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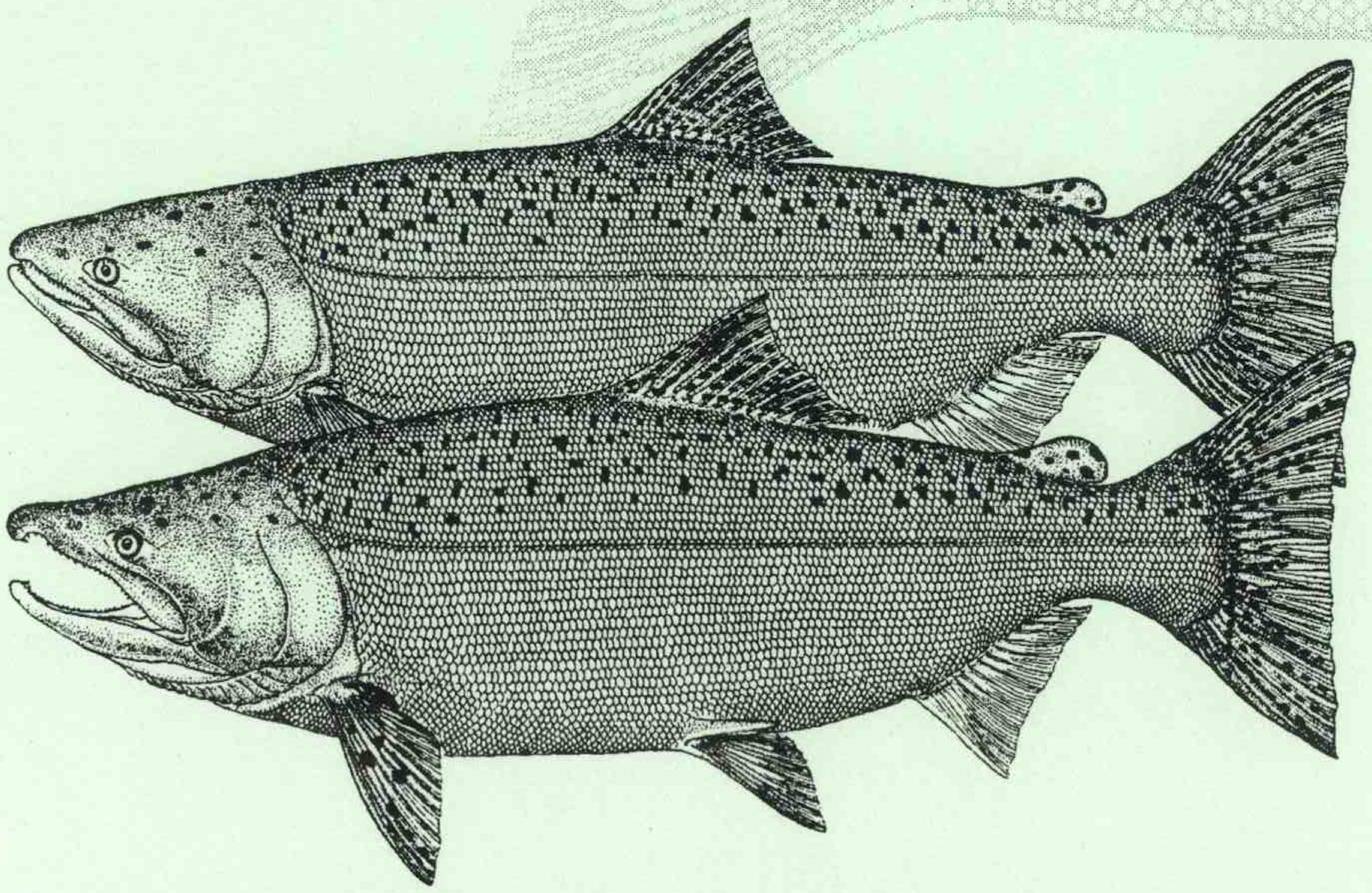
Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by Robert L. Emmett and Susan A. Hinton

October 1995



BENTHIC INFAUNA AND SEDIMENT CHARACTERISTICS OFFSHORE FROM THE COLUMBIA RIVER, JULY 1993

By

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CONTENTS

INTRODUCTION

The U.S. Army Corps of Engineers (COE), Portland District, is authorized to maintain navigational channels in the Columbia River and its estuary and entrance. Four Ocean Dredged-Material Disposal Sites (ODMDSs) off the mouth of the Columbia River have been designated by the Environmental Protection Agency to receive dredged material (Fig. 1). These sites are identified as ODMDSs A, B, E, and F and are used for disposal of materials dredged primarily from shoals at the mouth of the Columbia River, but may also receive dredged material from other areas in the lower estuary. Average annual dredged material quantities in the mouth of the Columbia River estuary range from 3 to 9 million cubic yards, with an average of 5 million cubic yards (1980-1994), with most of the material historically disposed at Sites A and B. Site F has been used little, except for disposal of material dredged during the 1989 Tongue Point Monitoring Program (Siipola et al. 1993). In 1994, ODMDSs A, B, and F were expanded to accept additional material because material disposed at the primary ocean disposal site (ODMDS B) had not dispersed, but accumulated into a mound, which came to within 48 ft of the MLLW.

This temporary (5-year) spatial expansions of Sites A, B, and F were initiated by the COE, Portland District, in 1992 while searching for a long-term solution for dredged material disposal. In 1993 material dredged from the mouth of the Columbia River was deposited at expanded ODMDSs B and F.

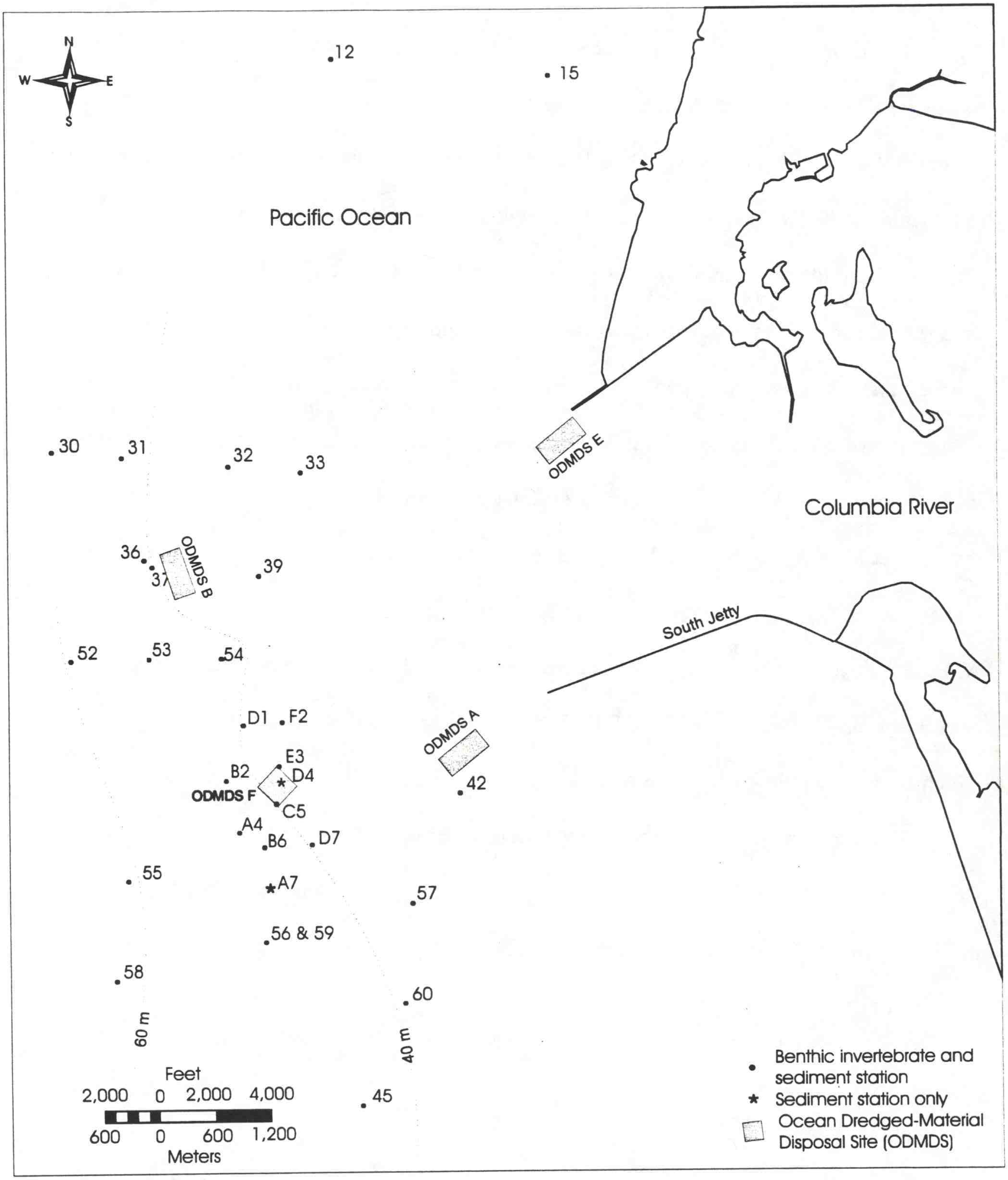

Figure 1. Locations of benthic invertebrate and sediment stations offshore from the Columbia River sampled during July 1993. Stations 56 and 59 were in the same location.

To minimize negative biological effects, ODMDSs should be located in areas with no unique biological characteristics and relatively low standing crops of benthic and epibenthic invertebrates and fishes. Also, candidate ODMDSs must be carefully evaluated from the standpoint of technical feasibility and economics.

A widespread benthic invertebrate survey offshore from the Columbia River was conducted during the mid 1970s under the COE's Dredged Materials Research Program (Richardson et al. 1977). A relatively recent site-specific survey of ODMDS F and its vicinity was conducted by the COE, Portland District, from 1989 to 1992 (Siipola et al. 1993).

The primary goal of the present study was to assess benthic invertebrate communities at 28 stations and sediment characteristics at 30 stations in an area offshore from the Columbia River during July 1993. Eight of the benthic invertebrate stations were previously sampled during an intensive benthic survey at ODMDS F (Siipola et al. 1993) and 11 stations previously sampled during a reconnaissance-level benthic invertebrate survey (Siipola 1994).

METHODS

Sampling

Benthic Invertebrates

The sampling stations were located offshore from the Columbia River, extending about 16 km north, 17 km south, and 16 km west of the river mouth (Fig. 1). Twenty eight stations were sampled for both benthic invertebrates and sediments; two additional stations were sampled for sediments only. Station depths ranged from 12.2 to 65.8 m (Appendix Table 1).

The Global Positioning System (GPS) was used to identify station geographic coordinates and locate previously sampled stations.

A 0.1-m^2 modified Gray-O'Hara box corer (Pequegnat et al. 1981) was used to collect bottom samples (Appendix Fig. 1). Five benthic invertebrate samples were taken at each station. Benthic invertebrate samples were preserved in 18.9-liter buckets with a buffered 4% formaldehyde solution containing rose bengal (a protein stain). Within 2 weeks, the samples were individually sieved through a 0.5-mm mesh screen, and the residue, containing the macroinvertebrates, preserved in a 70% ethanol solution. Benthic organisms were sorted from the preserved samples, identified to the lowest practical taxonomic level (usually species), and counted. All specimens were placed in vials containing 70% ethanol and stored at the NMFS Point Adams Biological Field Station, Hammond, Oregon.

Sediments

Sediment samples for physical analyses were collected at all 30 stations. These samples were collected from the box corer using a stainless steel spoon, placed in labeled plastic bags, and refrigerated until delivered to the COE North Pacific Division Materials Testing Laboratory at Troutdale, Oregon.

Data Analyses

Benthic Invertebrates

At each station where benthic invertebrates were collected, the total number of organisms was determined and the number of organisms/m^2 calculated. Each sample collected at a station was treated as a replicate, allowing calculation of a mean number of organisms/m^2 and standard deviation for each species and for each station. Two community structure indices were also calculated for each station. The first was diversity (H), which was determined using the Shannon-Wiener function (Krebs 1978):

$$H = -\sum_{i=1}^{s} p_i \log_2 p_i$$

where $p_i = n_i/N$ (n_i is the number of individuals of the ith taxon in the sample, and N is the total number of individuals in the sample) and s = number of taxa. The second community structure index was equitability (E), which measures proportional abundances among the various taxa in a sample (Krebs 1978):

$$E = H/\log_2 s$$

where H = Shannon-Wiener function and s = number of taxa. E has a possible range of 0.00 to 1.00, with 1.00 indicating that all taxa in the sample are numerically equal.

Cluster analysis, using the Bray-Curtis dissimilarity index with a group averaging fusion strategy (Clifford and Stephenson 1975), was used to identify stations that had similar species and densities in July 1993. A 0.5 dissimilarity value was considered a significant difference between groups. The mean number of organisms/m^2 for each species per station was used in the analysis. Species that had densities less than 20 organisms/m^2 were excluded from the analysis to reduce the effect of uncommon species.

Sediments

Physical analyses of sediments included determination of grain size and volatile solids. Median grain size and percent sand and percent silt/clay were calculated for each sample.

Statistical Analyses

Linear and polynomial regression were used to identify significant relationships between various sediment characteristics (median grain size, percent silt/clay, and percent volatile solids) and benthic invertebrate community metrics (density, number of taxa, H, and E). We used analysis of variance (ANOVA) to identify significant differences between invertebrate densities, number of taxa, H, and E between different years. Densities were $\log_{10}(x)$ transformed to normalize the data before performing statistical tests.

RESULTS

Benthic Invertebrates

During the July 1993 benthic invertebrate survey, 361 different taxa were identified (Appendix Table 2). However, specimens from 25 taxa were not considered benthic organisms and were eliminated from the analysis. The number of benthic invertebrate taxa per station averaged 107 and ranged from 65 (Station 42) to 145 (Station 52) (Table 1, Appendix Table 3). Overall densities averaged 8,768 invertebrates/m^2, ranging from 1,392 organisms/m^2 (Station 42) to 14,728 organisms/m^2 (Station 52). Stations with high densities generally had higher number of taxa (Fig. 2) (regression, $r^2 = 0.51$, $P < 0.001$).

The three most abundant taxa within each major taxonomic group found throughout the study area included the polychaetes *Prionospio lighti*, *Spiochaetopterus costarum*, and *Magelona* spp.; the molluscs *Nitidella gouldi*, *Tellina* spp., and *Axinopsida serricata*; and the crustaceans, *Euphilomedes carcharodonta*, *Diastylopsis tenuis*, and *Diastylopsis* spp. (Table 2). Polychaetes were the most abundant taxa, averaging 4,777/m^2 and molluscs the least abundant, averaging 1,018/m^2.

Diversity (H) was generally high at most stations and ranged from 2.60 to 5.13, with most values greater than 3.50 (Table 1, Appendix Table 3). Equitability (E) was moderate,

Table 1 . Summary of benthic invertebrates collections, by station, offshore from the Columbia River, July 1993.

Station	Date	Number of taxa	Number/m^2	SD	H[a]	E[b]
A4	21 Jul 93	112	9,278	3,659	3.79	0.56
B2	20 Jul 93	115	8,807	1,640	4.80	0.70
B6	21 Jul 93	111	5,783	806	4.79	0.71
C5	20 Jul 93	80	1,542	525	4.97	0.79
D1	20 Jul 93	103	6,124	3,971	4.72	0.71
D7	21 Jul 93	118	12,381	4,855	3.53	0.51
E3	20 Jul 93	89	5,156	3,065	3.38	0.52
F2	20 Jul 93	92	3,101	1,843	4.42	0.68
12	19 Jul 93	89	13,171	7,645	2.70	0.42
15	19 Jul 93	80	3,239	942	4.80	0.76
30	19 Jul 93	141	12,329	3,342	4.78	0.67
31	19 Jul 93	115	9,353	3,099	4.53	0.66
32	19 Jul 93	107	7,613	1,950	4.17	0.62
33	19 Jul 93	79	5,145	1,406	4.71	0.75
36	19 Jul 93	135	13,375	2,524	4.49	0.63
37	19 Jul 93	107	3,653	590	5.13	0.76
39	19 Jul 93	81	5,937	1,214	4.14	0.65
42	21 Jul 93	65	1,392	318	4.74	0.79
45	21 Jul 93	114	9,801	1,649	4.27	0.62
52	20 Jul 93	145	14,728	2,275	3.85	0.54
53	20 Jul 93	79	9,639	1,824	3.66	0.58
54	20 Jul 93	115	7,138	2,357	4.58	0.67
55	21 Jul 93	127	13,663	3,416	3.94	0.56
56	21 Jul 93	123	11,664	889	4.31	0.62
57	21 Jul 93	98	13,006	9,890	2.60	0.39
58	21 Jul 93	140	12,204	1,237	4.10	0.57
59	21 Jul 93	127	12,646	848	4.31	0.62
60	21 Jul 93	110	13,627	5,061	3.14	0.46
Mean		107	8,768		4.19	0.63
SD		21	4,104		0.66	0.11

[a]Diversity (Shannon-Wiener function)

[b]Equitability

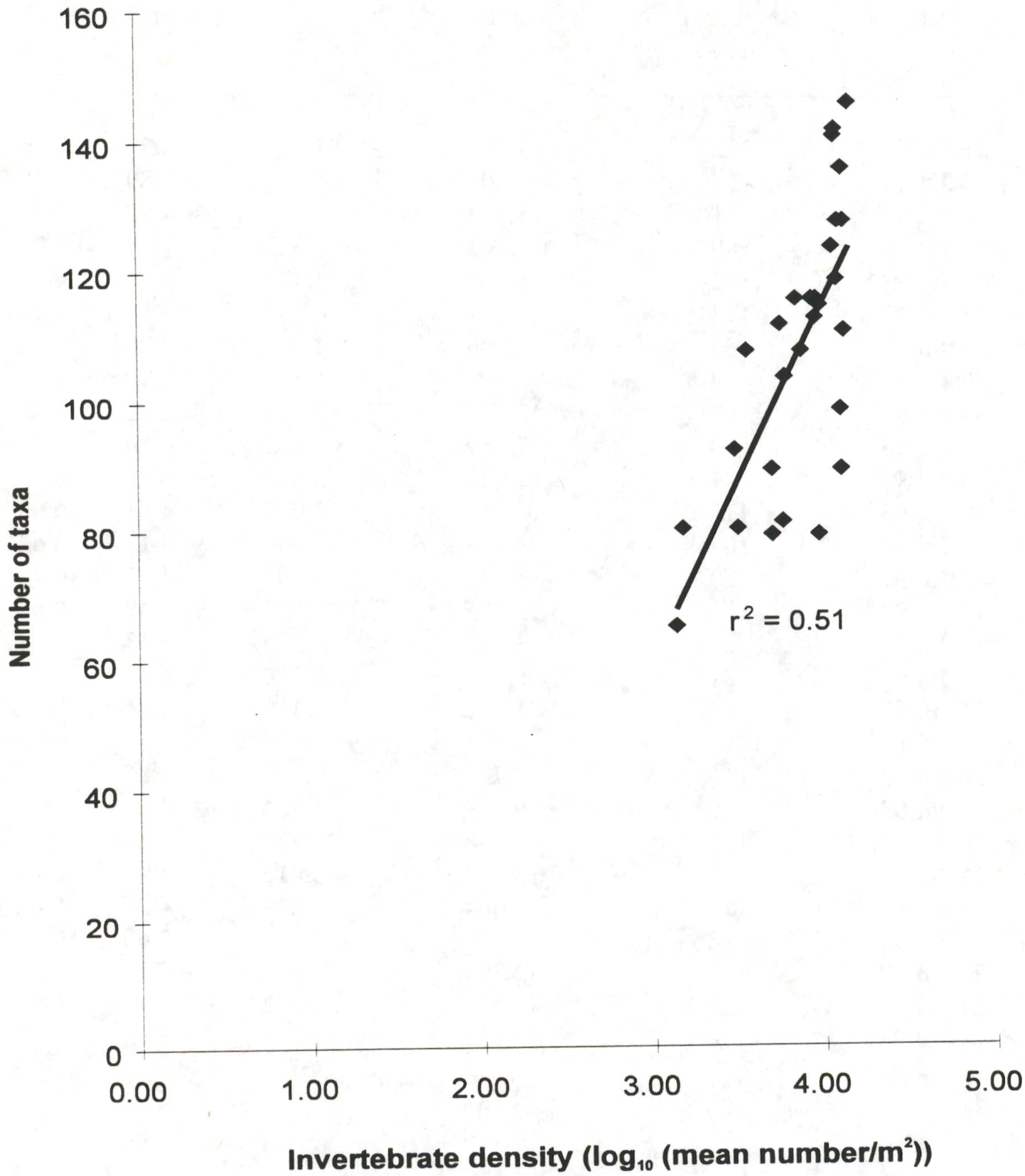

Figure 2. Regression relationship between benthic invertebrate density and number of taxa at 28 stations offshore from the Columbia River, July 1993.

Table 2. Dominant benthic invertebrates found at 28 stations offshore from the Columbia River, July 1993 (all stations combined).

Taxon	Mean number/m^2
Polychaeta	
Prionospio lighti	1,323
Spiochaetopterus costarum	847
Magelona spp.	360
Phyllodoce hartmanae	327
Chaetozone setosa	318
Mediomastus californiensis	174
Nephtys caecoides	160
Pholoe minuta	157
Leitoscoloplos pugettensis	118
Glycinde spp.	100
Miscellaneous	893
Total	4,777
Mollusca	
Nitidella gouldi	175
Tellina spp.	128
Axinopsida serricata	127
Olivella pycna	120
Olivella spp.	120
Acila castrensis	98
Olivella baetica	53
Macoma spp.	34
Cylichna attonsa	29
Mytilidae	21
Miscellaneous	113
Total	1,018
Crustacea	
Euphilomedes carcharodonta	327
Diastylopsis tenuis	142
Diastylopsis spp.	131
Orchomene pinquis	91
Rhepoxynius spp.	86
Diastylopsis dawsoni	51
Callianassa californiensis	43
Leucon spp.	40
Rhepoxynius vigitegus	38
Rhepoxynius abronius	34
Miscellaneous	356
Total	1,339
Miscellaneous	
Dendraster excentricus	1,367
Nemertea	161
Echiurida	63
Amphiodia spp.	27
Miscellaneous	17
Total	1,635
Total	8,769

ranging from 0.39 to 0.79 with most values between 0.50 and 0.79. There was an inverse relationship between benthic invertebrate densities and H and E values (Figs. 3 and 4). However, invertebrate densities were a poor predictor of H and E. Stations with the highest densities, although often having above average number of taxa, generally had lower H and E values due to the dominance of one or more taxa. Stations with highest H and E values usually had a low to above average number of taxa, but no numerically dominant taxa. This was reflected in the strong direct relationship between H and E (Fig. 5) ($r^2 = 0.91$, $P < 0.01$).

The results of benthic invertebrate station cluster analysis are displayed in Figures 6 and 7. Stations designated by letters A through E should not be confused with cluster groups A through E. Five cluster groups (stations with similar benthic invertebrate species and densities) were identified, but six stations were not included in any grouping. The largest two cluster groups were composed of six stations (Groups A and C). Although cluster Group C was composed of adjacent stations, Group A had only three adjacent stations. The next largest cluster group, D, was comprised of five contiguous deeper-water stations located just west of ODMDS B off the mouth of the Columbia River. For cluster Groups A and B, the sand dollar *Dendraster excentricus* and the polychaetes *Spiochaetopterus costarum* and *Magelona* spp. were the primary invertebrate species. However, these cluster groups had different invertebrate densities (11,104 organisms/m^2 for Group A versus 5,120 organisms/m^2 for Group B). Cluster groups C and D had polychaetes as primary species, while Group E had the cumaceans *Diastylopsis tenuis* and *Diastylopsis* spp. and the polychaete *Prionospio lighti* as its primary species.

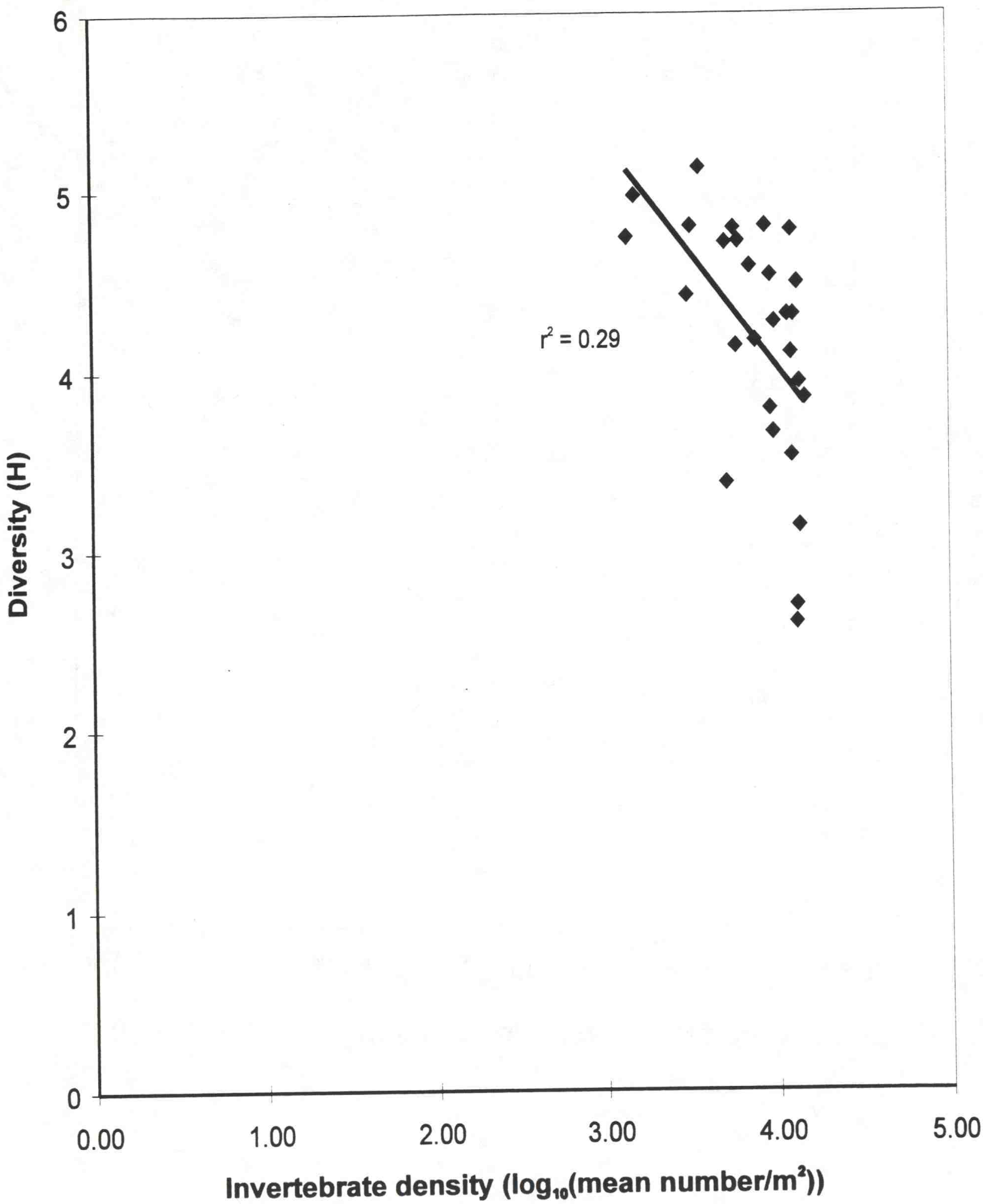

Figure 3. Regression relationship between benthic invertebrate density and diversity (H) at 28 stations offshore from the Columbia River, July 1993.

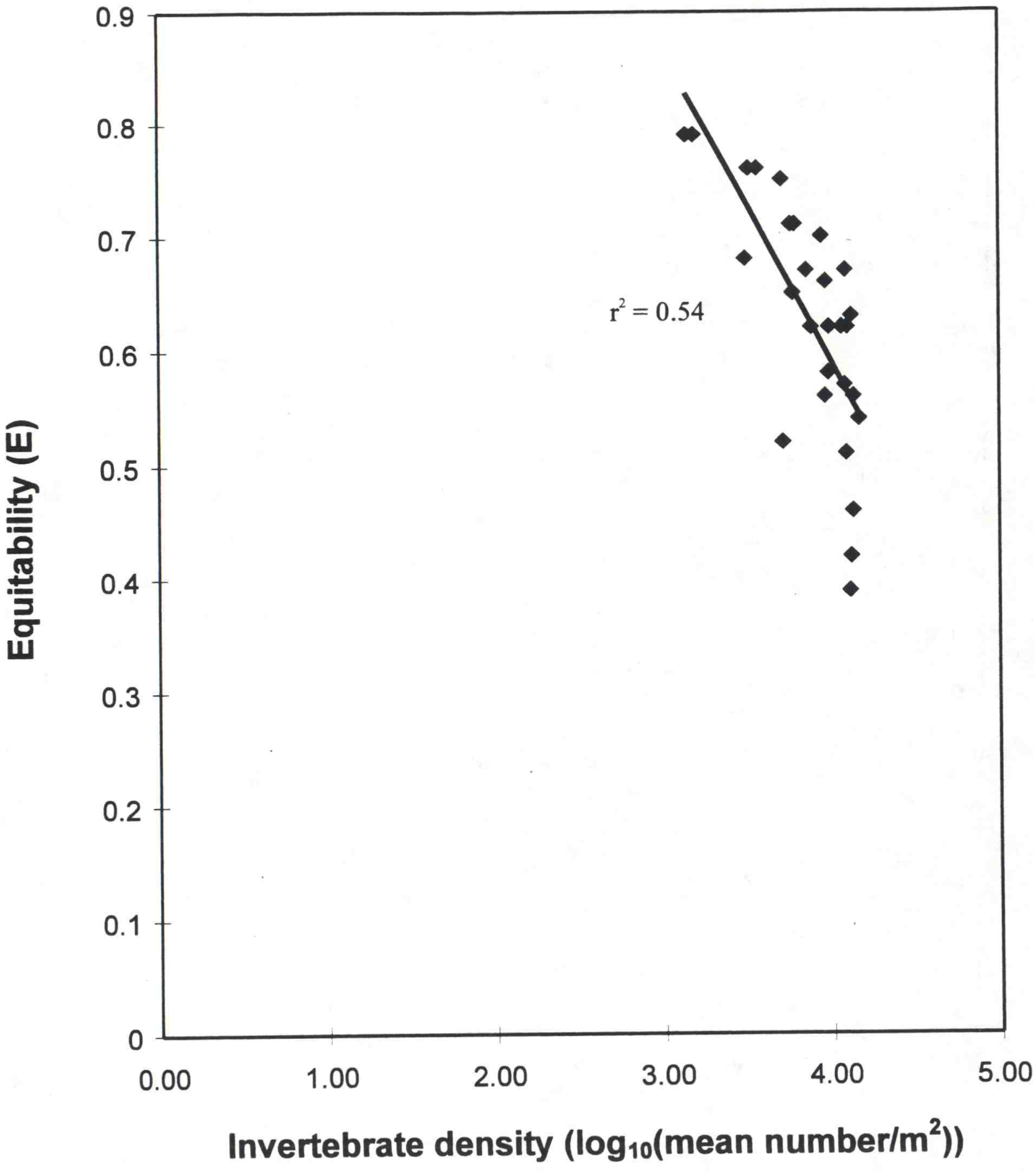

Figure 4. Regression relationship between benthic invertebrate density and equitability (E) at 28 stations offshore from the Columbia River, July 1993.

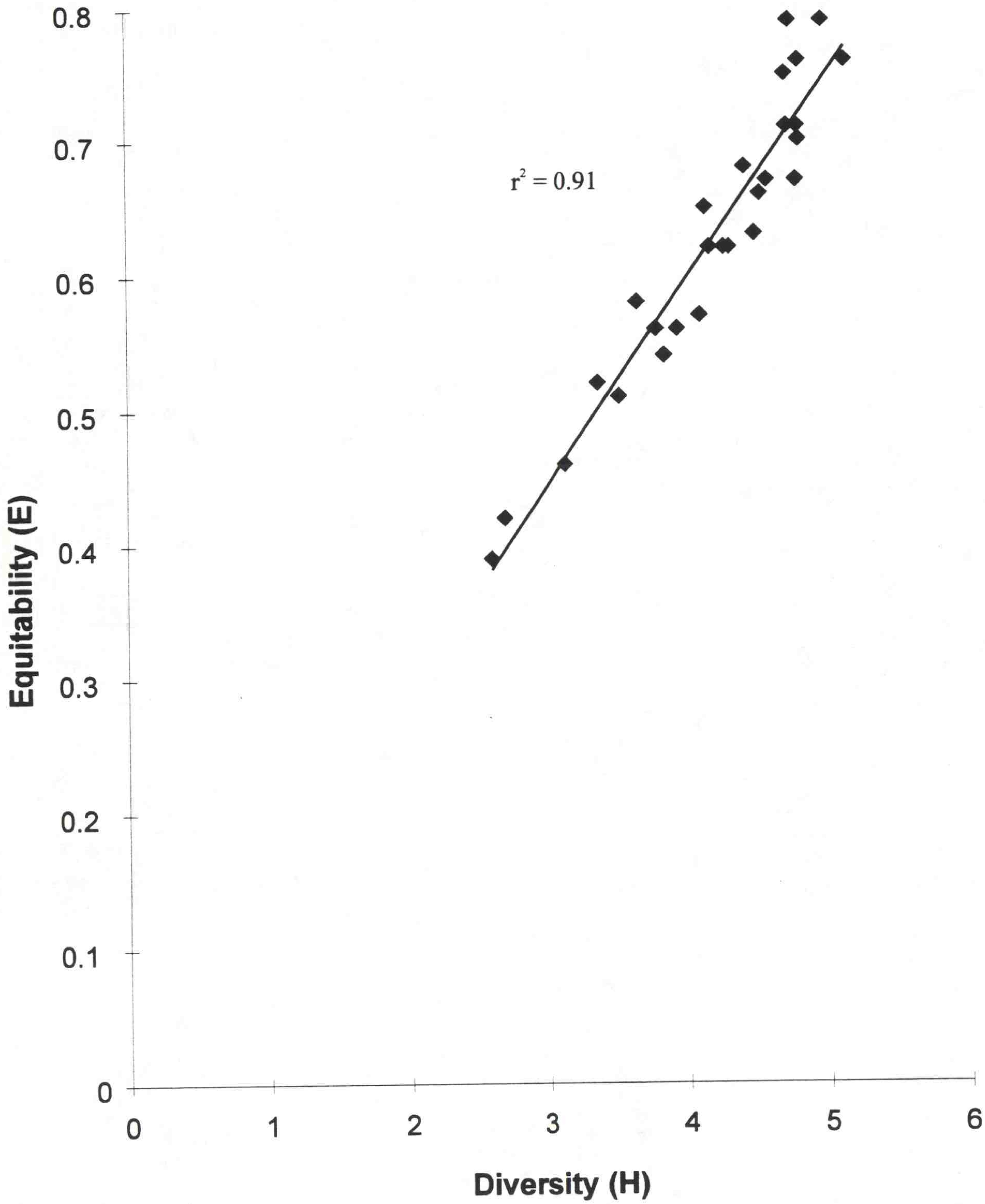

Figure 5. Linear regression between benthic invertebrate diversity (H) and equitability (E) at 28 stations offshore from the Columbia River, July 1993.

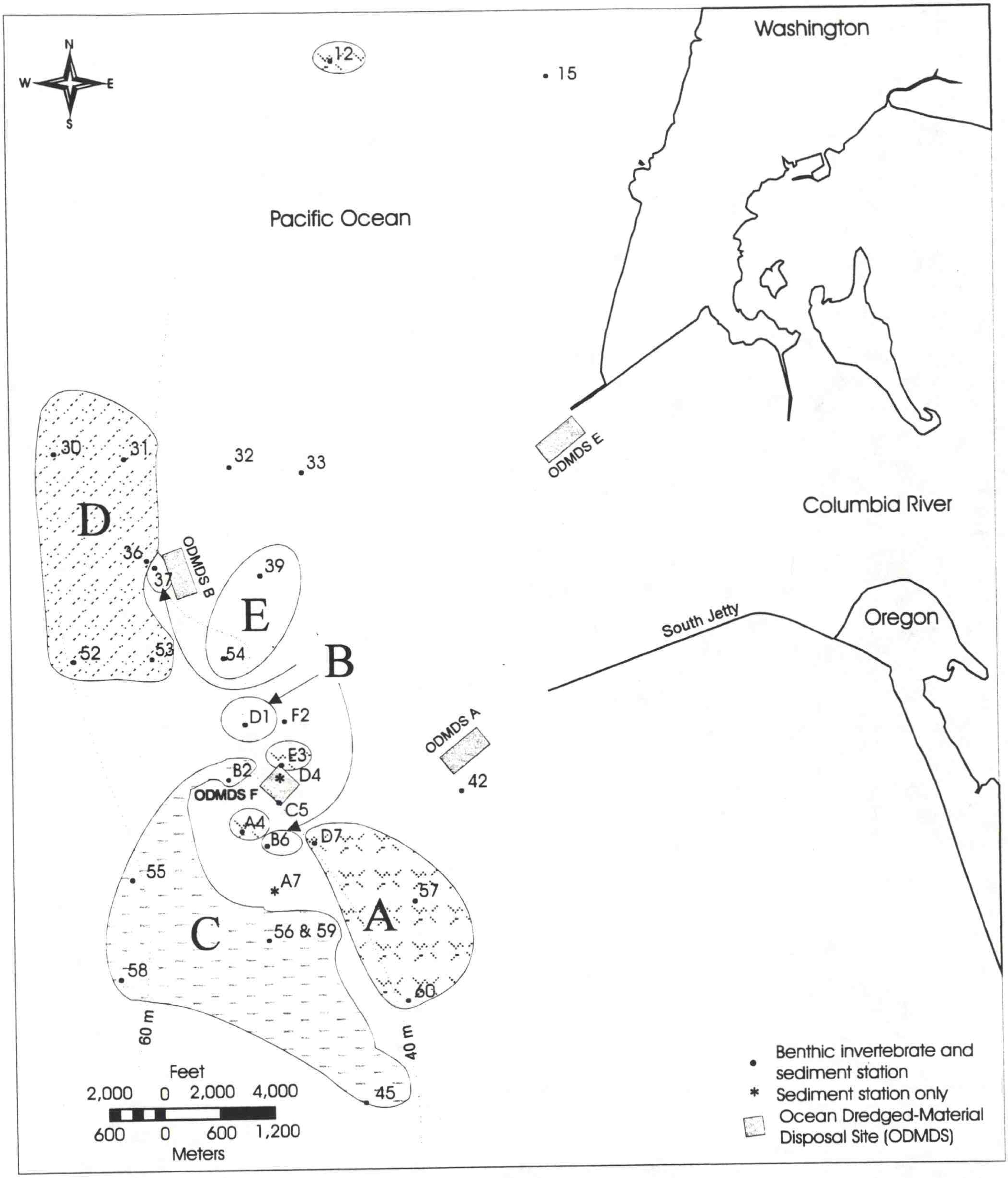

Figure 6. Locations of benthic invertebrate cluster groups (A-E) offshore from the Columbia River, July 1993. Stations 56 and 59 were in the same location. Six stations did not cluster.

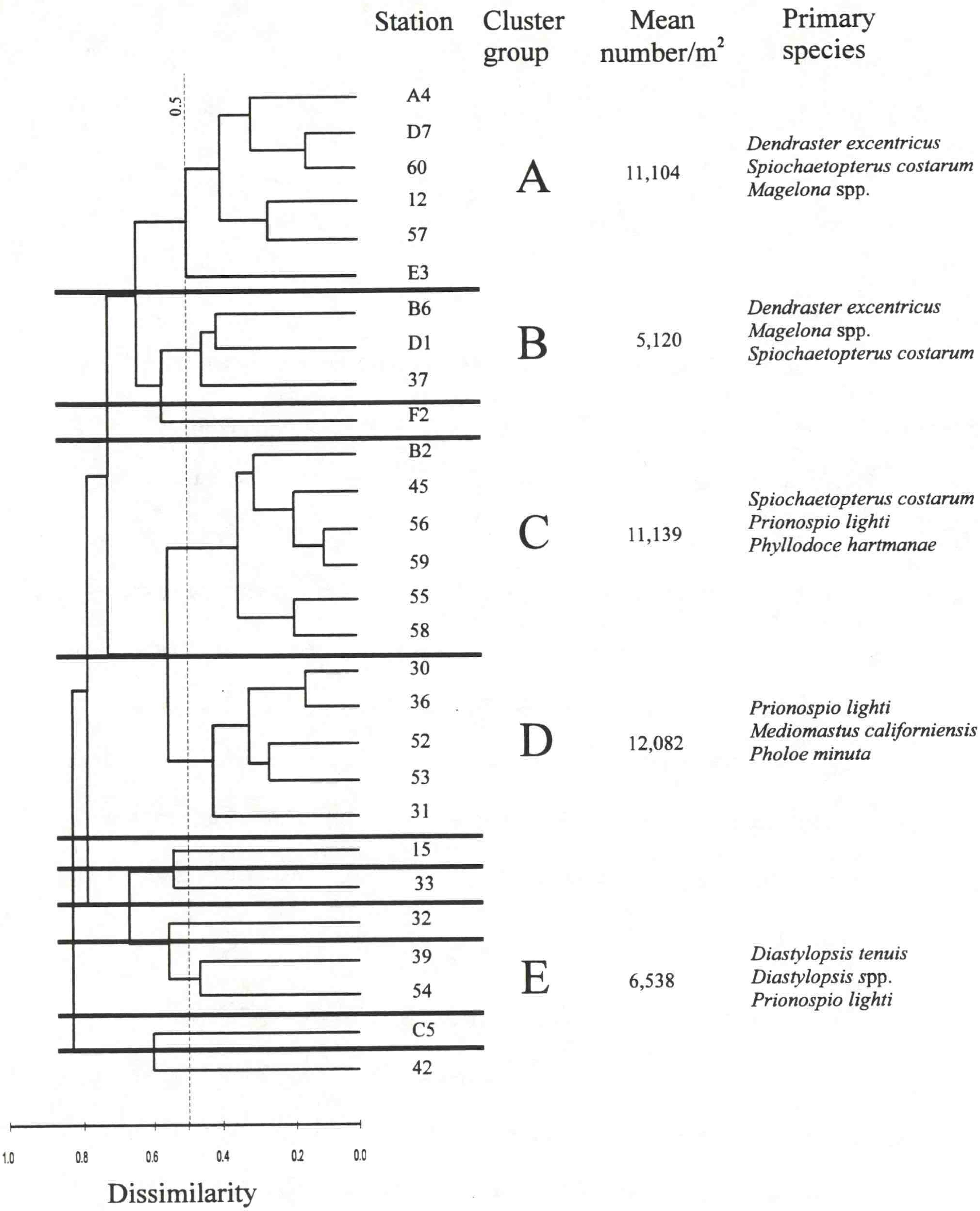

Figure 7. Dendrogram results from cluster analysis of benthic invertebrate densities at 28 stations off the mouth of the Columbia River, July 1993.

Stations in shallow water near the mouth of the Columbia River generally had lower benthic invertebrate densities than deeper water stations away from the Columbia River (Fig. 8).

Sediments

Physical Analyses

Overall average median grain size was 0.16 mm, percent silt/clay was 10.6%, and volatile solids were 1.7% (Table 3). There was less variation in median grain size than in percent silt/clay, which ranged from 1.1% to 77.2%. The highest silt/clay value was measured at Station 54, which is almost directly off the mouth of the Columbia River. Stations with highest percent silt/clay were generally deeper on the north side of the Columbia River mouth (Fig. 9). Percent volatile solids were generally low, ranging from 0.6 to 3.4% at all stations except Station 54, where it was 9.0%.

We identified a significant but relatively poor relationship between percent silt/clay and median grain size (regression, $r^2 = 0.62$, $P < 0.01$) (Fig. 10). However, there was a good direct relationship between percent volatile solids and percent silt/clay (regression, $r^2 = 0.91$, $P < 0.01$) (Fig. 11).

Sediment and Invertebrate Relationships

We found no significant relationships (regression, $P > 0.05$) between the various sediment characteristics (median grain size, percent silt/clay, and percent volatile solids) and biological measurements (mean invertebrate densities, number of taxa, H, and E).

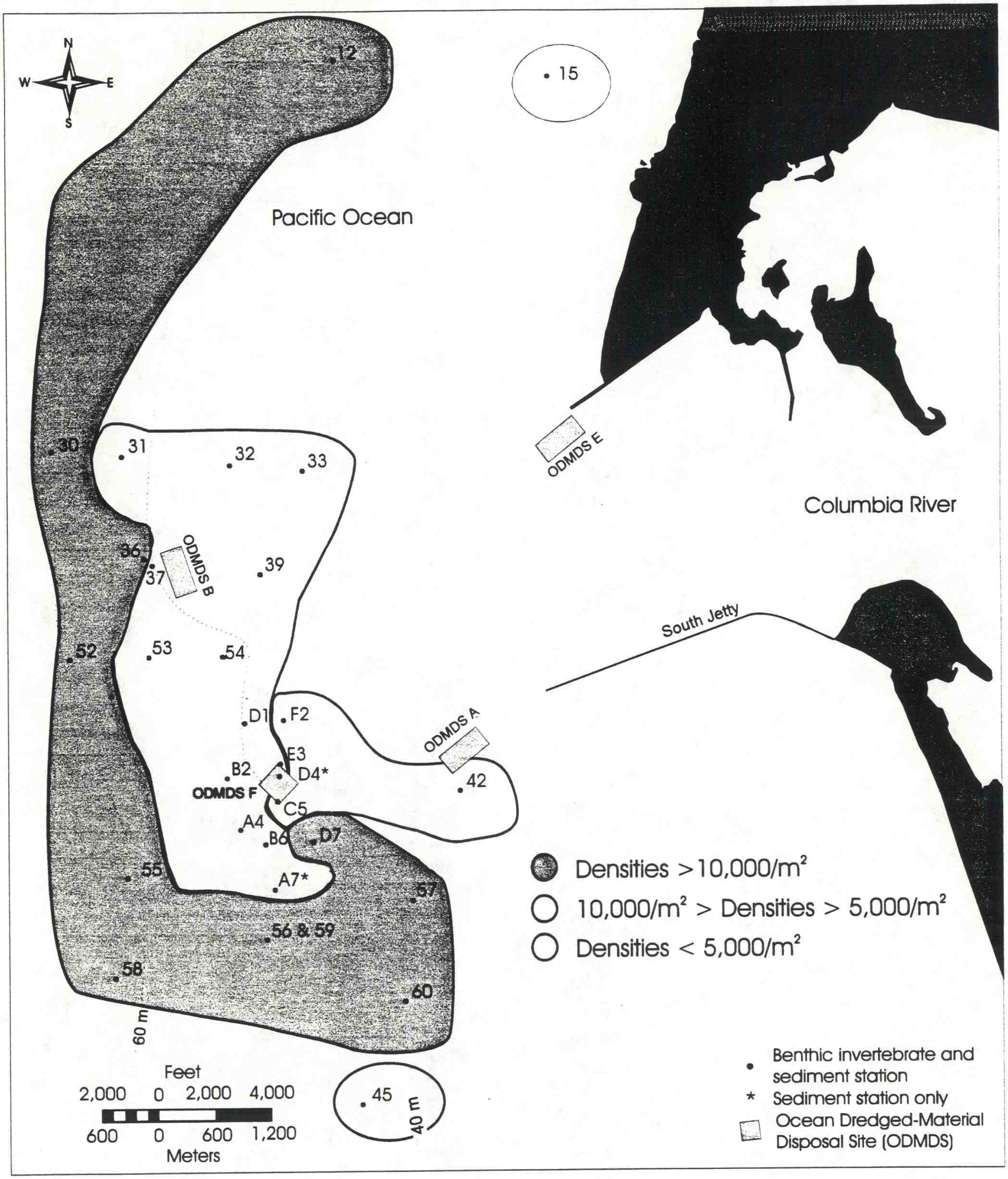

Figure 8. Benthic invertebrate densities at 28 stations offshore from the Columbia River July 1993. Stations 56 and 59 were in the same location.

Table 3. Sediment characteristics at 30 stations located offshore from the Columbia River, July 1993.

Station	Median grain size (mm)	Percent silt/clay	Percent volatile solids
A4	0.19	1.5	1.1
A7	0.17	2.2	1.1
B2	0.17	3.2	1.1
B6	0.18	2.1	0.8
C5	0.21	2.3	0.9
D1	0.17	4.6	0.9
D7	0.15	2.0	0.7
E3	0.19	1.7	0.9
F2	0.22	1.8	0.8
G1	0.19	1.1	0.6
12	0.10	11.7	0.8
15	0.13	3.4	0.7
30	0.09	27.3	3.1
31	0.09	26.7	2.7
32	0.08	36.3	3.3
33	0.14	7.3	1.0
36	0.14	11.7	1.5
37	0.19	2.7	1.2
39	0.13	36.4	3.4
42	0.17	1.7	0.6
45	0.16	2.4	1.2
52	0.16	13.8	3.4
53	0.15	18.9	3.1
54	*	77.2	9.0
55	0.17	4.8	1.2
56	0.16	2.3	1.1
57	0.15	1.5	0.7
58	0.17	4.1	1.5
59	0.16	2.5	1.0
60	0.15	1.5	0.7
Mean	0.16	10.6	1.7
SD	0.03	16.3	1.7

* Classified as silt, no further analysis was performed.

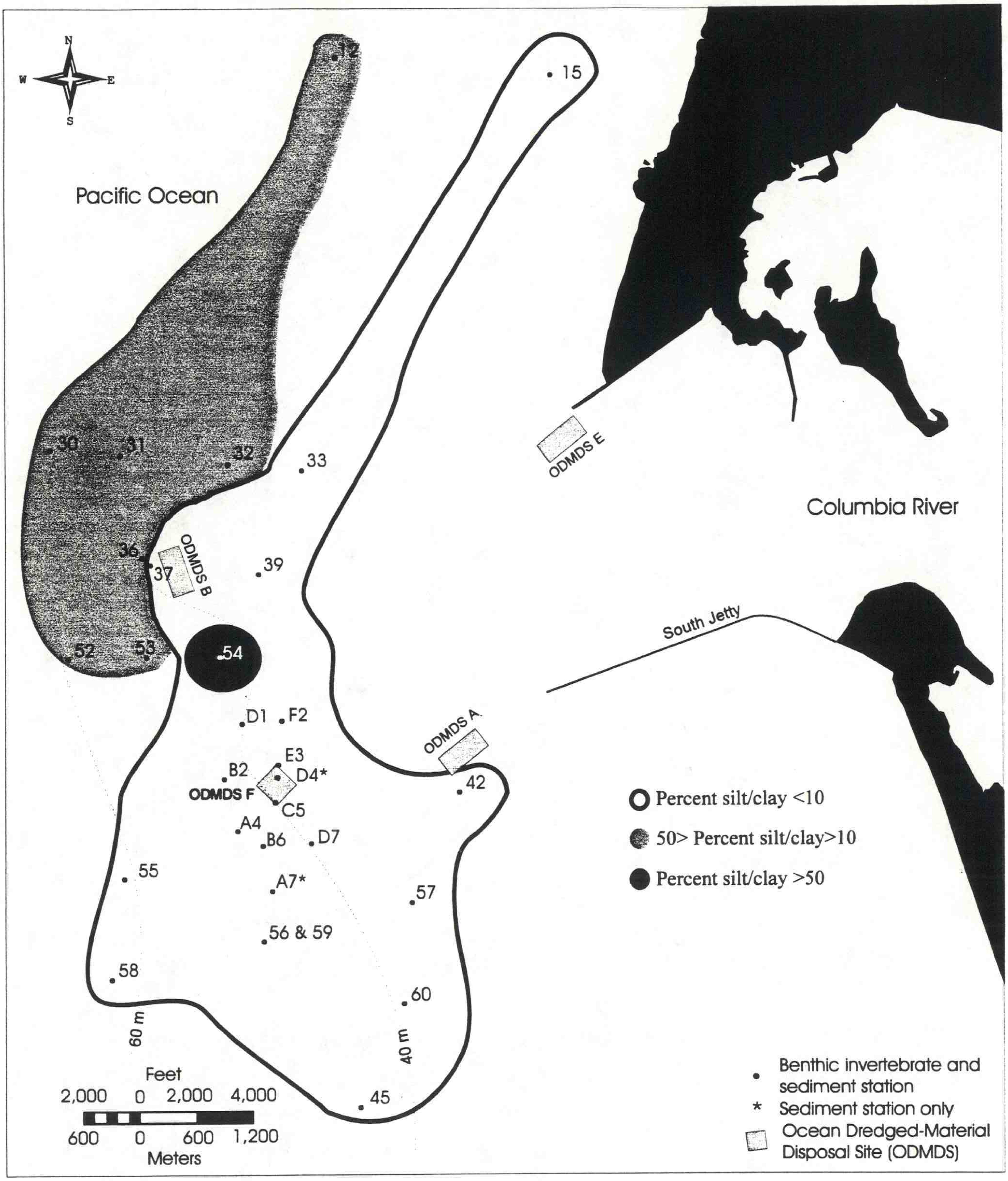

Figure 9. Percent silt/clay at 30 stations offshore from the Columbia River, July 1993. Stations 56 and 59 were in the same location.

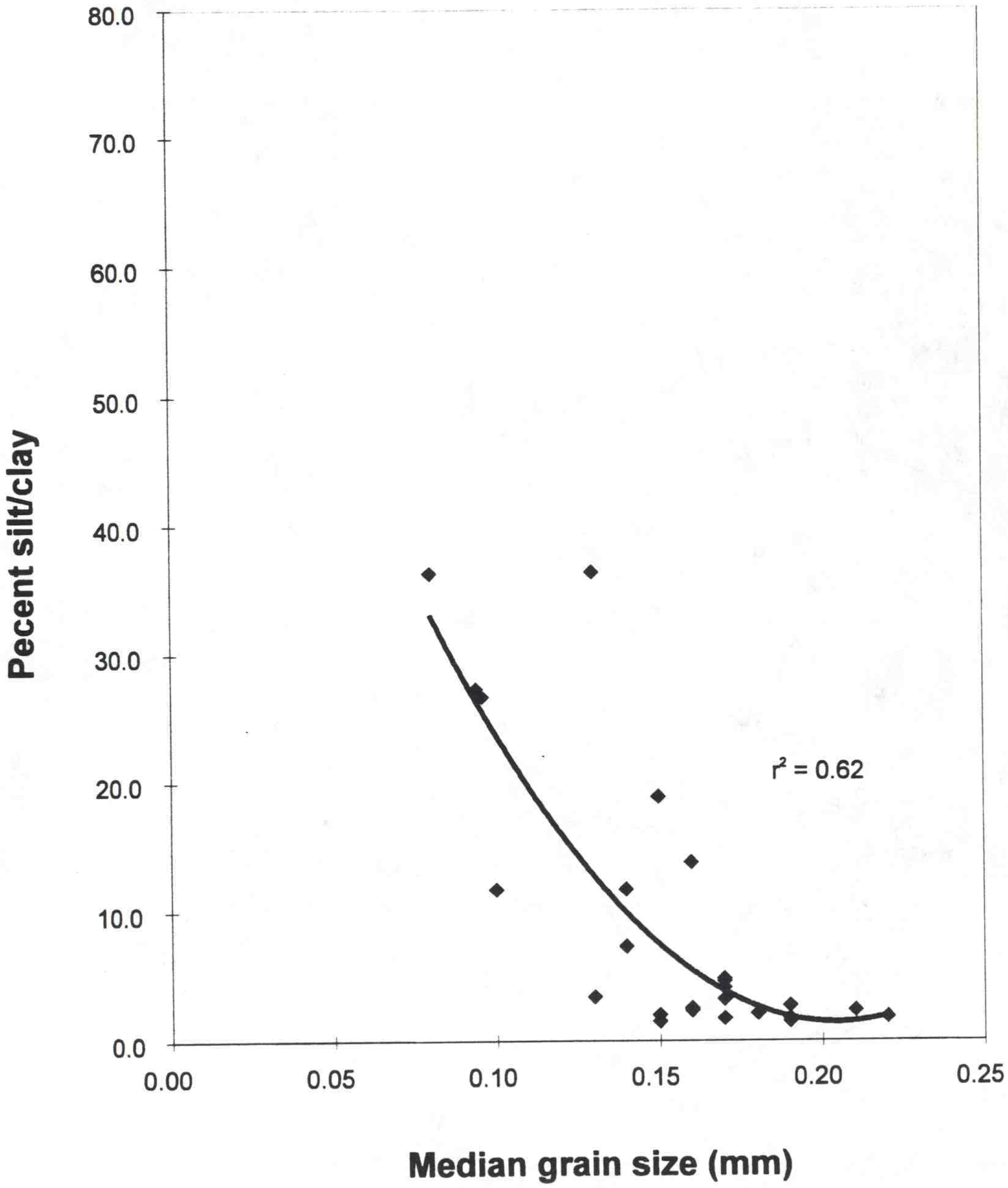

Figure 10. Regression relationship between median grain size and percent silt/clay at 30 benthic stations offshore from the Columbia River, July 1993.

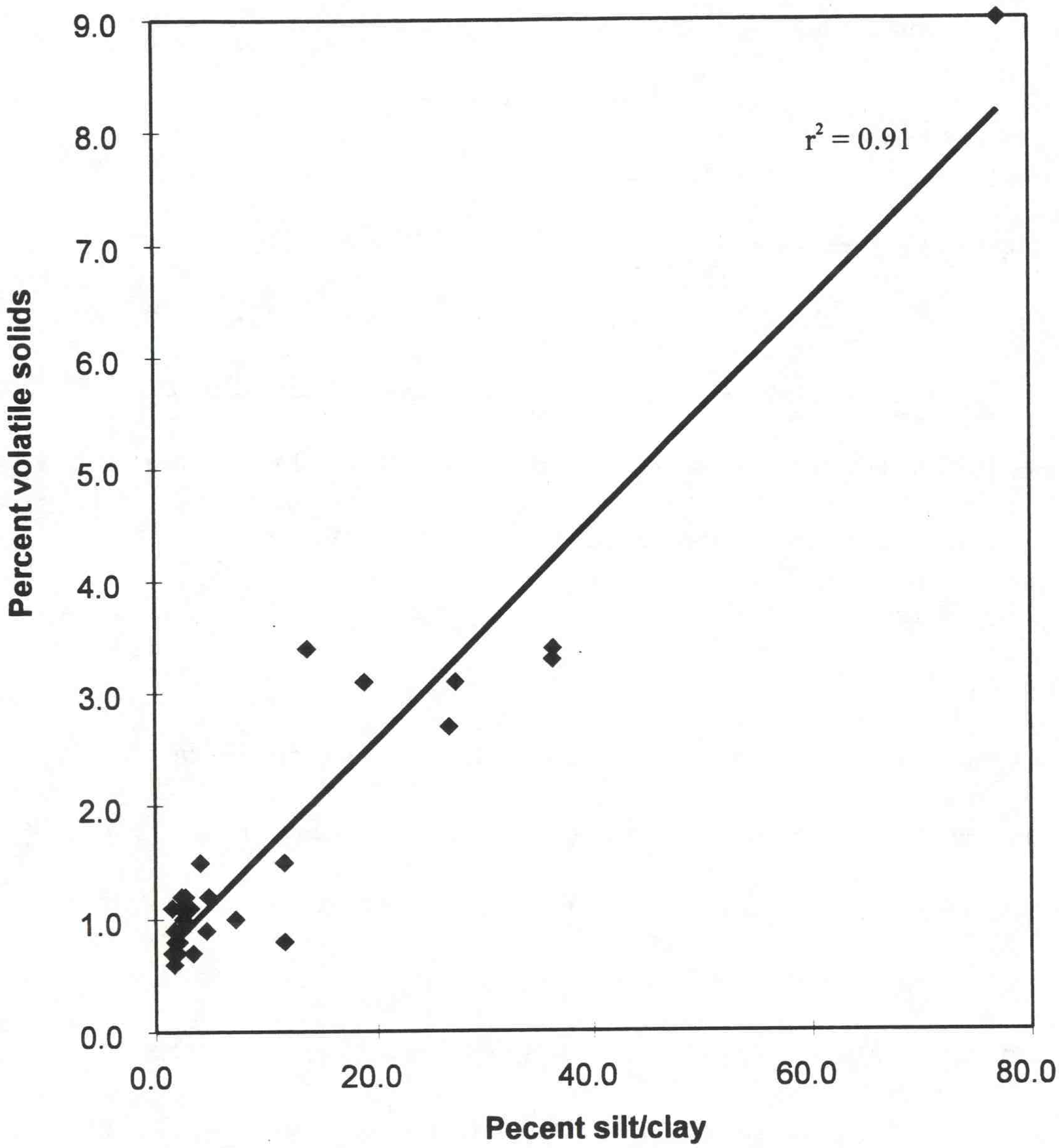

Figure 11. Regression relationship between percent silt/clay and percent volatile solids at 30 benthic stations offshore from the Columbia River, July 1993.

Annual Fluctuation

Eight ODMDS F stations sampled in 1993 were previously sampled during 1989 to 1992. Benthic invertebrate densities at these stations differed significantly from 1989 to 1992 (ANOVA, $P < 0.01$), increasing by an order of magnitude from 1989 to 1992. Invertebrate densities in 1993 were also high, but second to 1992 values (Table 4).

The number of benthic invertebrate taxa per station at and adjacent to ODMDS F increased from 1989 to 1992, and decreased slightly in 1993 (Table 5). These differences were significant (ANOVA, $P < 0.01$).

Diversity (H) and equitability (E) at and adjacent to ODMDS F also differed significantly from 1989 to 1993 (Tables 6 and 7) (ANOVA, $P < 0.01$). Lowest mean values for both indices occurred in 1992, with the second lowest values in 1993, showing that at least in these studies diversity and equitability are evidently inversely related to benthic invertebrate densities.

Eleven benthic invertebrate stations sampled in 1992 were also sampled in 1993 (Table 8). Invertebrate densities were not significantly lower in 1993 than 1992 (ANOVA, $P > 0.05$), (Table 8). This was opposite to what we found at the eight stations at ODMDS F. Also, unlike ODMDS F from 1992 to 1993, the number of taxa was significantly higher in 1993 than in 1992 (ANOVA, $P < 0.05$) (Table 8). These differences were probably a result of different sample sizes. In 1992, single grabs were taken at seven stations and five grabs at four stations, resulting in a total of 27 samples. In 1993, five grabs were taken at each station, resulting in a total of 55 samples. The larger number of samples in 1993 increased the number of uncommon taxa collected.

Table 4. Densities (mean number/m^2) of benthic invertebrates at and adjacent to ODMDS F, offshore from the Columbia River, June/July 1989 through 1993. Station densities were calculated by averaging replicates from each station.

Station	1989	1990	1991	1992	1993
A4	1,223	2,238	3,599	13,759	9,278
B2	1,294	3,262	4,362	14,027	8,807
B6	871	2,574	3,872	11,479	5,783
C5	1,142	2,978	3,833	7,821	1,542
D1	1,517	3,587	4,001	14,819	6,124
D7	788	2,584	3,660	6,646	12,381
E3	992	2,793	6,823	9,820	5,156
F2	1,046	1,588	5,760	9,422	3,101
Mean	1,109	2,701	4,489	10,974	6,522
SD	237	617	1,172	3,036	3,510

Table 5. Numbers of benthic invertebrate taxa at eight stations at and adjacent to ODMDS F offshore from the Columbia River, June/July 1989-1993.

Station	1989	1990	1991	1992	1993
A4	71	73	99	110	112
B2	68	93	105	121	115
B6	68	72	107	108	111
C5	67	109	106	110	80
D1	80	86	89	107	103
D7	59	71	100	92	118
E3	58	88	108	111	89
F2	71	73	92	93	92
Mean	68	83	101	107	103
SD	7	13	7	10	14

Table 6. Diversity (H) of benthic invertebrate taxa at eight stations at and adjacent to ODMDS F offshore from the Columbia River, June/July 1989-1993.

Station	1989	1990	1991	1992	1993
A4	4.88	4.75	5.13	3.81	3.79
B2	4.97	4.90	4.95	3.50	4.80
B6	5.08	4.28	5.27	3.98	4.79
C5	4.92	5.20	5.17	4.17	4.97
D1	4.89	4.84	4.60	3.66	4.72
D7	5.02	4.19	4.70	3.96	3.53
E3	4.71	4.33	4.95	4.04	3.38
F2	4.94	4.71	4.03	3.46	4.42
Mean	4.93	4.65	4.85	3.82	4.30
SD	0.11	0.35	0.40	0.26	0.64

Table 7. Equitability (E) of benthic invertebrate taxa at eight stations at and adjacent to ODMDS F offshore from the Columbia River, June/July 1989-1993.

Station	1989	1990	1991	1992	1993
A4	0.79	0.77	0.77	0.56	0.56
B2	0.82	0.75	0.74	0.51	0.70
B6	0.83	0.69	0.78	0.59	0.71
C5	0.81	0.77	0.77	0.61	0.79
D1	0.77	0.75	0.71	0.54	0.71
D7	0.85	0.68	0.71	0.61	0.51
E3	0.80	0.67	0.73	0.59	0.52
F2	0.80	0.76	0.62	0.53	0.68
Mean	0.81	0.73	0.73	0.57	0.65
SD	0.02	0.04	0.05	0.04	0.10

Table 8. Numbers of benthic invertebrate taxa and densities at 11 stations offshore from the Columbia River, 1992 and 1993. Most density values from 1992 are numbers/m^2 (single grabs) 1993 density values are mean numbers/m^2 (five replicates).

Station	1992		1993	
	Number of taxa	Density	Number of taxa	Density
12	75	29,780	89	13,171
15	68	152,455	80	3,239
30	79	23,132	141	12,329
*31	101	46,661	115	9,353
*32	63	6,556	107	7,613
33	11	844	79	5,145
*36	130	24,141	135	13,375
*37	75	1,955	107	3,653
39	37	6,247	81	5,937
42	47	4,679	65	1,392
45	59	21,028	114	9,802
Mean	68	28,862	101	7,728
SD	31	43,373	24	4,200

* mean values from five grabs in 1992.

Diversity (H) at these 11 stations was significantly lower in 1992 than in 1993 (ANOVA, $P < 0.05$) (Table 9). However equitability (E) was not significantly different between the 2 years (ANOVA, $P > 0.05$). The values for both these community structure indices at the 11 stations in 1993 was similar that observed at ODMDS F in 1993.

DISCUSSION

The benthic invertebrate community offshore from the Columbia River is subjected to a variety of influences: river flow, upwelling, downwelling, seasonal winds, and currents, all of which affect species diversity and densities. As a result, benthic invertebrate species and densities varied widely throughout the study area. This was illustrated clearly by cluster analysis, which clustered 22 benthic invertebrate stations into 5 cluster groups and 6 stations into no groups. The relatively large number of cluster groups and stations which did not cluster in such a small area indicates that a complex benthic invertebrate community exists off the mouth of the Columbia River. This complexity is probably the result of widely fluctuating environmental conditions (e.g., high currents and wave actions and shifting sediments) creating many different micro-habitats.

The harsh environmental conditions in shallow-water habitats near the mouth of the Columbia River appear to depress benthic invertebrate densities. As a result, there is a general trend toward higher benthic invertebrate densities with increasing distance westward from the mouth of the Columbia River. Environments deeper and farther offshore from the mouth of the Columbia River undoubtedly provide a more stable habitat for benthic invertebrates. Stable sediments, characterized by higher percent silt/clay, enhance the

Table 9. Benthic invertebrate diversity (H) and equitability (E) at 11 stations offshore from the Columbia River 1992 and 1993. Most values from 1992 were from single grab samples, whereas 1993 mean values were calculated using five replicates from each station.

Station	1992		1993	
	H	E	H	E
12	2.89	0.46	2.70	0.42
15	1.86	0.31	4.80	0.76
30	4.30	0.68	4.78	0.67
*31	2.73	0.41	4.53	0.66
*32	3.55	0.59	4.17	0.62
33	2.28	0.66	4.71	0.75
*36	4.61	0.66	4.49	0.63
*37	4.76	0.76	5.13	0.76
39	3.67	0.71	4.14	0.65
42	3.36	0.60	4.74	0.79
45	2.37	0.40	4.27	0.62
Mean	3.31	0.57	4.41	0.67
SD	0.98	0.14	0.64	0.10

* mean values from five grabs in 1992.

recruitment and survival of many different benthic invertebrate species, especially tube-dwelling polychaetes.

Similar to previous benthic invertebrate surveys off the mouth of the Columbia River, polychaetes numerically dominated most stations (Siipola et al. 1993, Siipola 1994, Hinton and Emmett 1994). These studies revealed that most stations were dominated by the polychaetes *Spiochaetopterus costarum* and *Owenia fusiformis,* both tube-building surface deposit feeders. *Spiochaetopterus costarum* presence is consistent with the findings of Siipola et al. (1993) during the Tongue Point Monitoring Program, where it was the dominant organism in 1992, but was virtually non-existent in 1989-1991. Siipola et al. (1993) speculated that environmental conditions were exceptionally favorable for this organism in 1991 and 1992 (i.e., abundant food resources and stable substrate), resulting in excellent recruitment. Although *S. costarum* was abundant at many stations, the most abundant organism during our study was *Prionospio lighti.* This polychaete worm was particularly abundant at cluster Group D. *Prionospio lighti* has not previously been reported to be highly abundant off Oregon or Washington (Lie and Kisker 1970, Richardson et al.1977, Emmett et al. 1987, Miller et al. 1988, Emmett and Hinton 1992, Siipola et al. 1993, Hinton and Emmett 1994).

Although benthic invertebrate densities in 1993 were relatively high, data from the past 5 years at 8 stations indicate that benthic invertebrate densities declined from 1992 to 1993. We hypothesize that low spring upwelling and resultant low primary productivity may have caused this reduction. As shown in Figure 12, benthic invertebrate densities tend to follow spring upwelling values, rising from 1989 to 1992 and then falling in 1993. Benthic

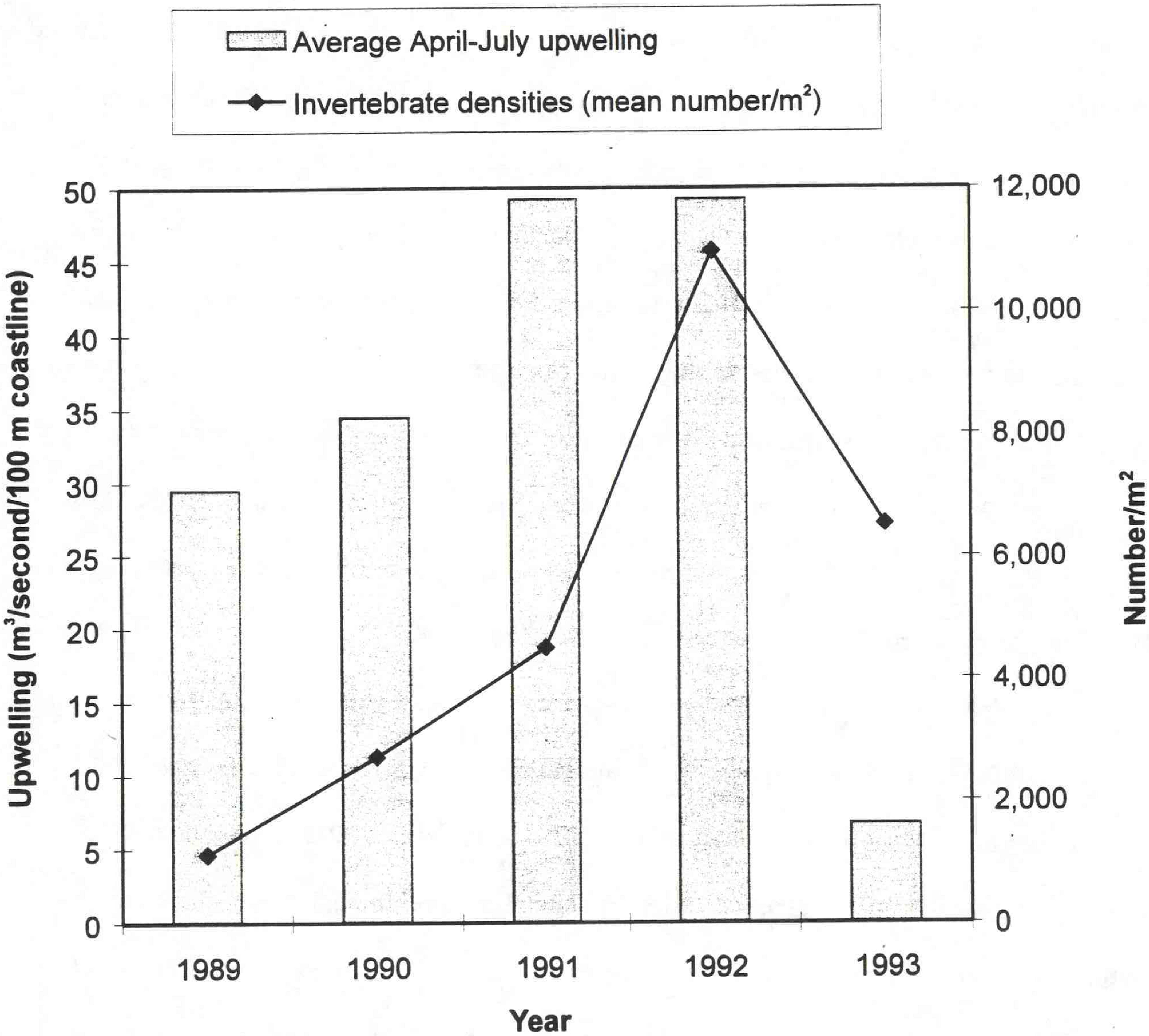

Figure 12. Plot of average upwelling during April through July and benthic invertebrate densities at eight stations offshore from the Columbia River, 1989-1993. Upwelling values are for 45N and 125W and were obtained from the Pacific Fisheries Environmental Group, Monterey, CA.

invertebrates are probably responding directly to nutrient levels and the resultant primary production in the water column. This is not surprising, since many of the benthic invertebrate species identified during 1993 were suspension and surface deposit feeders (Fauchald and Jumars 1979). These organisms are dependent on organic material (organic detritus and phytoplankton) settling on or near the bottom. Benthic invertebrate biomass has been directly related to pelagic productivity in the Bering and Chukchi Seas (Grebmeir et al. 1988), but no such studies have been conducted in the Pacific Northwest.

The distribution of sediment types offshore from the Columbia River observed during this survey agrees with sediment distributions described in previous studies of the area (Kulm et al. 1975, Sternberg et al. 1977). As expected, sediment grain size decreases with increasing depth north of the entrance to the Columbia River.

The lobe of organically enriched fine-grained sediments to the west and northwest of ODMDS B found in this survey and by Hinton and Emmett (1994) was previously described by Siipola et al. (1993) and Sternberg et al. (1977). Kulm et al. (1975) observed that the Cascadia Channel receives sediment from the Columbia River through the Willapa Canyon, which has its head on the outer edge of the continental shelf 45 km north of the mouth of the Columbia River. A northwest offshore transport of coarse silt and very fine sand is required to supply Willapa Canyon with sediment for periodic submarine slumps. Studies of fine-grained, river-borne particulate matter labeled by radionuclides in shelf sediments derived from the Columbia River showed a net northward and westward transport toward the vicinity of Willapa Canyon (Gross 1972). Near-bottom current studies showed the same net transport (Kulm et al. 1975).

Benthic sediment characteristics near the mouth of the Columbia River often vary annually. For example, percent fines at one benthic station in 1990, 1991, and 1992 were 1.2, 19.6, and 0.8%, respectively (Siipola et al. 1993). These variations are independent of any dredged-material disposal event. The origin, fate, and significance of these transitory fine-grained deposits are unknown, but were also noted by Kulm et al. (1975).

Benthic invertebrates are important prey for many species of demersal fish and shellfish, especially juveniles, which are abundant off the Columbia River (Durkin and Lipovsky 1977). Annual and longer-term fluctuations in benthic invertebrate abundance undoubtedly have direct effects on fish and shellfish populations, yet no long-term research or monitoring program has been established to identify these relationships. For example, Dungeness crab, *Cancer magister*, populations and landings fluctuate at roughly 10-year intervals. The exact cause of these population fluctuations is unknown, but variations in benthic invertebrate standing crop, an important food for juvenile crabs, may be important.

Benthic invertebrate abundance at individual stations appears to be related to specific physical and biological habitat parameters such as sediment grain size, percent silt/clay, percent volatile solids, frequency of disturbance, and predation, while overall population abundances within a large area reflect broad environmental factors, such as upwelling and primary production. A similar phenomenon was identified in the Bering and Chukchi Seas (Grebmeier et al. 1989).

Benthic invertebrate populations often cycle at various time scales (Gray and Christie 1983). Only by monitoring invertebrate species and populations over a wide area and long time periods can effects of dredging be separated from overall annual population fluctuations.

Unfortunately, some of the eight stations that we expected to provide long-term data (collections since 1989) were covered by dredged material in 1994, and no longer represent "control" sites.

CONCLUSIONS

Benthic invertebrate densities and community structure at numerous stations varied widely off the mouth of the Columbia River in 1993. Cluster analysis identified five station groupings and six stations that could not be grouped in any cluster. Annual fluctuations in benthic invertebrate densities and diversity at eight stations increased significantly from 1989 to 1991, did not change significantly 1992, and decreased significantly in 1993. The 1993 decrease perhaps reflected lower primary production resulting from lower spring upwelling. Nevertheless, benthic invertebrate species distributions and densities off the mouth of the Columbia River are evidently determined primarily by sediment and hydraulic conditions (see Lie and Kisker 1970, Brinkhurst 1987, and Ishikawa 1989) and secondarily by long-term coastal primary production. Benthic invertebrate densities were lowest in shallow-water habitats that are often disturbed by waves and currents (<40 m depth) immediately off the mouth of the Columbia River. This area should be investigated further when searching for new dredged-material disposal sites.

This report does not constitute NMFS's formal comments under the Fish and Wildlife Coordination Act or the National Environmental Policy Act.

ACKNOWLEDGMENTS

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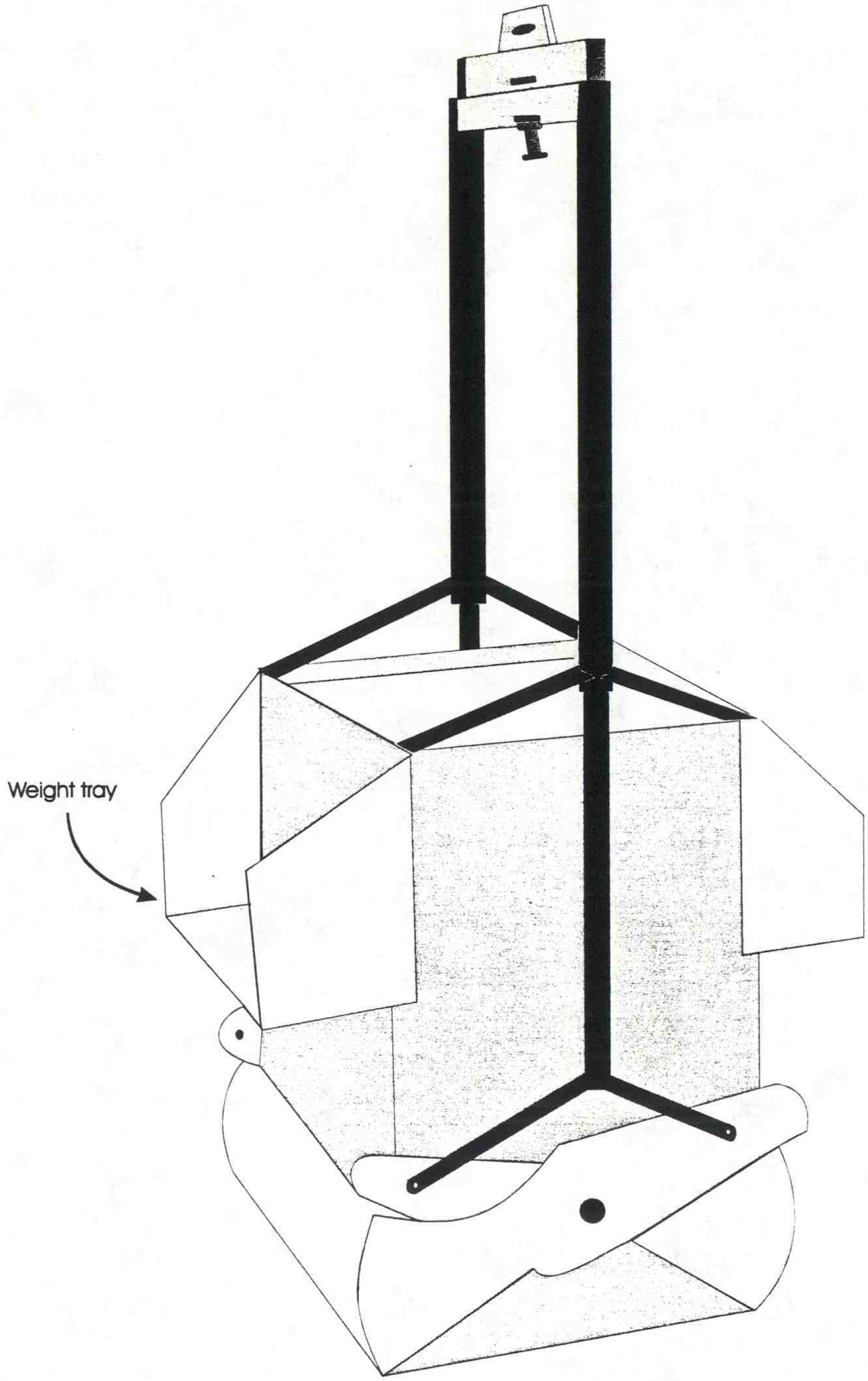

Appendix Figure 1. The 0.1-m^2 box corer (Gray-O'Hara modification of a standard box corer) used for benthic invertebrate sampling offshore from the Columbia River July 1993. For deeper penetration, 113-kg (250-lb) weights were placed in each tray located on opposite sides of the sampler.

Appendix Table 1. Geographic location, date of sampling, and water depth of benthic invertebrate and sediment stations sampled offshore from the Columbia River, July 1993.

Station	Date	Depth m (ft)	Latitude	Longitude
A4	21 Jul	46.3 (152)	46° 11.50'N	124° 9.50'W
A7	21 Jul	46.0 (151)	10.99	8.96
B2	20 Jul	44.2 (145)	11.99	9.73
B6	21 Jul	44.8 (147)	11.39	9.10
C5	20 Jul	39.3 (129)	11.80	8.99
D1	20 Jul	39.9 (131)	12.53	9.52
D7	21 Jul	40.2 (132)	11.47	8.45
E3	20 Jul	36.0 (118)	12.19	9.00
F2	20 Jul	35.1 (115)	12.61	8.99
G1	20 Jul	37.8 (124)	12.03	8.99
12	19 Jul	23.5 (77)	18.98	8.98
15	19 Jul	12.2 (40)	18.98	6.00
30	19 Jul	53.6 (176)	15.00	12.50
31	19 Jul	43.0 (141)	15.00	11.50
32	19 Jul	20.4 (67)	15.02	10.03
33	19 Jul	13.7 (45)	15.00	9.00
36	19 Jul	53.6 (176)	14.01	11.10
37	19 Jul	36.6 (120)	13.98	10.99
39	20 Jul	22.2 (73)	14.00	9.46
42	21 Jul	25.9 (85)	12.03	6.47
45	21 Jul	47.5 (156)	9.02	7.47
52	20 Jul	59.1 (194)	11.01	12.01
53	20 Jul	50.3 (165)	12.99	11.01
54	20 Jul	40.8 (134)	13.00	11.00
55	21 Jul	61.0 (200)	11.00	10.96
56	21 Jul	49.4 (162)	10.50	8.98
57	21 Jul	35.4 (116)	11.00	7.01
58	21 Jul	65.8 (216)	10.00	11.03
59	21 Jul	48.8 (160)	10.50	8.98
60	21 Jul	38.4 (126)	10.00	6.99

Appendix Table 2. Benthic and epibenthic invertebrate taxa collected by box corer offshore from the Columbia River, July 1993.

Taxon	Identified
Cnidaria	
Anthozoa	x
Ctenophora	
Pleurobrachiidae	
Pleurobrachia bachei	x
Platyhelminthes	
Turbellaria	x
Nemertea	x
Annelida	
Polychaeta	x
Aphroditidae	
Aphrodita spp.	x
Polynoidae	x
Bylgides macrolepidus	x
Gattyana spp.	x
Gattyana treadwelli	x
Tenonia priops	x
Sigalionidae	x
Pholoe minuta	x
Sthenelais tertiaglabra	x
Sigalion mathildae	x
Thalenessa spinosa	x
Phyllodocidae	x
Eteone fauchaldi	x
Eteone longa	x
Eteone pacifica	x
Eteone spilotus	x
Eteone spp.	x
Eumida sanguinea	x
Eumida spp.	x
Paranaitides (Phyllodoce) *polynoides*	x
Phyllodoce groenlandica	x
Phyllodoce hartmanae	x
Phyllodoce mucosa	x

Appendix Table 2. Continued.

Taxon	Identified
Phyllodoce spp.	x
Hesionidae	x
Heteropodarke heteromorpha	x
Microphthalmus sczelkowii	x
Micropodarke dubia	x
Parandalia fauveli	x
Podarkeopsis glabrus	x
Pilargidae	
Pilargis berkelyae	x
Syllidae	x
Ehlersia heterochaeta	x
Proceraea cornutus	x
Sphaerosyllis brandhorsti	x
Syllis elongata	x
Nereidae	x
Cheilonereis cyclurus	x
Nereis spp.	x
Nereis procera	x
Nereis zonata	x
Nephtyidae	
Nephtys spp.	x
Nephtys assignis	x
Nephtys caeca	x
Nephtys cornuta cornuta	x
Nephtys rickettsi	x
Nephtys ferruginea	x
Nephtys caecoides	x
Sphaerodoridae	
Sphaerodoropsis minuta	x
Glyceridae	
Glycera spp.	x
Glycera capitata	x
Glycera tenuis	x
Glycera americana	x
Glycera convoluta	x
Glycera nana	x
Goniadidae	
Glycinde spp.	x
Glycinde armigera	x

Appendix Table 2. Continued.

Taxon	Identified
Glycinde picta	x
Goniada brunnea	x
Onuphidae	x
Onuphis iridescens	x
Onuphis elegans	x
Lumbrineridae	x
Eranno bicirrata	x
Lumbrineris spp.	x
Lumbrineris californiensis	x
Lumbrineris limnicola	x
Lumbrineris luti	x
Arabellidae	
Notocirrus californiensis	x
Dorvilleidae	
Dorvillea pseudorubrovittata	x
Orbiniidae	x
Leitoscoloplos pugettensis	x
Orbinia (Phylo) *felix*	x
Scoloplos armiger	x
Paraonidae	
Aricidea (Acesta) *catherinae*	x
Levinsenia gracilis	x
Paraonella platybranchia	x
Spionidae	x
Boccardia pugettensis	x
Laonice cirrata	x
Paraprionospio pinnata	x
Polydora spp.	x
Polydora brachycephala	x
Polydora socialis	x
Prionopsio lighti	x
Prionospio pinnata	x
Prionospio steenstrupi	x
Pseudopolydora spp.	x
Scolelepis squamata	x
Spio spp.	x
Spio butleri	x
Spio filicornis	x
Spiophanes spp.	x

Appendix Table 2. Continued.

Taxon	Identified
Spiophanes berkeleyorum	x
Spiophanes bombyx	x
Megelona	
Magelona spp.	x
Magelona hobsonae	x
Magelona longicornis	x
Magelona sacculata	x
Trochochaetidae	
Trochochaeta multisetosa	x
Chaetopteridae	x
Mesochaetopterus spp.	x
Mesochaetopterus taylori	x
Spiochaetopterus spp.	x
Spiochaetopterus costarum	x
Cirratulidae	x
Aphelochaeta multifilis	x
Aphelochaeta (Tharyx) *secunda*	x
Chaetozone setosa	x
Cossuridae	
Cossura spp.	x
Flabelligeridae	x
Pherusa spp.	x
Scalibregmidae	
Asclerocheilus beringianus	x
Opheliidae	x
Armandia brevis	x
Ophelia spp.	x
Ophelina acuminata	x
Travisia brevis	x
Travisia japonica	x
Capitellidae	x
Barantolla americana	x
Capitella capitata complex	x
Decamastus gracilis	x
Heteromastus filiformis	x
Heteromastus filobranchus	x
Notomastus lineatus	x
Mediomastus spp.	x
Mediomastus ambiseta	x

Appendix Table 2. Continued.

Taxon	Identified
Mediomastus californiensis	x
Aberinicolidae	x
Maldanidae	x
Asychis spp.	x
Euclymene spp.	x
Euclymene zonalis	x
Oweniidae	
Galathowenia oculata	x
Owenia fusiformis	x
Pectinariidae	
Pectinaria spp.	x
Pectinaria californiensis	x
Ampharetidae	x
Ampharete spp.	x
Ampharete acutifrons	x
Asabellides lineata	x
Melinna elisabethae	x
Terebellidae	x
Pista estevanica	x
Polycirrus spp. complex	x
Sabellidae	
Chone dunneri	x
Euchone hancocki	x
Euchone incolor	x
Polygordiidae	
Polygordius spp.	x
Oligochaeta	x
Hirudinea	x
Mollusca	
Gastropoda	x
Turbinidae	
Spiromoellaria quadrae	x
Rissoidae	
Alvania compacta	x
Epitoniidae	
Epitonium spp.	x

Appendix Table 2. Continued.

Taxon	Identified
Epitonium indianorum	x
Nitidascala caamanoi	x
Nucellidae	
Nucella spp.	x
Naticidae	
Nitidella gouldi	x
Nassariidae	
Nassarius spp.	x
Nassarius mendicus	x
Nassarius fossatus	x
Olividae	
Olivella spp.	x
Olivella biplicata	x
Olivella baetica	x
Olivella pycna	x
Turridae	
Kurtzia arteaga	x
Kurtziella plumbea	x
Oenopota spp.	x
Oenopota crebicostata	x
Ophiodermella inermis	x
Pyramidellidae	
Odostomia spp.	x
Turbonilla spp.	x
Cephalaspidea	x
Cylichnidae	
Acteocina spp.	x
Cylichna attonsa	x
Scaphander willetti	x
Aglajidae	
Melanochlamys diomedea	x
Gastropteridae	
Gastropteron pacificum	x
Diaphanidae	
Diaphana spp.	x
Dendronotidae	
Dendronotus subramosus	x
Arminidae	
Armina californica	x

Appendix Table 2. Continued.

Taxon	Identified
Cuthonidae	
Cuthona spp.	x
Bivalvia	x
Nuculidae	
Acila castrensis	x
Nucula tenuis	x
Yoldia spp.	x
Yoldia scissurata	x
Mytilidae	x
Thyasiridae	
Axinopsida serricata	x
Kellidae	
Pseudopythina rugifera	x
Montacutidae	
Mysella tumida	x
Solenidae	
Siliqua spp.	x
Siliqua sloati	x
Tellinidae	
Macoma spp.	x
Macoma balthica	x
Macoma calcarea	x
Macoma nasuta	x
Tellina spp.	x
Tellina carpenteri	x
Tellina modesta	x
Tellina nuculoides	x
Veneridae	
Saxidomus giganteus	x
Compsomyax subdiaphana	x
Pandoridae	
Pandora filosa	x
Pandora punctata	x
Lyonsiidae	
Lyonsia californica	x

Appendix Table 2. Continued.

Taxon	Identified
Scaphopoda	x
Dentaliidae	
Dentalium spp.	x
Arthropoda	
Arachnida	x
Halacaridae	x
Crustacea	
Branchiopoda	
Daphnidae	
Daphnia spp.	x
Ostracoda	
Cylindroleberididae	x
Philomedidae	
Euphilomedes spp.	x
Euphilomedes carcharodonta	x
Copepoda	
Calanoida	x
Calanidae	
Calanus spp.	x
Temoridae	
Eurytemora spp.	x
Pontellidae	
Epilabidocera longipedata	x
Harpacticoida	x
Cyclopoida	x
Corycaeidae	
Corycaeus anglicus	x
Cirripedia	x
Chthamalidae	
Balanus spp.	x

Appendix Table 2. Continued.

Taxon	Identified
Malacostraca	
Leptostraca	
Nebaliidae	
Nebalia pugettensis	x
Mysidacea	
Mysidae	x
Acanthomysis columbiae	x
Acanthomysis macrops	x
Archaeomysis grebnitzkii	x
Neomysis spp.	x
Neomysis kadiakensis	x
Cumacea	
Lampropidae	x
Hemilamprops spp.	x
Hemilamprops californica	x
Leuconidae	x
Leucon spp.	x
Eudorellopsis longirostris	x
Colurostylidae	
Colurostylis occidentalis	x
Diastylidae	x
Diastylis spp.	x
Diastylopsis spp.	x
Diastylopsis dawsoni	x
Diastylopsis tenuis	x
Campylaspidae	
Campylaspis spp.	x
Nannastacidae	
Cumella vulgaris	x
Tanaidacea	
Paratanaidae	
Leptognathia gracilis	x
Isopoda	
Sphaeromatidae	
Ancinus granulatus	x

Appendix Table 2. Continued.

Taxon	Identified
Gnorimosphaeroma oregonensis	x
Tecticeps convexus	x
Idoteidae	
Edotea spp.	x
Edotea sublittoralis	x
Idotea fewkesi	x
Synidotea spp.	x
Synidotea angulata	x
Munnidae	x
Pleurogonium rubicundum	x
Amphipoda	x
Gammaridea	x
Ampeliscidae	
Ampelisca spp.	x
Ampelisca agassizi	x
Ampelisca macrocephala	x
Ampelisca unsocalae	x
Aoridae	x
Aoroides spp.	x
Aoroides columbiae	x
Agrissidae	
Argissa homatipes	x
Atylidae	
Atylus tridens	x
Corophidae	
Corophium spinicorne	x
Gammaridae	x
Megaluropus spp.	x
Haustoridae	
Eohaustorius spp.	x
Eohaustorius estuarius	x
Eohaustorius sencillus	x
Eohaustorius washingtonianus	x
Isaeidae	
Cheirimedia spp.	x
Gammaropsis spp.	x
Photis spp.	x
Photis brevipes	x

Appendix Table 2. Continued.

Taxon	Identified
Photis macinerneyi	x
Photis parvidons	x
Podoceropsis spp.	x
Protomedeia spp.	x
Protomedeia articulata	x
Lysianassidae	x
Anonyx liljeborgi	x
Lepidepecreum gurjanovae	x
Opisa tridentata	x
Orchomene spp.	x
Orchomene pacifica	x
Orchomene pinquis	x
Pachynus c.f. *barnardi*	x
Psammonyx longimerus	x
Prachynella spp.	x
Oedicerotidae	
Monoculodes spinipes	x
Synchelidium spp.	x
Synchelidium shoemakeri	x
Westwoodilla caecula	x
Pardaliscidae	x
Pardalisca spp.	x
Phoxocephalidae	
Foxiphalus major	x
Grandifoxus grandis	x
Mandibulophoxus spp.	x
Mandibulophoxus gilesi	x
Rhepoxynius spp.	x
Rhepoxynius abronius	x
Rhepoxynius bicuspidatus	x
Rhepoxynius daboius	x
Rhepoxynius tridentatus	x
Rhepoxynius vigitegus	x
Pleustidae	x
Parapleustes spp.	x
Parapleustes den	x
Pleusymtes spp.	x
Pleusmytes subglaber	x

Appendix Table 2. Continued.

Taxon	Identified
Podoceridae	
Dulichia spp.	x
Podocerus spp.	x
Stenothoidae	x
Hyperiiidea	
Hyperiidae	
Parathemisto spp.	x
Caprellidea	x
Caprellidae	x
Caprella spp.	x
Decapoda	
Hippolytidae	x
Crangonidae	x
Crangon spp.	x
Crangon alaskansis	x
Crangon franciscorum	x
Crangon nigricauda	x
Lissocrangon stylirostris	x
Rhynocrangon alata	x
Callianassidae	x
Callianassa spp.	x
Callianassa californiensis	x
Paguridae	x
Pagurus spp.	x
Brachyura	x
Cancridae	
Cancer spp.	x
Cancer magister	x
Pinnotheridae	
Pinnixa spp.	x
Pinnixa eburna	x
Insecta	
Collembola	x

Appendix Table 2. Continued.

Taxon	Identified
Sipuncula	
Sipunculidae	x
Sipunculus nudus	x
Golfingiidae	
Golfingia pugettensis	x
Echiurida	x
Phoronida	x
Echinodermata	
Ophiuroidea	x
Ophiura spp.	x
Amphiuridae	
Amphiodia spp.	x
Amphiura spp.	x
Echinoidea	x
Dendraster excentricus	x
Holothuroidea	x
Chaetognatha	x
Sagittidae	
Sagitta spp.	x
Urochordata	
Oikopleuridae	
Oikopleura spp.	x

Appendix Table 3. Summaries of benthic invertebrate collections, by station, for 28 stations offshore from the Columbia River, July 1993 (available upon request from National Marine Fisheries Service, Point Adams Biological Field Station, P.O. Box 155, Hammond, OR 97121).