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REPORTS

The Deep Benthos of Prince William Sound, Alaska, 16 Months After the *Exxon Valdez* Oil Spill

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In 1990, 16 months after the T/V *Exxon Valdez* oil spill (EVOS) in Prince William Sound, Alaska, an assessment of the benthic macrofauna and associated environmental parameters at 40 and 100 m was made. Assessment of the biota and environmental data demonstrated patterns in deep benthic assemblages reflective of oceanographic conditions, as indicated by sediment differences, rather than EVOS toxicity. Comparison of polynuclear aromatic hydrocarbons (PAH) and $\delta^{13}C$ values in sediments between stations within the oil trajectory and reference stations outside of the trajectory showed no significant differences. This investigation uncovered no signals of disturbance 16 months after the EVOS. These results agree with conclusions of studies of intertidal and shallow subtidal regions following the EVOS that demonstrated disturbance effects decreasing with depth. © 1998 Elsevier Science Ltd. All rights reserved

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Following the grounding of the tanker *Exxon Valdez* on Bligh Reef on 24 March 1989, approximately 35 500 t of crude oil were released into Prince William Sound, Alaska. The oil spread southwest to the shores of many islands within the Sound and into the Gulf of Alaska (Fig. 1; Royer *et al.*, 1990). An estimated 12% of this oil deposited on subtidal sediments (Wolfe *et al.*, 1994). Following the spill, the potential for contamination of the deep benthos appeared to be high as oil continued to leach from contaminated shorelines or was dispersed from the shore by beach-cleaning procedures (Wells *et al.*, 1995; O'Clair *et al.*, 1996). Beach-cleaning efforts continued through 1990 and oil continued to leach from sediments in noticeable quantities through 1991 (Short *et al.*, 1996). Since Prince William Sound supports sizable populations of commercially important bottom-feeding species of shrimps, crabs and fishes as well as resident populations of sea otters, there was concern about the effect of the *Exxon Valdez* oil spill (EVOS) on their food resources. Studies in the Sound and other Alaskan waters emphasized the importance of benthic organisms as food for these species (e.g. Feder and Hoberg, 1980; Rice *et al.*, 1980; Feder and Jewett, 1981a,b; Jewett and Feder, 1983; Anthony, 1995).

The fauna within the deep benthos of Prince William Sound was not well documented prior to the EVOS. However, a number of reports describing the deep benthic infauna and epifauna within several bays and fjords of the Sound and the contiguous shelf of the Gulf of Alaska were available (see review in Feder and Jewett, 1986). These studies indicated that a relatively diverse benthic fauna could be expected within the Sound and adjacent waters.

The multi-agency task group formed to assess the impact of the EVOS in Prince William Sound initiated investigations to examine the effect of the spill on the intertidal and shallow subtidal biota (≤20 m) shortly after the spill. Major effects of the EVOS on the intertidal flora and fauna are reported by Highsmith *et al.* (1996). Jewett and Dean (1993, 1997) and Dean *et al.* (1996) observed disturbance within the shallow benthic

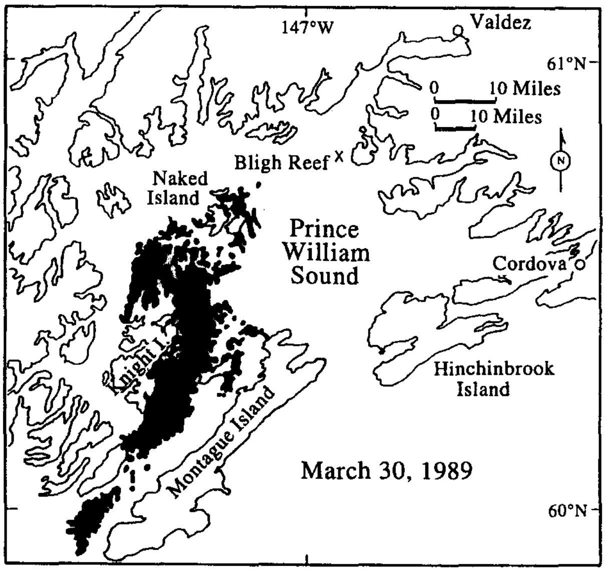

Fig. 1 The distribution of *Exxon Valdez* oil in Prince William Sound on March 30, 1989, six days after the oil spill. From Braddock *et al.*, 1995.

communities (≤20 m) of some bays within the oil trajectory and noted that disturbance decreased with depth. Evaluation of deep benthic infauna (≥40 m) was initiated by the task group 16 months after the oil spill. This paper presents the major findings of that study (Feder, 1995), thereby extending the record of oil spill effects of the EVOS from the intertidal region through the deep benthos.

Methods

Field sampling and laboratory procedures

The sites presented in this study (Fig. 2) were ones at which other investigations were underway shortly after the EVOS (i.e. studies on the fate and toxicity of oil in sediments: O'Clair *et al.*, 1996, microbial organisms: Braddock *et al.*, 1995, and shallow subtidal biota:

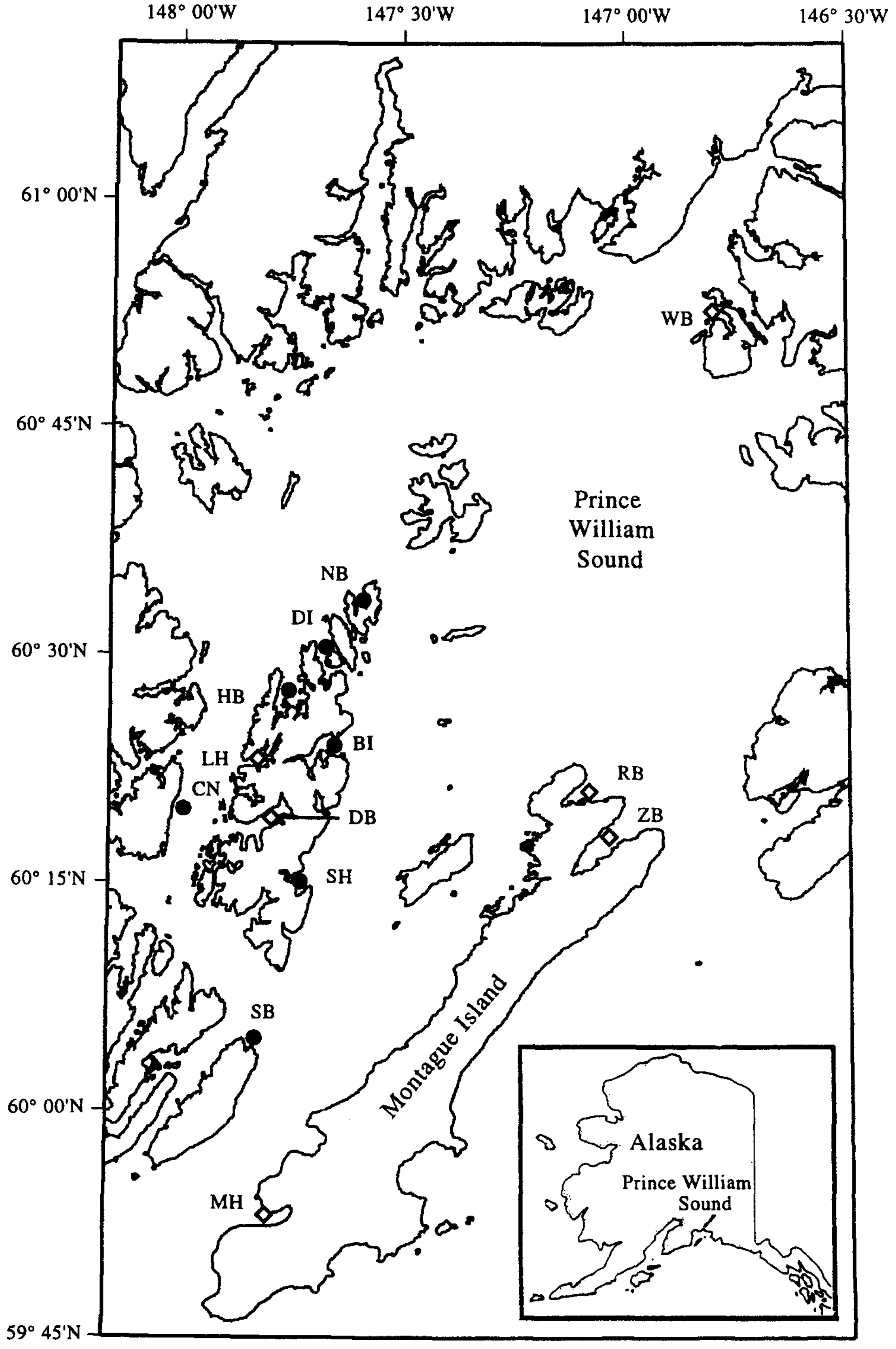

Fig. 2 Map of sites sampled in Prince William Sound in 1990. See text for site abbreviations. Circles are oil trajectory (OT) sites and diamonds are reference (R) sites.

Jewett and Dean, 1993, 1997 and Dean *et al.*, 1996). Seven of the sites were within the oil trajectory (OT sites—Bay of Isles (BI), Chenega Island (CN), Disk Island (DI), Herring Bay (HB), Northwest Bay (NB), Sleepy Bay (SB) and Snug Harbor (SH)) and six outside of the oil trajectory (reference (R) sites—Drier Bay (DB), Lower Herring Bay (LH), Macleod Harbor (MH), Rocky Bay (RB), West Bay (WB), and Zaikof Bay (ZB)). A seventh reference site, Mooselips Bay, included in Feder (1995), was so different from the other sites that it was excluded from analyses presented here. Sampling occurred from 1–23 July 1990 within two depth strata at approximately 40 and 100 m. Five replicates were taken at each depth using a van Veen grab (0.1 m^2). Samples were washed through 0.5 mm screens in the field and preserved in 10% formalin. In the laboratory, invertebrates were identified to family or higher taxonomic category and counted. Numerically abundant taxa were identified to lower taxonomic levels whenever possible to provide information on dominant species within families. Identifications to the family level were considered adequate measures of faunal composition for the purposes of this study. Previous investigations demonstrate that resolution of general trends in biological data emerge as clearly when higher taxonomic units are used in the procedures as compared to using species (Long and Lewis, 1987; Grebmeier *et al.*, 1989; Warwick, 1993). Single sediment samples were collected with the van Veen grab and analysed for grain-size parameters (Folk, 1980). Carbonate-free sediment samples were analysed for organic carbon and for $\delta^{13}C$ following Naidu *et al.* (1993a). Replicate sediment hydrocarbon samples were collected by the NOAA Technical Services Task Force, Analytical Chemistry Group (TSTF/ACG), NOAA/NMFS, Auke Bay, Alaska in conjunction with biological sampling.

Data analysis

Environmental and biological data were analysed using univariate and multivariate techniques. Univariate comparisons analysed metrics associated with sediment grain size, hydrocarbon levels and various community parameters as well as taxon abundance for four selected families. The Mann-Whitney test was used to compare the environmental and biotic parameters between OT and R stations. Multivariate procedures were applied to dissimilarity matrices to identify community relationships not detectable using univariate approaches. Dissimilarity matrices for the analyses were calculated utilizing the Bray Curtis coefficient (Bray and Curtis, 1957) on $ln(x+1)$ transformed abundance data (ind. m^{-2}).

The environmental variables and biotic parameters assessed in this study are among those useful in detecting hydrocarbon contamination and community level effects. Environmental variables utilized include grain-size parameters (% sand, % mud and mean grain size (phi units)), sediment organic carbon, $\delta^{13}C$, and PAHs indicative of *Exxon Valdez* oil (EVPAH: sum of naphthalenes, fluorenes, phenanthrenes, dibenzothiophenes and chrysenes and C-1 fluoranthenes and biphenyl: source TSTF/ACG NOAA/NMFS, Auke Bay, Alaska). Population measures calculated for each station include average abundance (ind. m^{-2}), Simpson dominance (Simpson, 1949) and Shannon diversity (Shannon and Weaver, 1963). Shannon diversity values were calculated using natural logarithms. Whisker plots and Mann-Whitney comparisons of abundance values were made for selected families known to decrease in the presence of oil (amphipods: Ampeliscidae, Phoxocephalidae; Dauvin, 1982; Spies, 1987; Jewett and Dean, 1997) and for opportunistic families known to increase in the presence of petroleum hydrocarbons (i.e. Capitellidae, Spionidae; Hyland *et al.*, 1985; Olsgard and Gray, 1995).

The multivariate analyses applied to the abundance data included group-average agglomerative hierarchical cluster analysis (Clifford and Stephenson, 1975) and two ordination techniques: nonmetric multidimensional scaling (MDS; Field *et al.*, 1982) and correspondence analysis (CA; Jongman *et al.*, 1995). As suggested by Olsgard and Gray (1995), a number of multivariate techniques were utilized to determine if similar patterns, representative of a community response, would emerge. Station groupings were then determined by assessing the results of the three multivariate procedures for similar patterns in station separations. Following determination of station groups, taxon groups were ranked by abundance to identify the numerically dominant groups. To assess the potential relationships between the environmental variables and taxon composition data, Spearman's correlation coefficients were calculated between the environmental variables and the correspondence analysis axes and various biotic parameters (e.g. Kingston *et al.*, 1995; Olsgard and Gray, 1995). Environmental variables with high correlations to a CA axis may be important factors influencing taxon composition within stations. Overlays of percent mud, EVPAH and station abundance values on the MDS ordinations are presented (Field *et al.*, 1982). Multivariate techniques applied here were successfully used elsewhere to evaluate community level responses to petroleum hydrocarbons (e.g. Kingston *et al.*, 1995; Olsgard and Gray, 1995).

Results

Environmental variables and univariate measures of biotic parameters are presented in Tables 1 and 2 and Figs 3 and 4 and plots of selected polychaete and amphipod groups are included in Fig. 5. Comparisons of sediment parameters between R and OT stations at 40 m showed that R stations had significantly higher percent mud ($p=0.010$) and mean grain-size ($p=0.012$: phi-units; higher values = smaller grain-size) (Fig. 3b,c). Comparisons of sediment parameters, EVPAH and

TABLE 1

Environmental variables for the 13 sites and two depths sampled in Prince William Sound in 1990. An asterisk (*) indicates a site was located within the oil trajectory. See Methods for site abbreviations. OC = organic carbon, Mean = mean grain size (phi units), and EVAPH = selected hydrocarbons (ng g^{-1}).

Depth	Site	% Sand	% Mud	Mean (Ø)	% OC	$\delta^{13}C$	EVAPH
40 m	BI*	46.9	14.3	−0.2	0.92	−21.7	376
	CN*	56.6	15.5	−0.3	1.59	−22.7	479
	DI*	62.8	35.3	3.7	0.84	−21.9	490
	HB*	49.0	16.9	0.7	1.17	−21.9	108
	NB*	63.4	27.2	1.9	1.56	−23.3	245
	SB*	70.9	24.2	1.0	0.38	−22.5	315
	SH*	63.2	36.8	2.9	0.65	−22.7	741
	DB	41.4	32.1	2.1	2.32	−21.1	689
	LH	57.9	40.1	3.7	6.44	−21.5	761
	MH	52.2	47.9	5.6	0.55	−22.8	647
	RB	64.5	35.6	4.2	0.75	−21.9	476
	WB	26.6	74.4	5.1	1.75	−20.8	149
	ZB	8.0	92.0	7.2	1.51	−22.0	584
100 m	BI*	29.9	67.0	5.6	3.69	−21.7	114
	CN*	50.9	23.0	1.3	0.49	−22.3	305
	DI*	42.6	55.1	4.0	0.60	−21.6	387
	HB*	53.3	45.2	3.4	0.93	−21.6	504
	NB*	9.6	26.9	2.2	1.11	−21.4	760
	SB*	41.6	52.3	4.3	0.69	−21.7	654
	SH*	8.2	91.8	6.7	1.39	−21.5	1170
	DB	36.5	57.9	4.5	2.71	−21.1	712
	LH	43.7	44.1	3.3	2.24	−21.1	667
	MH	92.4	7.6	2.1	0.21	−22.0	448
	RB	4.5	95.5	7.4	0.91	−21.4	261
	WB	4.0	96.0	8.1	0.73	−21.4	309
	ZB	17.3	81.3	6.0	0.47	−22.5	541

TABLE 2

Population abundance and diversity values for 13 stations and two depths from Prince William Sound in 1990. Abund. = average abundance (ind. m^{-2}). D = Simpson Dominance, and H′ = Shannon Diversity. An asterisk (*) indicates a station located within the oil trajectory. See Methods for site abbreviations.

Depth	Station	Abund.	D	H′
40 m	BI*	5124	0.08	2.99
	CN*	2904	0.06	3.45
	DI*	3600	0.05	3.32
	HB*	2880	0.07	3.14
	NB*	2578	0.06	3.44
	SB*	4146	0.05	3.37
	SH*	1048	0.06	3.17
	DB	1336	0.08	2.90
	LH	394	0.07	2.96
	MH	7370	0.18	2.67
	RB	6762	0.10	3.12
	WB	744	0.05	3.19
	ZB	1874	0.12	2.66
100 m	BI*	3228	0.15	2.30
	CN*	2032	0.06	3.14
	DI*	3256	0.10	2.84
	HB*	3816	0.06	3.11
	NB*	2438	0.13	2.70
	SB*	4897	0.06	3.15
	SH*	1346	0.08	2.90
	DB	1676	0.12	2.60
	LH	2008	0.10	2.63
	MH	2224	0.06	3.40
	RB	1234	0.09	2.93
	WB	1598	0.12	2.78
	ZB	2182	0.06	3.15

$\delta^{13}C$ values for 100 m (Fig. 3) showed no significant difference ($p < 0.05$) between OT and R stations. Comparisons between OT and R stations for biotic parameters at 40 m demonstrate that Shannon diversity (H′) was higher ($p = 0.015$) at the OT stations than at R stations (Fig. 4c). At 100 m, the OT stations demonstrated higher abundance values ($p = 0.046$) compared to the R stations (Fig. 4a). Ampeliscidae and Phoxocephalidae abundance values were higher ($p = 0.035$) at OT stations at 40 m but not significantly different at OT and R stations at 100 m (Fig. 5a,c). Capitellidae and Spionidae abundance values were not significantly different between oil trajectory (OT) and reference stations (R) at 40 and 100 m (Fig. 5b,d).

Three station groups were apparent in the multivariate analyses of the 40 m data (Fig. 6a–c). Station Group C contained only five OT stations. One of the other two OT stations did not join a group and the last OT station was associated with R stations in Station Group A. In the MDS and CA ordinations, all seven OT stations were located to the right in the plots. Ranking by abundance of the dominant faunal families and dominant taxa within the station groups is included in Table 3. Correlations between environmental variables and the CA axes and biotic parameters show that sediment parameters and organic carbon are significantly correlated with the first three CA axes (Table 4). In the overlays of percent mud and EVPAH on the

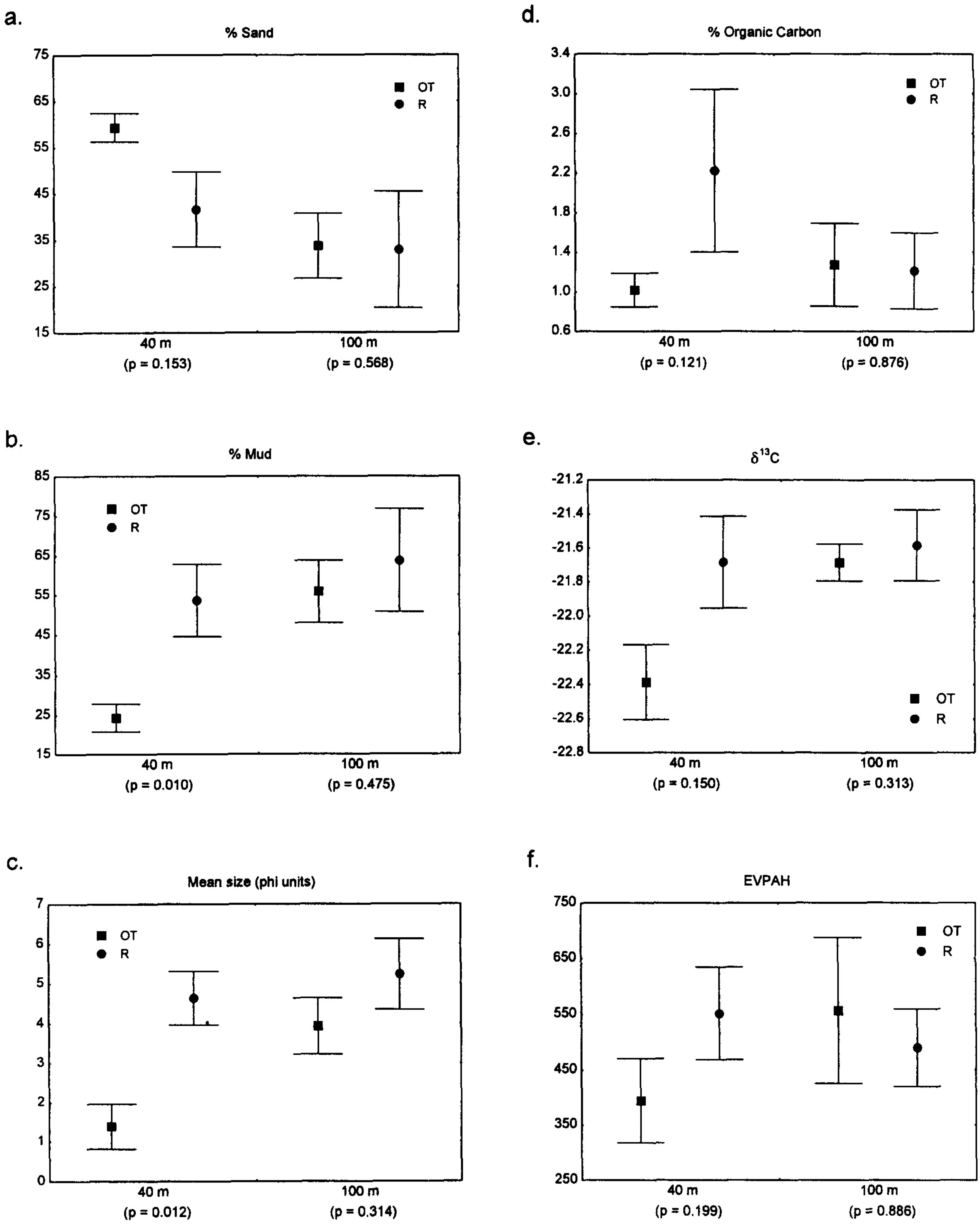

Fig. 3 Plots of environmental variables (a–f) for 40 and 100 m at oil trajectory (OT) and reference (R) stations. Symbols are mean values and the whiskers are ±1 standard error. P-values for Mann-Whitney comparisons are given below x-axis labels.

MDS plots, percent mud generally increases from the bottom right to top left corners of the plot while values for EVPAH are variable throughout the station groups in the plot (Fig. 7a,b). The overlay of abundance values on the MDS plot for 40 m indicates an inverse relationship to mud with abundance generally decreasing from the bottom right to the left corner of the plot (Fig. 7a,c).

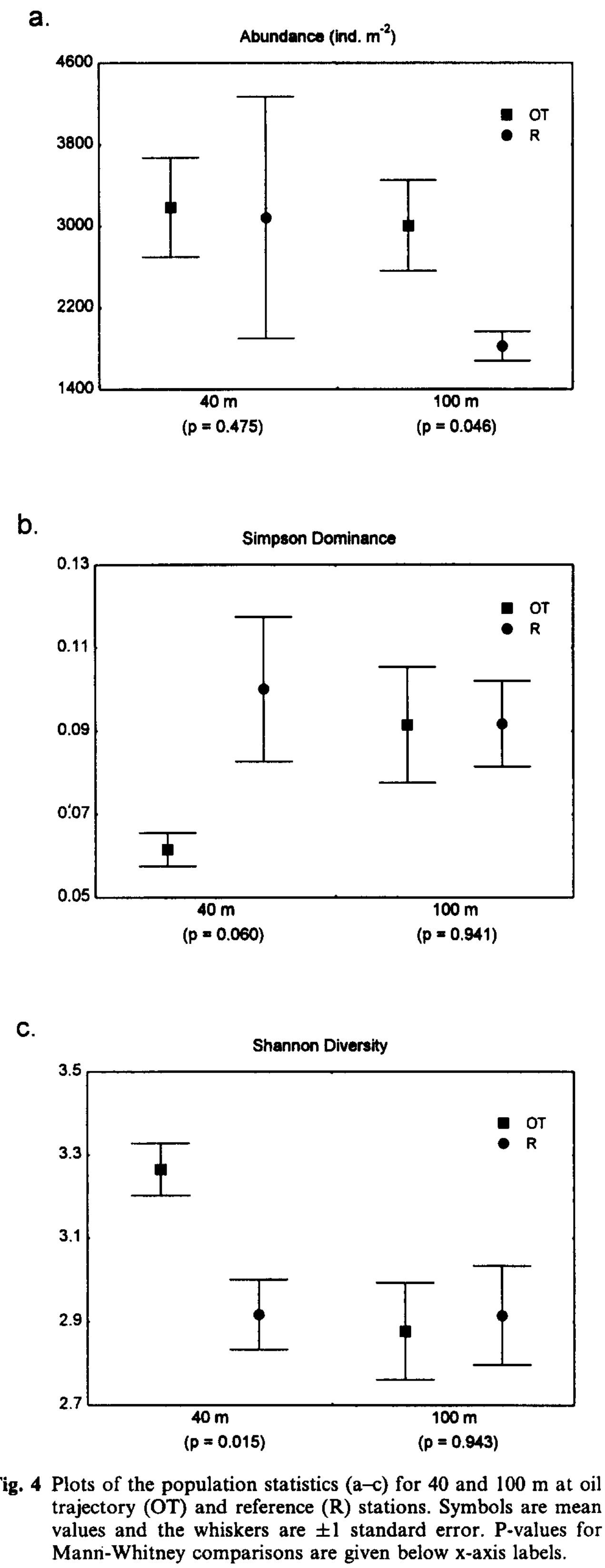

Fig. 4 Plots of the population statistics (a–c) for 40 and 100 m at oil trajectory (OT) and reference (R) stations. Symbols are mean values and the whiskers are ±1 standard error. P-values for Mann-Whitney comparisons are given below x-axis labels.

Four station groups were determined from the multivariate analyses of abundance data from 100 m (Fig. 6d–f). The OT stations are interspersed throughout the groups with one group, Group B, consisting of only OT stations. Ranking of the dominant faunal families within the station groups is included in Table 5. Also, similar to 40 m, correlations between physical variables and the biotic parameters and CA axes show sediment parameters and organic carbon to be significantly correlated with various CA axes and biotic variables (Table 4). Overlays of percent mud and EVPAH on the MDS plots show no discernible trends with high and low mud and EVPAH values scattered throughout the plots (Fig. 7d,e). The overlay of abundance values on the MDS plots for 100 m showed no clear patterns either (Fig. 7f).

Discussion

Oil and hydrocarbon-degrading bacteria were detected within sediments for several years after the *Exxon Valdez* oil spill (EVOS) at some of the oil trajectory (OT) stations occupied in the present study (Wolfe *et al.*, 1994; Braddock *et al.*, 1995; O'Clair *et al.*, 1996). Oil concentrations at the OT stations were always low and consisted of weathered oil fractions (O'Clair *et al.*, 1996). None of the total PAH concentrations observed by O'Clair *et al.* (1996) exceeded the 'Effects Range-Low' (ERL) sediment toxicity threshold proposed by Long and Morgan (1990). Further, no oil-related sediment toxicity was detected within the deep benthos for several years after the spill (Wolfe *et al.*, 1994). Additionally, no statistical differences between OT and R stations in EVPAH concentrations and percent OC were demonstrated in the present study. Page *et al.* (1995) indicate that most hydrocarbons within the deep benthic sediments of Prince William Sound were derived from naturally occurring seeps and note that EVOS derived hydrocarbons comprised only a small portion of the background hydrocarbon concentrations. Bragg and Yang (1995) suggest that the low levels of deep subtidal oil present after the EVOS can be explained by the formation of neutrally-buoyant oil-clay aggregates that were dispersed by the coastal circulation and flushed out of the Sound (Royer *et al.*, 1990; Niebauer *et al.*, 1994). The findings by Page *et al.* (1995) and O'Clair *et al.* (1996) that the EVOS did not add significantly to the background levels of hydrocarbons within the deep benthos is supported by the isotope studies of Naidu *et al.* (1993b). They found that $\delta^{13}C$ values of pre-spill deep sediments (for 1979, 1980 and 1981) were similar to values at OT stations in 1990, and concluded that sediments within the EVOS trajectory were not markedly contaminated with oil. In the present study, the $\delta^{13}C$ values at 40 m and 100 m OT sites were not significantly different from values for the R stations (Fig. 3).

Assessment of selected fauna, univariate measures and multivariate analyses of the benthic biological data at 40 and 100 m indicate that the benthos was not disturbed during the study period. Specifically, the abundance of opportunistic taxa known to increase in the presence of petroleum hydrocarbons (Capitellidae

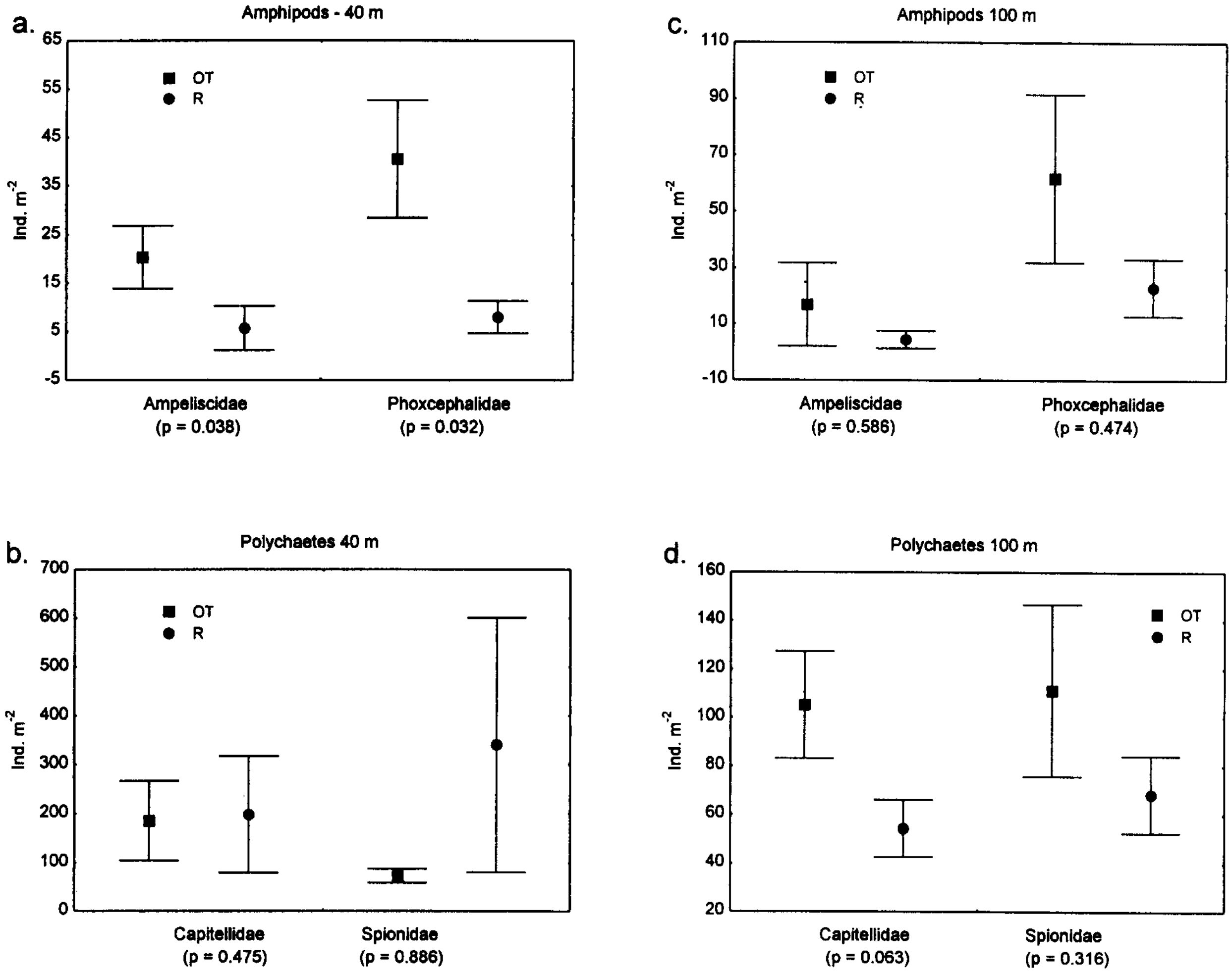

Fig. 5 Abundance (ind. m^{-2}) of selected amphipod and polychaete families (a–d) for 40 and 100 m at oil trajectory (OT) and reference (R) stations. Symbols are mean values and the whiskers are ±1 standard error. P-values for Mann-Whitney comparisons are given below x-axis labels.

and Spionidae) was similar at OT and R stations for both depths (Fig. 5). Taxa typically reduced in abundance in the presence of oil (Ampeliscidae and Phoxocephalidae) were either similar at OT and R stations or were more abundant at OT stations. In contrast, Jewett and Dean (1997) report a decline in abundance of Phoxocephalidae and four other amphipod families at depths < 20 m following the EVOS with effects in some of the families persisting through 1995. Massive declines in benthic amphipods also occurred following the *Amoco Cadiz* oil spill (Dauvin, 1982). Univariate analyses of benthic data from our study showed none of the trends (i.e. low faunal abundance, relatively high dominance and low diversity) observed elsewhere following oil spills (Sanders *et al.*, 1980; Dauvin, 1982; Glemarec and Hussenot, 1982; Elmgren *et al.*, 1983). In fact, effects related to hydrocarbon toxicity would not be expected based on the low levels of weathered oil found in benthic sediments (Page *et al.*, 1995; O'Clair *et al.*, 1996) and the low toxicity of sediments (Wolfe *et al.*, 1994) in 1990. Correlations between the environmental variables and CA axes and biotic parameters, as well as overlays of percent mud and faunal abundance values on the MDS plots, suggest a relationship of sediment grain-size parameters to faunal distribution rather than EVPAH. However, as discussed by Snelgrove and Butman (1994), grain size may only be a correlate of actual causative factors.

Relatively high faunal abundance values at some stations indicate high spatial variability among locations in the Sound. Most stations within the oil trajectory, as well as two reference stations (MacLeod Harbor and Rocky Bay), were in the path of major currents (Royer *et al.*, 1990). These stations had high faunal abundance and diversity values. Differences in hydrodynamic regimes and associated bottom boundary layer flows (Snelgrove and Butman, 1994) likely resulted in the dissimilarities of faunal abundance and diversity between stations.

The high faunal abundance values at some OT and R stations (Table 2) were considerably greater than those

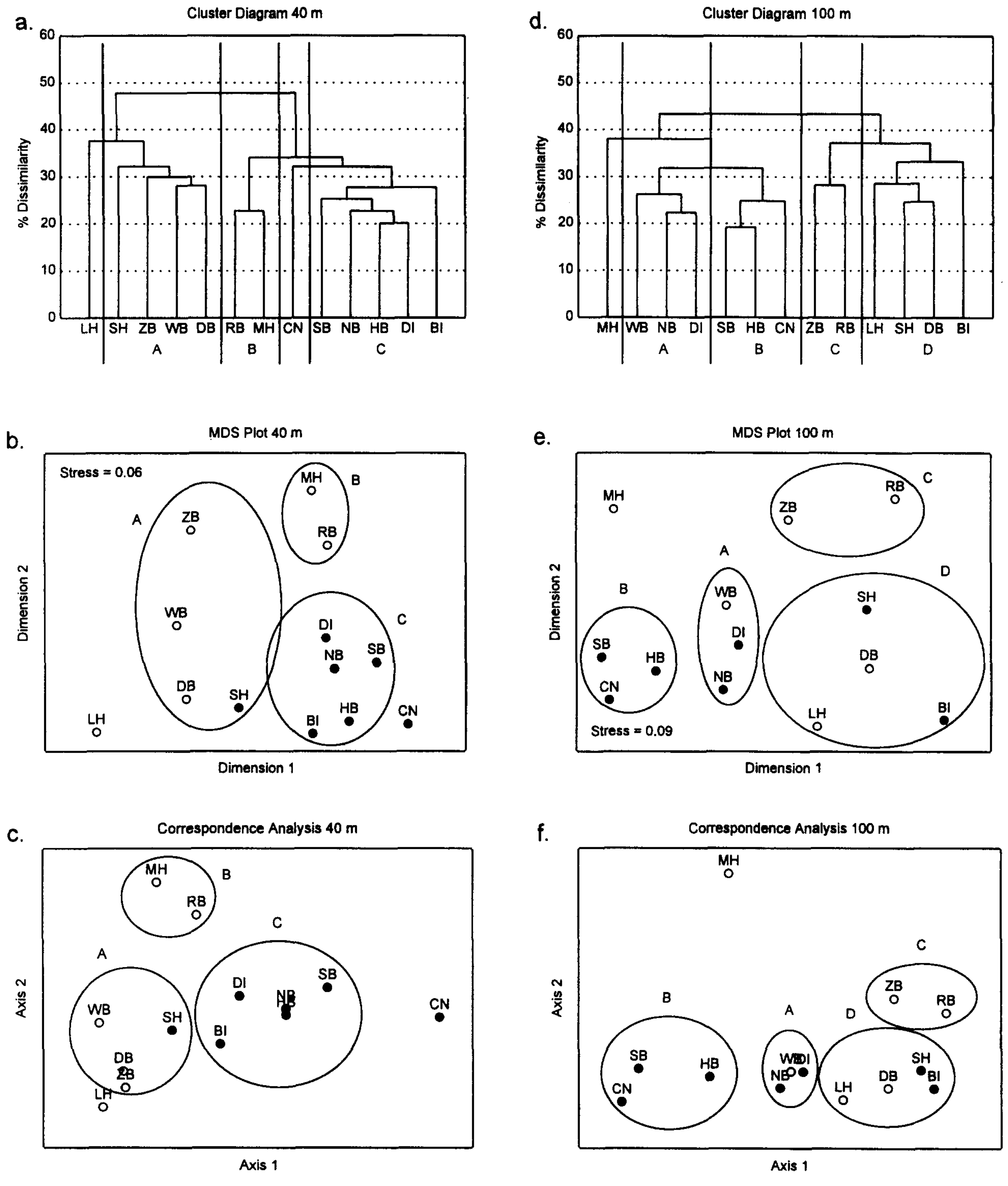

Fig. 6 Results of multivariate analyses for *ln*-transformed abundance data from Prince William Sound in 1990. Station groups are denoted in each figure. Solid symbols indicate sites within the oil trajectory and hollow symbols indicate reference sites.

at similar depths within two bays in western Prince William Sound in 1982 (Hoberg, 1986) and on the shelf of the adjacent Gulf of Alaska from 1974–1976 (Feder and Jewett, 1986). Prince William Sound is typically a pelagic system in which POC in the water column is decoupled from the benthos with most POC flowing through pelagic links (Feder and Jewett, 1986; Cooney and Coyle, 1988; Cooney, 1993). High abundance values for benthic fauna in 1990 may reflect a flux of unusual amounts of phytoplankton to the bottom when low levels of grazing zooplankters were present (Cooney *et al.*, 1993), resulting in increased availability of food

TABLE 3

Ranking by abundance of the five top-ranked taxon groups within station groups for sites at approximately 40 m. Dominant taxa indentified to lower taxon levels within familes are presented. An asterisk (*) indicates a site was located within the oil trajectory.

Group	Taxon groups	Dominant taxa	Ind. m^{-2}
Group A	Nephtyidae	*Nephtys ferruginea, N. cornuta, N. punctata*	196
DB, SH*, WB, ZB	Paraonidae	*Aedicera antennata, Aricidea ramosa, Tauberia gracilis*	114
	Bivalvia	Juvenile bivalves	113
	Spionidae	*Polydora* spp.	88
	Capitellidae	*Barantolla americana*	69
Group B	Owenidae	*Myriochele oculata, Owenia fusiformis*	1564
MH, RB	Spionidae	*Laonice cirrata, Prionospio cirrifera, Spio cirrifera, Spio filicornis*	912
	Capitellidae	*Decamastus gracilis, Notomastus lineatus*	502
	Bivalvia	Juvenile bivalves	412
	Paraonidae	*Aedicera antennata, Aricidea minuta, Aricidea neosuecica, Aricidea ramosa, Tauberia gracilis*	327
Group C	Cirratulidae	*Chaetozone setosa, Tharyx secundus*	362
BI*, DI*, HB*, NB*, SB*	Paraonidae	*Aedicera antennata, Aricidea minuta, Aricidea neosuecica, Aricidea ramosa, Tauberia gracilis*	322
	Bivalvia	Juvenile bivalves	292
	Capitellidae	*Decamastus gracilis, Notomastus lineatus*	232
	Lumbrineridae	*Lumbrineris* spp. , *Ninoe gemmea*	222
CN*	Syllidae	*Exogone* spp. , *T. armillaris*	464
	Polyodontidae	*Peisidice aspera*	372
	Spirorbidae	*Spirorbis* spp.	234
	Onuphidae	*Onuphis conchylega*	130
	Ampharetidae	*Melinna elisabethae,*	106
LH	Lucinidae	*Lucina tenuisculpta*	48
	Orbiniidae		46
	Paraonidae	*Aricidea* spp.	44
	Capitellidae		26
	Tellinidae	*Macoma* spp.	26

TABLE 4

Spearman rank correlations between environmental parameters and four axes (eigenvectors) from correspondence analysis and biotic parameters. Abun = mean ind. m^{-2}, D = Simpson dominance, H = Shannon diversity, Mean = mean grain size (phi units), EVPAH = selected hydrocarbons, and NS = not significant.

40 m	Axis 1	Axis 2	Axis 3	Axis 4	Abun	D	H
% Sand	NS	0.57^a	NS	NS	NS	NS	NS
% Mud	-0.78^b	NS	NS	NS	NS	NS	NS
Mean	-0.70^b	NS	NS	NS	NS	NS	NS
OC	NS	-0.73^b	0.72^a	NS	NS	NS	NS
EVPAH	NS	NS	NS	NS	NS	NS	NS
100 m	Axis 1	Axis 2	Axis 3	Axis 4	Abun	D	H
% Sand	0.61^a	NS	0.71^b	NS	NS	NS	NS
% Mud	-0.70^b	NS	-0.65^a	NS	NS	NS	NS
Mean	-0.74^a	NS	-0.56^a	NS	NS	NS	NS
OC	0.66^a	-0.56^a	0.59^a	NS	NS	0.74^b	-0.87^b
EVPAH	NS	NS	NS	NS	NS	NS	NS

[a] $0.05 > p > 0.01$; [b] $0.01 > p > 0.001$

resources for the benthos. Similar fluxes of ungrazed phytoplankton to the bottom are described for Alaskan waters by Grebmeier *et al.* (1988) and Ziemann *et al.* (1993) (see review of benthic-pelagic coupling in Grebmeier and Barry, 1991). Based on a long-term data set for Port Valdez (an embayment of Prince William Sound), extreme interannual fluctuations in zooplankton levels and benthic faunal abundance within the deep benthos may be characteristic of the Sound (Feder and Jewett, 1988; Jewett and Blanchard, 1997).

Studies accomplished elsewhere also suggest an absence of significant effects of oil spills on deep-benthic communities (review by Clark, 1992). For example, following the *Braer* oil spill off the Shetland Islands the benthos at 50–146 m was not affected, although elevated hydrocarbon concentrations were detected in bottom sediments (Kingston *et al.*, 1995). Additionally, ecological impacts predicted to occur one year after the *Braer* spill were not apparent (Spaulding *et al.*, 1994). Dicks and White (1992), studying the benthos in the North Sea, note that after an oil spill, deep benthic

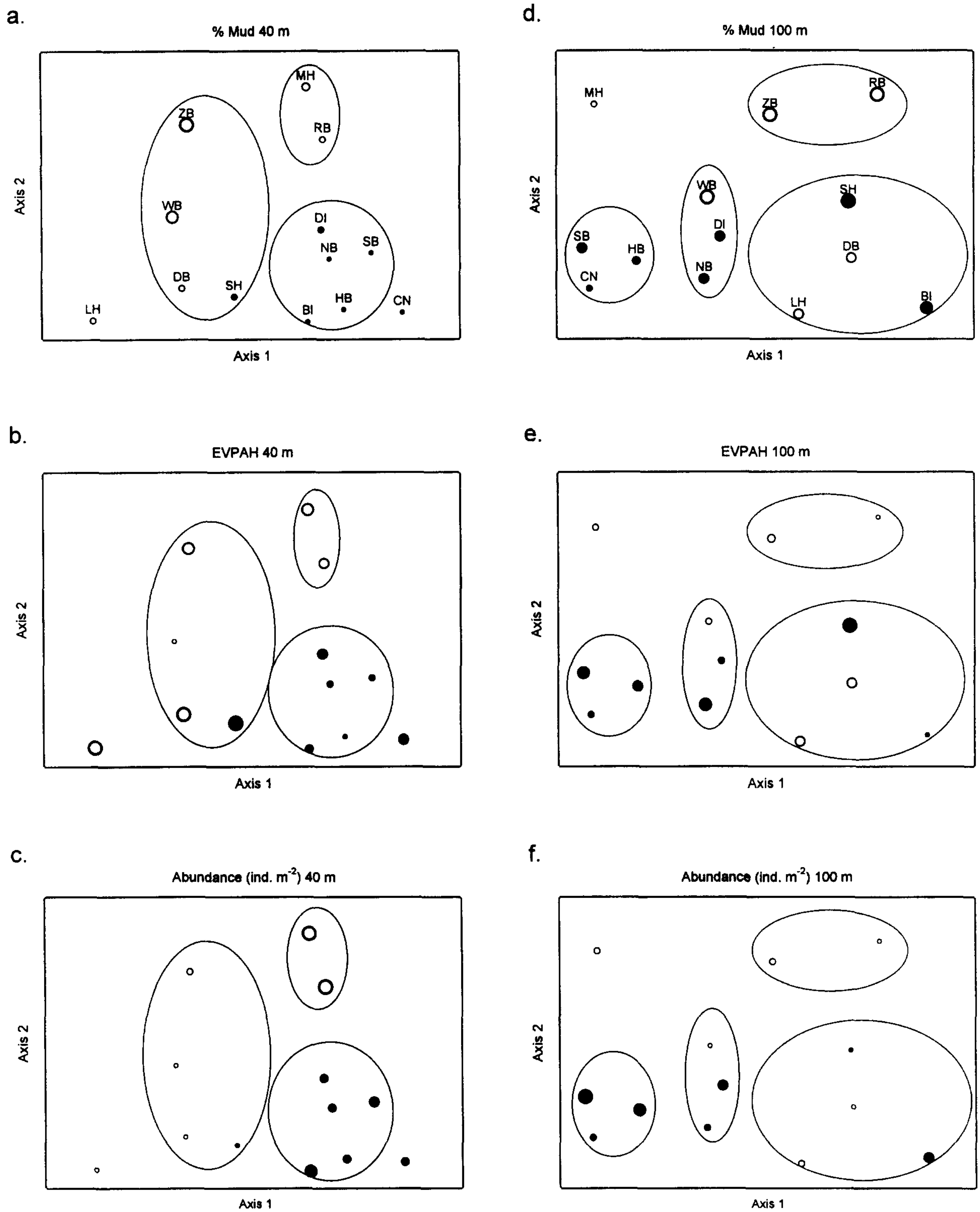

Fig. 7 Overlays of environmental variables and abundance values on MDS plots (Fig. 6b,e). Solid circles indicate sites within the oil trajectory and hollow circles indicate reference sites. Station labels are included in figures a for 40 m and d for 100 m. Size of circles represents relative magnitude of variable values.

communities typically showed no adverse effects. In the present study 16 months after the EVOS, the deep benthic infauna did not demonstrate responses attributable to the effects of oil but instead showed patterns consistent with physical differences within the subtidal environment. Additionally, within the deep benthic environment of Prince William Sound, Armstrong *et al.* (1995) found no evidence of adverse effects of the

TABLE 5

Ranking by abundance of the five top-ranked taxon groups within station groups for sites at approximately 100 m. Dominant taxa indentified to lower taxon levels within familes are presented. An asterisk (*) indicates a site was located within the oil trajectory.

Group	Taxon groups	Dominant taxa	Ind. m^{-2}
Group A	Bivalvia	Juvenile bivalves	547
DI*, NB*,	Golfingiidae	*Golfingia margaritacea*	337
WB	Lumbrineridae	*Lumbrineris* spp., *Ninoe gemmea*	242
	Cirratulidae		143
	Paraonidae	*Aedicera antennata Tauberia gracilis*	117
Group B	Golfingiidae	*Golfingia margaritacea*	413
CN*,	Bivalvia	Juvenile bivalves	347
HB*,SB*	Sabellidae		302
	Syllidae	*Exogone* spp., *Sphaerosyllis* spp., *Typosyllis armillaris*	283
	Paraonidae	*Aedicera antennata, Aricidea minuta, Aricidea neosuecica, Aricidea ramosa, Tauberia gracilis*	264
Group C	Nephtyidae	*Nephtys cornuta, N. punctata*	162
RB, ZB	Nuculanidae	*Nuculana fossa, Yoldia amygdalea, Y. berigiana*	162
	Sternaspidae	*Sternaspis scutata*	151
	Cirratulidae		145
	Lumbrineridae	*Lumbrineris* spp., *Ninoe gemmea*	107
Group D	Nephtyidae	*Nephtys cornuta, N. punctata*	261
BI*, DB,	Lumbrineridae	*Lumbrineris* spp., *Ninoe gemmea*	238
LH, SH*	Tellinidae	*Macoma carlottensis*	238
	Cirratulidae		207
	Bivalvia	Juvenile bivalves	178
MH	Owenidae	*Myriochele oculata*	424
	Polyodontidae	*Peisidice aspera*	152
	Syllidae	*Exogone* spp., *Sphaerosyllis* spp., *Odontosyllis phosphorea*	122
	Maldanidae	*Petaloproctus tenuis borealis, Praxillella affinis, Notoproctus pacificus*	118
	Golfingiidae	*Golfingia margaritacea*	96

EVOS at either the individual or population level for scallops (*Chlamys rubida)*, pandalid shrimps (*Pandalus platyceros, P. hypsinotus, P. borealis*), Tanner crab (*Chionoecetes bairdi*) and the flathead sole (*Hippoglossoides elassodon*).

In conclusion, in 1990, 16 months after the EVOS, infauna within the deep benthic environment of Prince William Sound showed no disturbance signals. However, the investigations of Highsmith *et al.* (1996) and Jewett and Dean (1993) following the EVOS demonstrated effects of the spill in the intertidal and shallow subtidal regions through 1990. The formation of neutrally buoyant oil-clay flocculates within the EVOS slick and the major currents within the Sound were apparently important in preventing substantial oil accumulation at depth. The findings in the present study and other investigations cited above indicate that the effects of spilled petroleum hydrocarbons are greatly reduced with depth.

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