7518
Green Island	GR008A	3	46	10			
Herring Bay, e	KN113A	3	8106	1444		*	
Herring Bay, e	KN113B	3	14967	1098			
Herring Bay, e	KN114A-1	6	17318	1097	3	21751	3440
Herring Bay, e	KN114A-2				3	6991	2335
Herring Bay, e	KN115A	3	2814	534			
Herring Bay, e	KN119A	9	7983	1400	3	5422	1748
Herring Bay, e	KN120A	3	7771	1744			
Herring Bay, e Islet	KN121A	3	1695	435			
Herring Bay, s Islet	KN133A-1	9	35029	8793	12	25245	4695
Herring Bay, s Islet	KN133A-2	3	23497	505			
Herring Point	KN500B	3	10705	1173			
Ingot Island, sw	IN031B	3	12515	1014		*	
Knight Island, n	KN103A	3	26728	1004	3	44	3
Knight Island,w	KN505A				3	7801	5698
Latouche Island, ne	LA015E-2	8	21570	9846	8	16565	7255
Latouche Island, ne	LA015E-3	7	12810	5241	3	6480	2867
Marsha Bay	KN702B				3	10098	1537
New Year Island	NY001	3	940	432			
Olsen Bay (Control)	none	3	1	1	3	18	18
Sleepy Bay	LA018A	3	280	73	6	70	27
Squire Island, Islet	SQ004B	3	19	1			
Squirrel Island, e	SL001D-1	3	3063	558			
Squirrel Island, e	SL001D-2	3	14467	1118	3	12716	3803

Table 2. Sum of PAHs in mussels from oiled mussel beds in PWS, 1992 and 1993. Segment # is the beach designation assigned during the *Exxon Valdez* cleanup process. Numbers following the segment # indicate multiple mussel beds sampled within that segment. Units are μg/g PAH dry weight as measured by gas chromatography/mass spectroscopy.

		1992			1993		
Location	Segment#	N	Mean	SE	N	Mean	SE
Aguliak Island, s	AG009A	3	2.88	0.84			
Applegate Island, e	AE005B	3	2.07	0.28	3	0.24	0.07
Barnes Cove	KN575A	1	0.02		3	0.07	0.07
Bay of Isles	KN004A-2	2	2.39	0.89			
Bay of Isles	KN136A-1	1	2.78		3	1.56	0.14
Bay of Isles	KN136A-2	3	5.57	0.94	2	1.32	0.71
Bay of Isles	KN205B				2	0.08	0.04
Bay of Isles, Islet	KN016A	3	1.23	0.18			
Bay of Isles, S. Arm	KN205B	3	0.14	0.01			
Bay of Isles, w	KN203A	3	0.23	0.06			
Bay of Isles, w	KN005A	2	0.43	0.05			
Block Island, nw	EL011A-1	1	1.96		3	0.39	0.19
Chenega Island, n	CH009A-3	2	4.88	2.43	3	0.95	0.26
Chenega Island, n	CH010B-2	5	3.11	0.73	3	4.15	0.66
Chenega Island, n	CH010B-3				3	0.23	0.10
Disk Island, n	DI059A	3	1.22	0.37	2	0.05	0.02
Disk Island, nw	DI067A-2				2	0.21	0.08
Disk Island, nw	DI067A-3	1	4.90				
Disk Island, nw	DI067A-6				2	0.38	0.07
Disk Island, nw	DI067A-7				3	0.80	0.29
Disk Island, w	DI066A	3	1.25	0.36	3	0.10	0.02
Eleanor Island, sw	EL013A	3	0.43	0.14	3	6.99	4.83
Eleanor Island, sw	EL015A-3				3	0.17	0.06
Evans Island, ne	EV036A	3	0.24	0.03	3	0.18	0.05
Foul Bay	MA002C	3	8.09	1.13	3	4.83	0.60
Herring Bay, e	KN114A-1	3	2.18	0.09			
Herring Bay, e	KN119A	3	0.29	0.03	3	0.14	0.02
Herring Bay, e	KN114A-1				3	0.12	0.02
Herring Bay, s Islet	KN133A-1	7	4.04	0.86	7	1.24	0.18
Herring Bay, se Islet	KN144B	2	0.01	0.00			
Latouche Island, ne	LA015E-3	3	0.58	0.21			
Latouche Island, ne	LA015E-2				3	0.13	0.07
Marsha Bay	KN702B				2	0.17	0.01
New Year Island	NY001	2	0.17	0.05			
Olsen Bay	none				3	0.24	0.10
Sleepy Bay	LA018A	2	0.03	0.02	3	0.12	0.03
Squirrel Island, e	SL001D-2	2	8.30	0.26	3	4.07	0.43

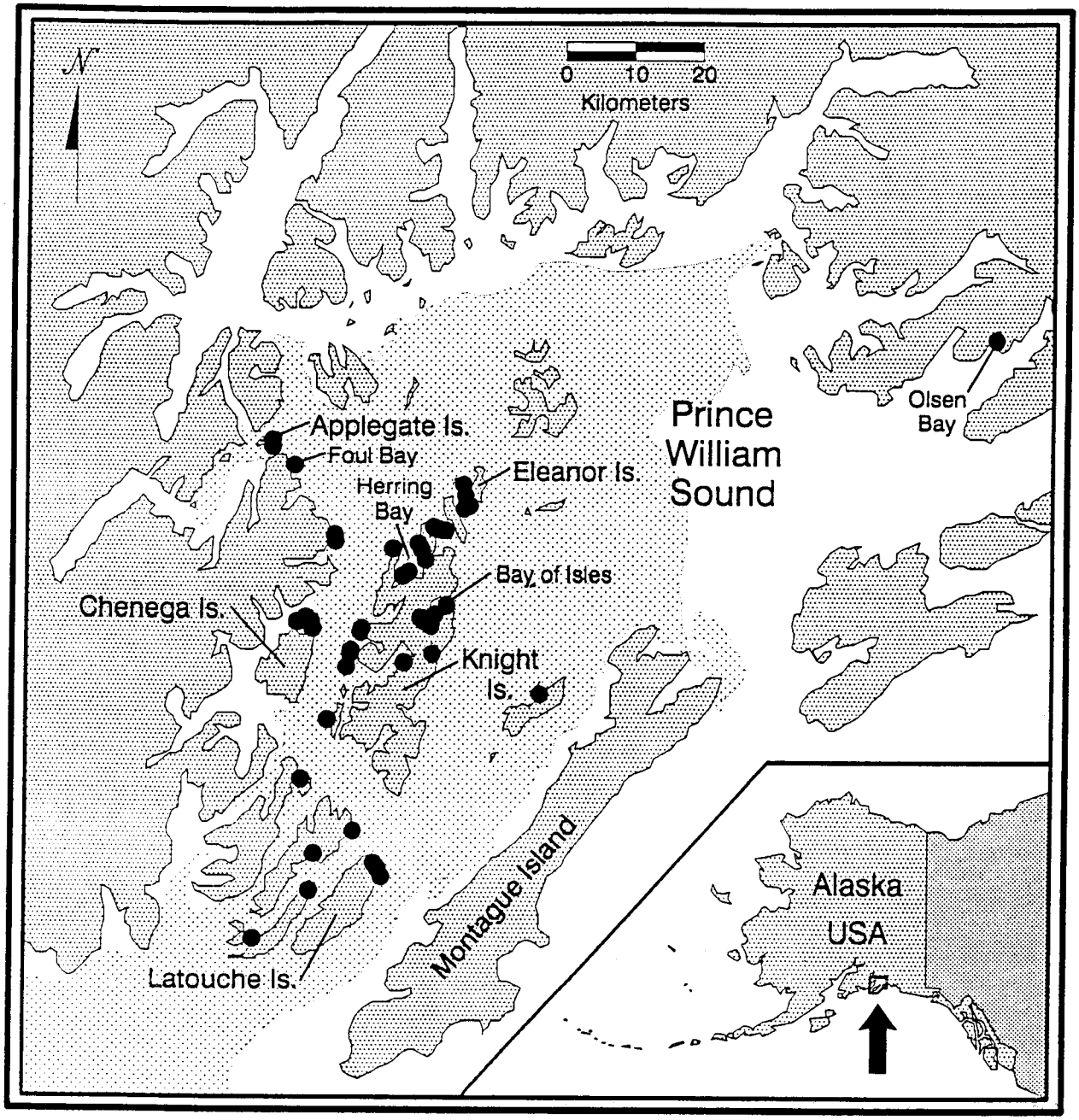

Figure 1. Prince William Sound, Alaska, showing locations where mussels and underlying sediments were sampled, 1992 and 1993, for analyses of residual petroleum hydrocarbon concentrations. Shaded area indicates the extent of floating EVO. All beds were in the EVOS impact area with the exception of Olsen Bay which was one of five sites sampled to provide control data.

that was a site of experimental manipulation and intensive sampling (35,029 ± 8793 μg/g, N = 12) (Harris et al., In press), another experimental bed on northern Chenega Island (27,872 ± 4359 μg/g, N = 11), a mussel bed on eastern Applegate Island (26,867 ± 2,107 μg/g), and a bed on northern Knight Island (26,728 μg/g ± 43.6 μg/g) (see Fig. 1).

Sediments underlying the remaining mussel beds sampled had mean oil concentrations <1,000 μg/g TPH. Five of the remaining 13 sites represented stations established under the Natural Resource Damage Assessment Coastal Habitat 1B study (Short and Babcock, In press), which were intentionally sampled to provide control data and were sites where data existed from previous years.

Substantial concentrations of TPAHs (>1.00 μg/g, dry weight, measured by GC/MS) were found in mussels from 16 beds in PWS. In PWS, the highest mean TPAH concentrations in mussels were found in mussels from Squirrel Island (8.30 μg/g TPAH dry weight, N = 2), the Foul Bay site (8.09 ± 1.13 μg/g), a Bay of Isles site (5.57 ± 0.94 μg/g), a bed on Disk Island (4.90, N = 1), at a site on north Chenega Island (4.88 ± 2.43 μg/g, N = 2), and in Herring Bay (4.04 ± 0.86 μg/g, N = 7).

Changes in petroleum hydrocarbons from 1992 to 1993

Total petroleum hydrocarbons in sediments showed some reductions from 1992 to 1993 in the mussel beds that were examined in both years. The mean TPH concentration in sediments from oiled mussel beds in 1993 were 41% ± 37% (STD) of the concentration found in 1992; 13 of the 30 beds retained more than 50% (Table 3). Changes were variable, retentions ranging from 0% to 100%. Sediments underlying four oiled mussel beds actually showed higher TPH values in 1993, but are shown at 100% in Table 3. Most of these higher values were within the standard error, and did not differ between years.

A similar reduction was seen in mussels from 1992 to 1993. The mean TPAH concentrations in mussels in 1993 averaged 44% ± 30% (STD). Mussels from two beds actually had a higher concentration but the differences were not significant except for the Eleanor Island--discussed later. They are shown at 100%, or no change, for 1993 (Table 3).

Exxon Valdez oil fingerprints

The PAH patterns in mussels collected from the oiled beds in 1992 and 1993 were consistent with EVO. PAH fingerprints in PWS mussels for both 1992 and 1993 all show a pattern similar to EVO.

Table 3. Relative amounts of oil remaining in sediments and in mussels from oiled mussel beds in PWS in 1993, given as percent of 1992 levels, for all sites observed in both years. Segment # is the beach designation assigned during the *Exxon Valdez* cleanup process. Numbers following the segment # indicate multiple mussel beds sampled within that segment. Percentages for sediments are based on measurements of μg/g TPHs as measured by ultraviolet fluorescence are presented; percentages for mussels are based on measurements of μg/g PAHs as measured by gas chromatography/mass spectroscopy. * indicates that no evidence of oiling was observed at the site in 1993, so % remaining in sediments is assumed to be near 0 although site was not sampled for chemical analysis.

Location	Segment #	% TPH Remaining in Sediments	% PAH Remaining in Mussels
Chenega Island, n	CH009A-2	*	
Eleanor Island, sw	EL015A-1	*	
Eleanor Island, sw	EL015A-2	*	
Eleanor Isl., NW Bay	EL052A-1	*	
Eleanor Isl., NW Bay	EL052A-2	*	
Ingot Island, sw	IN031B	*	
Knight Island, n	KN103A	0	
Disk Island, n	DI059A	1	4
Applegate Island, e	AE005B	5	12
Disk Island, w	DI066A	6	8
Block Island, nw	EL011A-1	10	20
Chenega Island, n	CH010B-3	18	
Foul Bay	MA002C	19	60
Sleepy Bay	LA018A	25	
Bay of Isles, w	KN005A	25	
Chenega Island, n	CH009A-3	42	19
Disk Island, nw	DI067A-2	49	
Latouche Island, ne	LA015E-3	51	
Disk Island, nw	D1067A-3	53	
Bay of Isles	KN136A-2	54	24
Disk Island, nw	DI067A-6	56	
Herring Bay, e	KN119A	68	49
Herring Bay, s Islet	KN133A-1	72	31
Latouche Island, ne	LA015E-2	77	
Squirrel Island, e	SL001D-2	88	49
Chenega Island, n	CH010B-2	99	>100
Bay of Isles	KN136A-1	≥100	56
Eleanor Island, sw	EL015A-3	≥100	
Eleanor Island, sw	EL013A	≥100	≥100
Herring Bay, e	KN114A-1	≥100	
Evans Island, ne	EV036A		72

DISCUSSION

In mussels and sediments sampled during this study, in both 1992 and 1993, we have found the highest concentrations of EVO seen in any mussels and sediments collected by any study sponsored by the *Exxon Valdez* Trustee Council since 1990, the year after the oil spill. In sediments, a mean TPH over 62,000 μg/g wet weight (measured by UVF) was found at one site, and a mean TPAH concentration over 8.00 μg/g dry weight (measured by GC/MS) was documented in mussels. In contrast, sediments from known control beds showed a mean TPH concentration <100 μg/g, and mussels from control beds had a mean TPAH concentration <0.30 μg/g, both of which approach the detection limit for the analytical methods. Historically (1977 through 1980), sediments and mussels collected from established stations along the shipping lane through PWS, as well as those collected in 1989 before landfall of the oil, indicated little or no contaminating petroleum hydrocarbons (Karinen et al. 1993; Short and Babcock, In press).

The geographic distribution (Fig. 1) of these substantially contaminated mussel beds included almost the entire area of PWS that was impacted by the spill. Documented oiled mussel beds were bounded by Applegate Island and Foul Bay in the northwest, north Eleanor Island in the northeast, Bay of Isles on the east, and northern Elrington Island in the south. Most of the contaminated mussel beds were located within the Knight Island group, an area particularly impacted by EVOS.

Most mussel beds within PWS were oiled in the first or second week after the spill when oil was not weathered into a thick mousse. The floating EVO coming ashore was thick in volume and very fluid. Intertidal exposure was sustained through several tidal cycles.

Many mussel beds throughout the study area showed natural reductions in oil--about 50%; however, several showed little decrease in HC concentrations from 1992 to 1993. Mean HC concentration decreased over 50% in both mussels and sediments for sites where there were data from both years. Although sediment samples from four beds showed increases in TPH and mussels from two beds showed increases in TPAH for 1993 over 1992, most of these values were within the margin of error.

One mussel bed that showed HC increases in both sediment and mussels from 1992 to 1993, the tombolo at Eleanor Island, incurred vigorous storm activity over the winter of 1992-1993. When we visited the site in June 1993, approximately 20% of the mussel layer had disappeared and the underlying sediments were redistributed. In August, even more of the mussel layer (total estimated at 30%) had eroded and disappeared, indicating that storm activity had continued during the summer. This disruption of the bed, and subsequent remobilization of EVO entrained in the underlying sediments, probably accounted for the marked increase in body burden of TPAHs seen in the mussels (0.43 $\pm$ 0.14 μg/g in 1992 vs. 6.99 $\pm$ 4.83 μg/g for 1993) and simultaneous doubling of TPHs in underlying sediments from 10,070 $\pm$ 3,821 μg/g in 1992 to 21,208 + 9,436 μg/g in 1993.

Most of the beds that exhibited less than 50% decrease in oil (TPH in sediments and TPAH in mussels) between 1992 and 1993 were either sheltered beaches or had large cobble/small boulders which armored the surface sediments and mussels. Vandermeulen and Gordon (1976) and Gundlach et al. (1982) found similar persistence of Bunker C spilled from the *Arrow* and *Metula* in intertidal areas of Chedabucto Bay, Nova Scotia and the Strait of Magellan, 5 and 6.5, years, respectively, after each accidental grounding. Residual crude oil remained on both the surface and in subsurface sediments, although not specifically associated with mussel beds as described herein.

In addition to large differences in HC concentrations between sites, there was a high degree of variability of concentrations within the beds. The uneven distribution of residual crude oil was confirmed by our intensive sampling of selected beds (Harris et al., In press) and by incidental samples collected at depths of 5-10 cm at three mussel beds during regular survey sampling. At two of these mussel beds, oil concentrations were significantly higher ($P < 0.01$) at the subsurface depths (5-7 cm) compared to surface sediment (0-2 cm)(Bay of Isles, 18,653 ± 3,791 vs. 1,764 ± 827 μg/g TPH; Herring Bay, 35,029 ± 8,793 vs. 5,473 ± 876 μg/g TPH), whereas at the mussel bed on Squirrel Island, surface sediments had a higher mean TPH than subsurface sediments (14,467 ± 913 vs. 3,499 μg/g). The patchiness of distribution of EVO was also shown by Michel and Hayes (1993a, b). There were many references to subsurface "lenses" of oil throughout ADEC's Shoreline Assessment Patrol reports, and the presence of subsurface lenses was also documented by Michel and Hayes (1993a, b). These lenses were not necessarily associated with mussel beds. Oil at depth is probably less available as a source of chronic exposure to surface-dwelling organisms than oil only 0-2 cm below the surface.

We recognized the variability of oil distribution within these mussel beds (Harris et al., In press) and designed pooled sampling strategies to minimize these effects and to characterize the overall HC concentration within each bed. However, variability was still high in many cases, as reflected by relatively high standard errors for both sediments and mussels. In addition to within-bed variability of EVO distribution both horizontally and vertically (Harris et al., In press), we have identified three other possible sources of the high variability seen at some sites: 1) Those sites studied intensively by ABL and ADEC were sampled by a "spot" method (i.e., samples were not pooled to reduce variability); 3) some mussel bed sediments were sampled at two different periods in 1992, and those sampled during the second period may not have been collected from exactly the same place; and finally, 3) sampling was conducted by numerous personnel from several agencies, and strict adherence to sampling protocol as outlined previously was not followed in all cases.

The dense mussel layer probably provides a protective layer against natural environmental and weathering processes degrading EVO entrained in underlying sediments. The lack of weathering was indicated by the fluidity and odors when sampling and by the similarity of profiles in the GC/MS fingerprints. Relative proportional distribution of PAH analytes in mussels are consistent with those of EVO mousse collected April, 1989 from floating material. The distribution patterns are somewhat similar to those shown by Michel and Hayes

(1993a) for a surface (1-5 cm) sediment sample taken in September 1991 (N13/2B--not associated with any mussel bed) from a sheltered, set–aside area in eastern Herring Bay. The main differences are relatively lower naphthalenes and lower C3- and C4-alkylated homologues, particularly C4-phenanthrene, for the mussels. This would indicate less degradation of the EVO available for uptake by these mussels than in the sediments from their site in Herring Bay. The patterns in our samples more closely resemble their profile from Station N3/3B, a subsurface sample (40-45 cm deep) from Smith Island that they depict as only intermediately degraded (Michel and Hayes 1993a).

As we have seen in this study, there are still mussel beds that contain substantial amounts of EVO. There is evidence that for some beaches natural weathering and flushing are playing a role in reducing the amount of petroleum hydrocarbons that are available for uptake in mussels.

Although the geographic spread of oil-contaminated sites is throughout the oil spill region and the amount of oil contamination can be high, the actual contaminated area is rather small. This begs the question: Should we be concerned about small physical areas? If there is disproportionate consumption by top predators, including subsistence harvesters, then there would be obvious concern.

CONCLUSIONS

Nature, in 3 and 4 years has not taken care of the oiling problem in many beds, and some of these beds will likely continue to be sources of oil for a rather long time. Most of twenty beds sampled in both 1992 and 1993 that showed less than 50% decrease in TPH are in relatively protected areas not vulnerable to natural disturbances. Some of these beds are on fairly uniform mixed sand and gravel substrates, and could be candidates for manual restoration. Certainly these beds need to be monitored for EVO concentrations in mussels and underlying sediments until the beds are at prespill or background levels (Karinen et al. 1993; Short and Babcock, In press).

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