APPDENDIX C - ATTACHMENT 2

Benthic Monitoring Results for 1990 – 2003 [Updated]

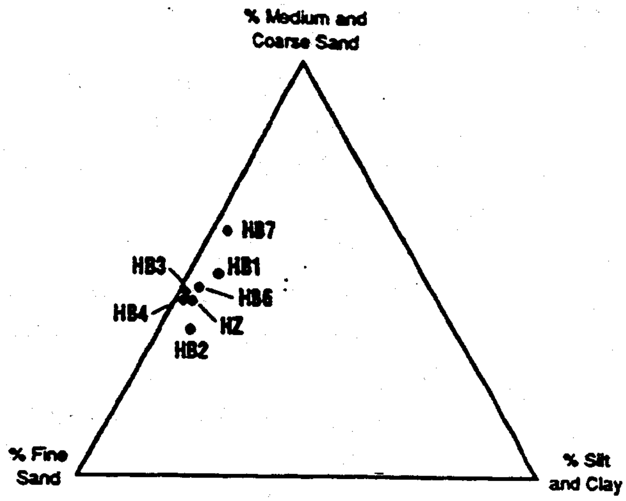

Figure 3. Sediment-grain-size characteristics, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following ANOVA, the a posteriori Student-Newman-Keuls (SNK) test was used to determine which differences among stations were significant.

An overall comparison of species composition among stations was carried out using cluster analysis (Pielou 1984). The Bray-Curtis similarity index (Bloom 1981) on untransformed data was performed using the flexible sorting strategy. To make the analysis more manageable, only those non-mollusk species that contributed at least 0.07% of the total abundance were included in the analysis. As a result of adhering to this criterion, only species represented by a total of more than three individuals were included in the analysis, and the analysis data set was reduced from 164 to 84 species. The Cluster program developed by the EPA Corvallis Environmental Research Laboratory (Mathews 1981) was used to compute the similarity matrix.

The Shannon-Wiener diversity index (H') ($\log_{10}$) and evenness index (J) were calculated for all stations (all replicates pooled), as recommended by EPA procedures. Calculations of these parameters were carried out with Quattro Pro spreadsheet software.

RESULTS

Sediment Parameters

Results of sediment-grain-size analysis are given in Appendix Table A.2. The mean sediment compositions, based on three grain-size categories, at the sampling stations are compared in Figure 3. The grain-size categories (Folk 1968) were as follows: medium and coarse sand, retained on a +2-phi sieve; fine sand, passed through a +2-phi sieve but retained on a +4-phi sieve; and silt and clay, passed through a +4-phi sieve.

Sediments at all stations were generally similar in grain-size distribution, with the exception of Station HB7, which had a higher percentage of medium and coarse sand and a lower percentage of fine sand than the other stations. The sediment at all stations was more than 93% sand (App. Tab. A.2). Replicate sediment samples at all seven stations indicated homogeneity in grain size within stations (App. Tab. A.2).

Direct electrode measurements of ORP (App. Tab. A.2) were positive in the range of +11 to +125 mV. These readings show no evidence of strongly reducing conditions in the surface sediments at any station. There was no statistically significant difference (one-way ANOVA, $F_{7, 14} = 1.6$, n.s.) among the seven stations (App. Tab. A.2) and, hence, no trend that would suggest an increase in reducing conditions in the vicinity of the outfall.

Values for total sediment organic carbon (App. Tab. A.2) were in the range of 414 to 3 260 mg/kg (0.04–0.33%) at all stations. TOC values were highest at three of the stations closest to the outfall diffuser (HB2, HB4, and HZ), yet it was only 790 mg/kg at Station HB3, a station also on the ZID boundary. The highest levels of organic carbon recorded at the Barbers Point stations are still indicative of relatively low organic content.

Biological Parameters

TOTAL NON-MOLLUSK COMPONENT. The non-mollusk fraction of the benthic fauna included polychaetes, oligochaetes, Platyhelminthes, Chaetognatha, sipunculans, echinoderms, a chordate species, amphipods, copepods, cumaceans, decapods, isopods, ostracods, pycnogonids, and tanaidaceans.

The 4 392 non-mollusk specimens counted and identified for all stations and replicates represent a total of 164 taxa. Polychaetes were the dominant non-mollusk taxon both in terms of numbers (2 827 or 64%) and species richness (110 species). Oligochaetes constituted 14% of numerical abundance, with crustaceans contributing an additional 8% of total non-mollusk abundance. The 36 crustacean taxa, 17 of which were amphipods, represented 22% of the total species list. A complete breakdown of each species's abundance in each replicate is provided in Appendix Tables D.1 and D.2.

Basic statistics for the non-mollusk data, including 95% confidence limits and a Kolmogorov-Smirnov test for normality of distribution, are provided in Appendix Tables B.1. (number of individuals) and B.2. (number of species). Data were normal for all stations, except for non-mollusk abundance data at Stations HB1 and HB3 (App. Tab. B.1).

Mean total non-mollusk abundance ranged from 42.1 individuals per sample (9 279/m^2) at Station HB2 to 82.3 individuals per sample (18 139/m^2) at Station HB4 (Fig. 4). The difference between Stations HB4 and HB2 was significant (ANOVA, App. Tab. B.3). No other differences were significant.

The mean number of non-mollusk species per sample ranged from a low of 15.8 species at Station HB2 to a high of only 21.9 species at Station HB6 (Fig. 5). There were no significant differences in mean number of species per sample among stations (ANOVA, App. Tab. B.4).

Composite station diversity (H') and evenness (J) are shown in Figure 6. Patterns of diversity and evenness were highly similar among stations. Both parameters were extremely similar at all stations. Values for H' ranged between 2.89 at Station HB4 and 3.48 at Station HB1. This compares to a similar range of 3.15 to 3.47, which was seen in the samples taken in September 1986 (Nelson et al. 1987). Evenness ranged only between 0.67 (Sta. HB4) and 0.77 (Sta. HB1), comparable to the range of 0.77 to 0.82 observed in the 1986 samples (Nelson et al. 1987). Relative to other stations, there was no pattern of lower diversity or evenness at ZID or near-ZID stations.

Results of cluster analysis indicating the relative similarity of stations based on the 84 most abundant non-mollusk species are shown in Figure 7. Stations formed two clusters at relatively low dissimilarity-index values, indicating that, overall, all stations were fairly similar. In general, the clustering pattern reflected the east-to-west gradient of the station locations. One group consisted of the easternmost stations HB2, HB1, and HB3, and the second of the remaining stations.

Polychaetes. The most worm individuals were found at Station HB4 (556) and the fewest at Station HB3 (271). The stations, ranked in decreasing order according to the abundance of polychaetes, were as follows: HB4, HB7, HZ, HB6, HB2, HB1, and HB3. Polychaetes were the most species rich group at all stations (App. Tab. D.1). The maximum polychaete species richness occurred at Station HB1 (56); the remaining stations, ranked in descending order according to species abundance, were as follows: HB3 (51), HB7 (50), HZ (49), HB2 (46), HB4 (43), and HB6 (43).

The pilargid *Synelmis acuminata*, syllid *Pionosyllis gesae*, hesionid *Podarke angustifrons*, spionid *Prionospio cirrobranchiata*, and oweniid *Myriochele oculata* were the dominant worms at Stations HB4, HZ, and HB1.

TROPHIC CATEGORIES. Trophic categories are based on Fauchald and Jumars (1979) and are summarized in Figures 8, 9, and 10.

Detritivores. Deposit-feeding polychaetes comprised the largest proportion of polychaete abundance at the ZID and near-ZID stations HZ, HB2, HB3, and HB6; they were least represented at Station HB7 (Fig. 8). Among the ZID stations, Station HB4, located on the ZID

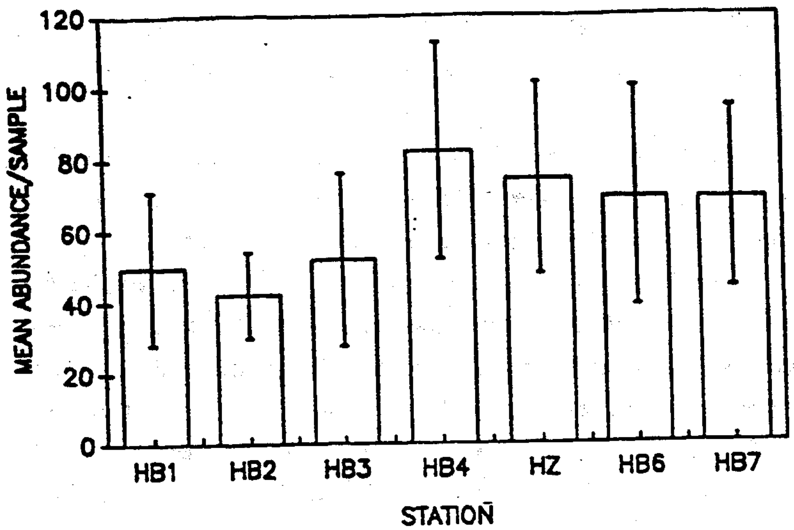

Figure 4. Mean (±1 S.D.) non-mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

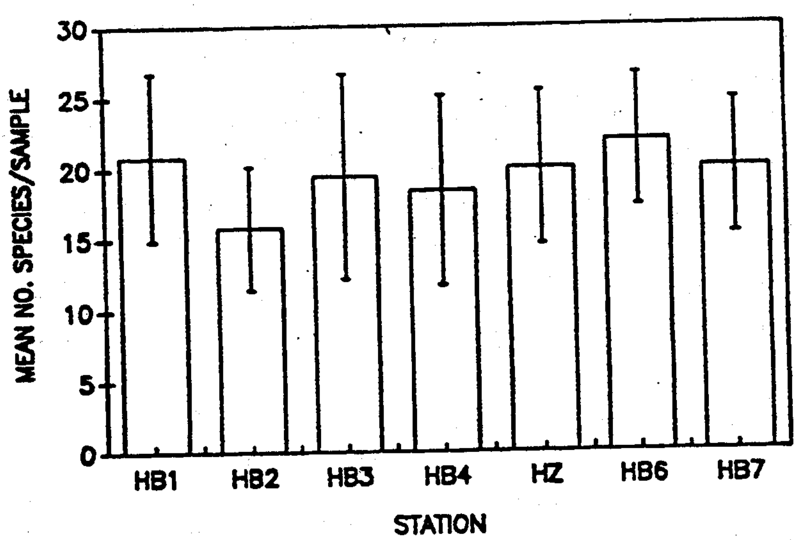

Figure 5. Mean (±1 S.D.) number of non-mollusk species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

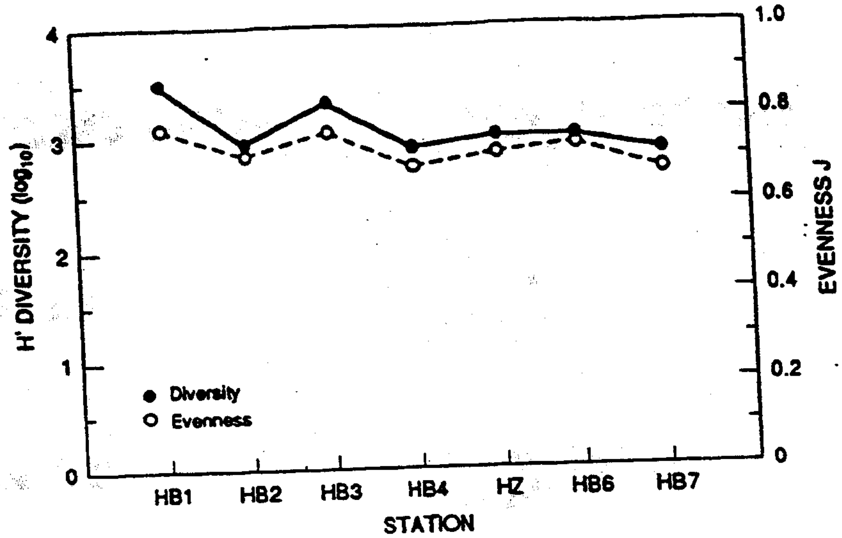

Figure 6. Shannon-Wiener H' diversity (log_{10}) and evenness (J) for non-mollusks, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

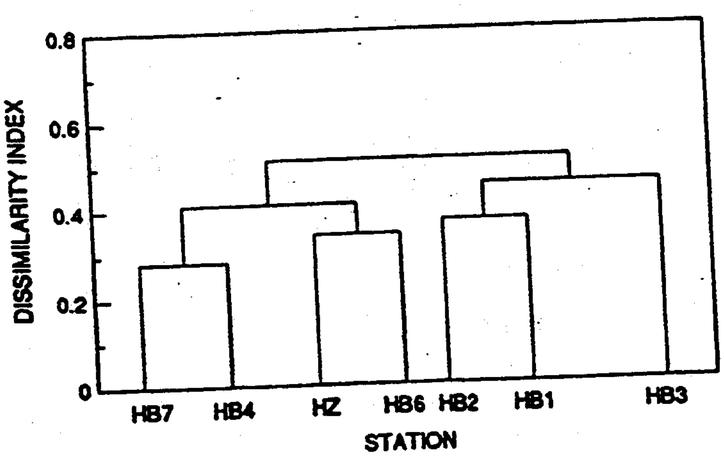

Figure 7. Dendrogram for untransformed non-mollusk data showing dissimilarity among Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

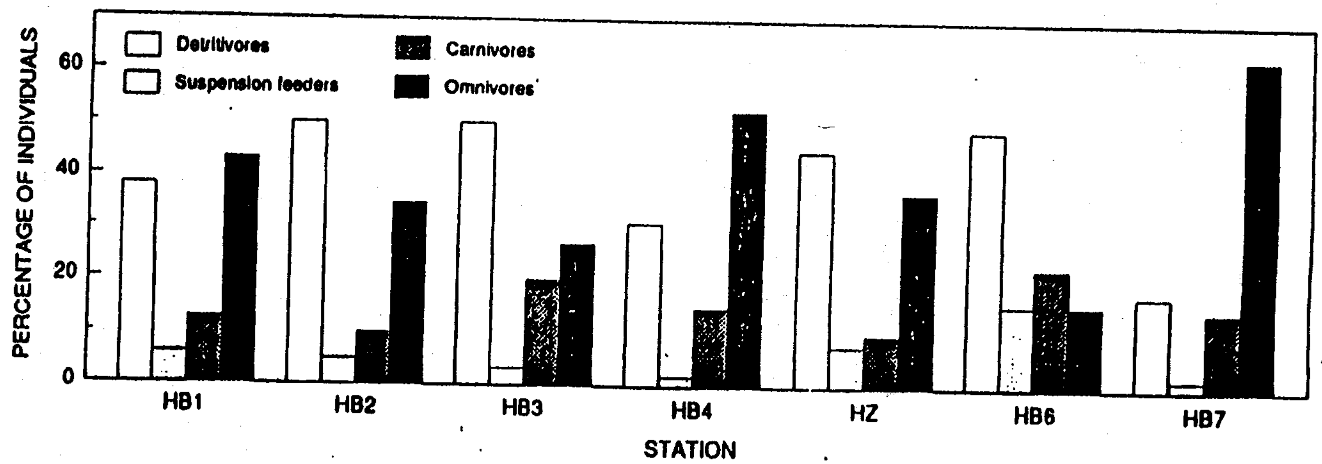

Figure 8. Percentage of total polychaetes in four trophic categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

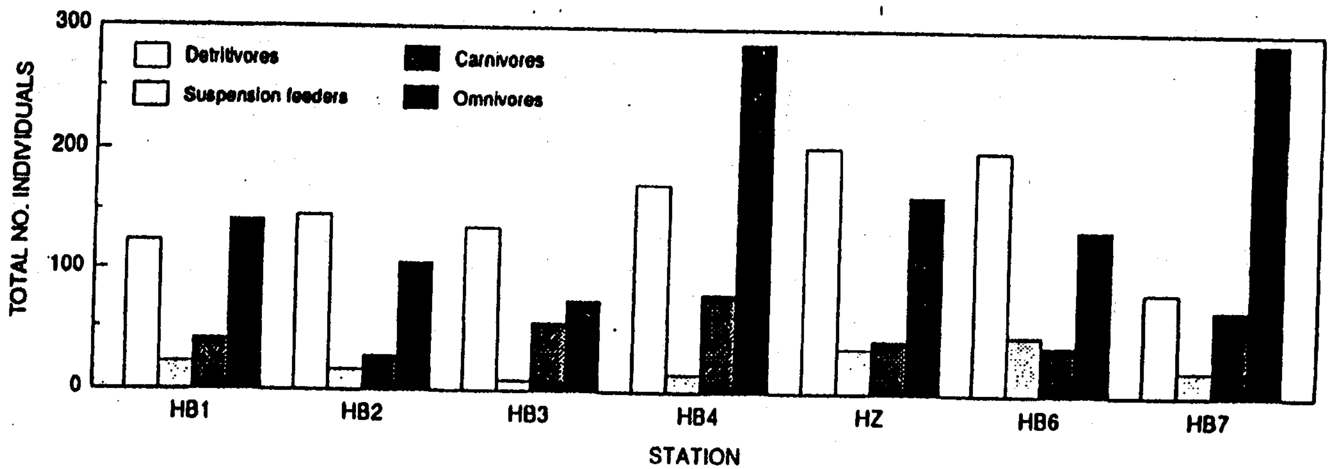

Figure 9. Total number of polychaetes in four trophic categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

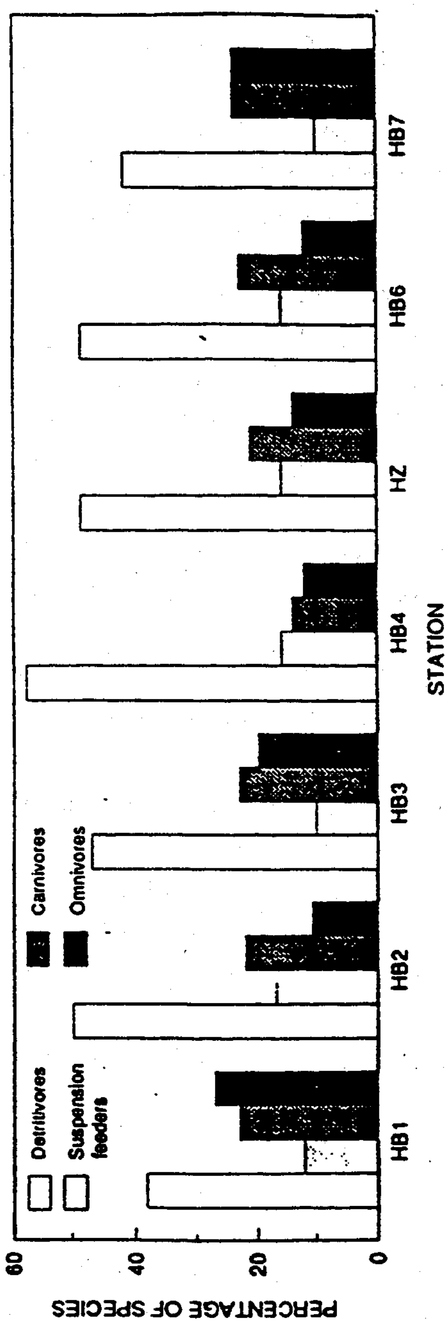

Figure 10. Percentage of polychaete species in four trophic categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

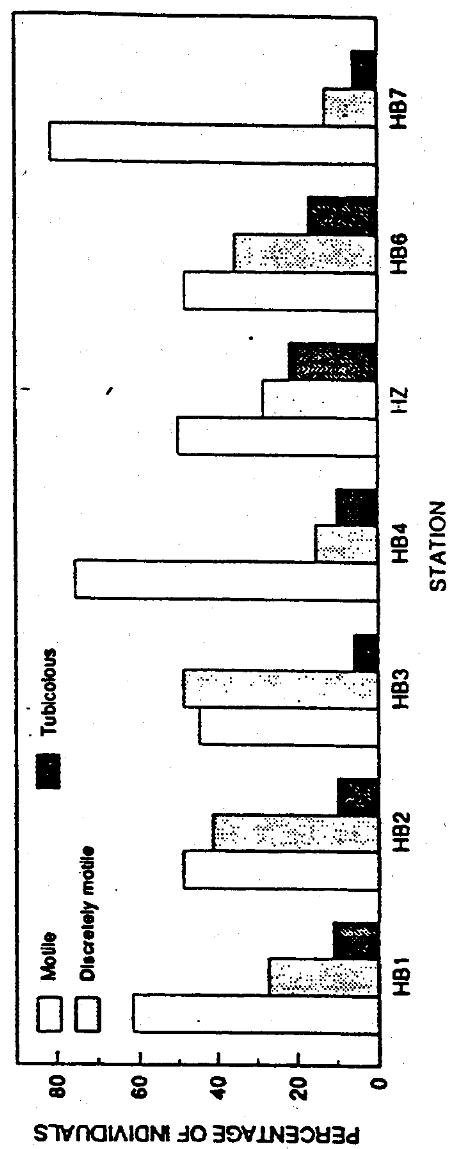

Figure 11. Percentage of total polychaetes in three motility categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

boundary, had the smallest percentage of deposit feeders. The proportion of deposit feeders at the ZID and near-ZID stations was two to three times greater than that at Station HB7, but not at Station HB1. Deposit-feeding patterns were similar when expressed as total number of polychaete individuals (Fig. 9).

The dominant polychaetes in the deposit-feeding category were the oweniids, *Myriochele* spp., and spionids, *Prionospio* spp. In terms of proportion of total number of species, deposit feeders were the most species rich group at all stations, making up from 38 to 58% of the species list (Fig. 10).

Omnivores. In terms of percentage of total polychaetes, omnivorous polychaetes were best represented at Station HB7 (Fig. 8), which is consistent with the results of the 1986 sampling (Nelson et al. 1987 [Sta. HB7 is Sta. F in that report]). In terms of total polychaete abundance, omnivores were most abundant at Stations HB4 and HB7 (Fig. 9). The pilargid *Synelmis acuminata* dominated the omnivorous component at all stations (App. Tab. D.1) and was the most abundant polychaete at all stations except Station HB3, where it ranked second. *Pionosyllis gesae* was the next most abundant omnivore at all stations except Station HB2, where only four specimens were collected. Nereidids were poorly represented, and only one specimen of *Neanthes arenaceodonta* was found.

Suspension Feeders. The highest proportion of suspension feeders (primarily the families Sabellidae and Serpulidae) was found at Station HB6 (Fig. 8). Suspension feeders made up the smallest proportion of the community at all stations.

Carnivores. Carnivorous polychaetes were present at all stations, with maximum proportional representation at Stations HB6 and HB3 (Fig. 8). The percentage of carnivorous species was similar at all stations (Fig. 10). The eunicid complex (Eunicidae, Lumbrineridae, and Onuphidae) and *Podarke angustifrons* comprised most of the carnivorous polychaetes.

MOTILITY CATEGORIES. Motility categories are based on Fauchald and Jumars (1979) and are summarized in Figures 11, 12, and 13.

Communities at Stations HB1, HB4, and HB7 were dominated by motile omnivores, while motile and discretely motile deposit feeders characterized Stations HB2 and HB3 (Figs. 11, 12). Tubicolous suspension-feeding forms were most abundant at Stations HB6 and HZ (Figs. 11, 12), but fewer tubicolous forms were collected in 1990 than in 1986 (Nelson et al. 1987). Overall, fewer polychaetes were collected in 1990 than in 1986.

The largest proportion of motile polychaetes consisted of three species, the pilargid *Synelmis acuminata*, the syllid *Pionosyllis gesae*, and the hesionid *Podarke angustifrons*. The rank order of abundance of these three motile species was the same at all stations except Station HB2, where the order of *P. gesae* and *P. angustifrons* was reversed.

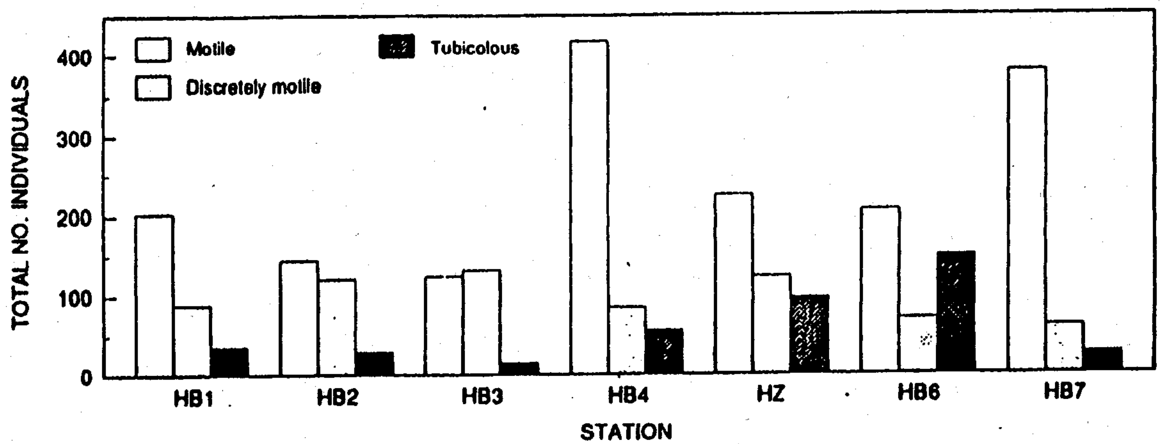

Figure 12. Total number of polychaetes in three motility categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

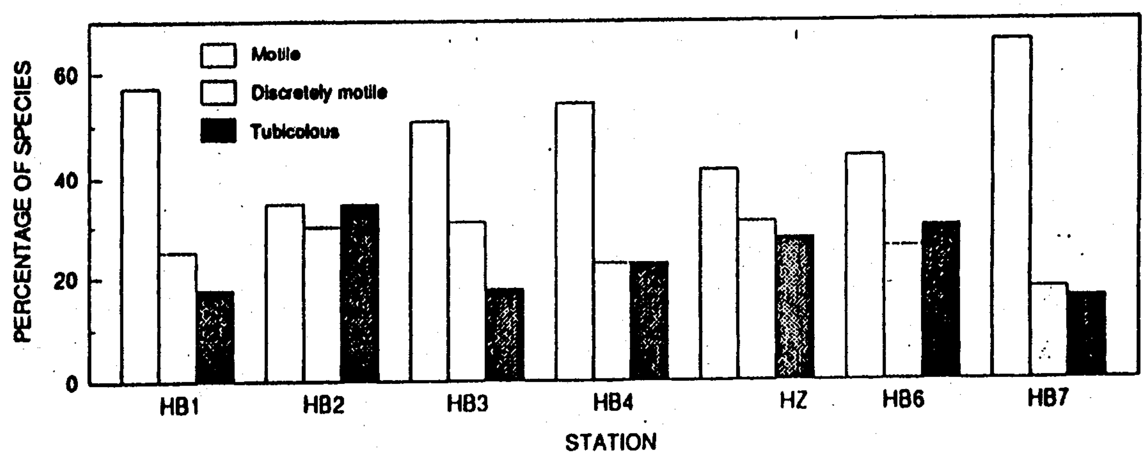

Figure 13. Percentage of polychaete species in three motility categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

The spionids (e.g., *Prionospio cirrobranchiata* and *P. cirrifera*) were the most species rich and numerically dominant family in the discretely motile category. Discretely motile polychaetes made up more than 35% of polychaete abundance at Stations HB3, HB4, and HB6 (Fig. 11).

Tubicolous worms had their largest proportional representation in terms of abundance at Station HZ (Fig. 11). The greatest percentage of species in the tubicolous category was found at Station HB2, where it equaled that of the proportion of motile species (Fig. 13). Sabellids, terebellids, and serpulids were well represented at all stations but never were present in large numbers.

Crustaceans. A total of 328 crustaceans were collected, representing 8% of the non-mollusk abundance (App. Tab. D.2). Mean crustacean abundance (no./sample) ranged from 2.4 (529/m^2) at Station HB2 to 7.9 (1 741/m^2) at Station HB6 (Fig. 14). Variances were homogeneous. There were no significant differences in mean abundance among stations (ANOVA, App. Tab. B.5).

A total of 36 taxa (copepods were not identified to species) of crustaceans were collected, of which 17 species (47%) were amphipods. Mean number of crustacean species ranged from 1.5 (Sta. HZ) to 4.1 (Sta. HB7) (Fig. 15). Variances were homogeneous. There were no significant differences in mean number of crustacean species among stations (ANOVA, App. Tab. B.6).

Tanaidaceans and amphipods were the numerically dominant taxa, making up 34% and 31%, respectively, of total abundance. The tanaids *Leptochelia dubia* and *Leptochelia* sp. were the most abundant species. A complete list of crustacean species abundance for all replicates and stations is given in Appendix Table D.2.

MOLLUSKS. Mean abundance of mollusks per sample (no./10 cm^3) ranged from a low of 117.4 at Station HB6 to a high of 237.2 at Station HB1 (Fig. 16). Data at all stations except Station HB6 were normally distributed (App. Tab. C.2). Complete basic statistics for total mollusk data are shown in Appendix Table C.2. Variances were heterogeneous (App. Tab. C.1.1) and could not be corrected by application of standard transformations. Therefore, the nonparametric Games and Howell test for comparison of means was carried out in lieu of performing an ANOVA.

There were significant differences in mean mollusk abundance among stations (Games and Howell test, App. Tab. C.1.2). Mean abundance was significantly greater at Station HB1 than at the other stations except for Station HZ, and significantly greater at Station HZ than at Station HB6. No other differences in means were significant.

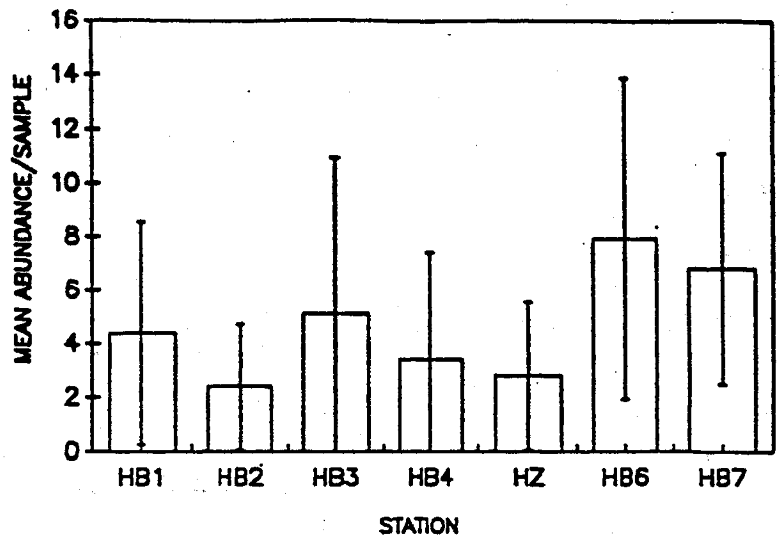

Figure 14. Mean (±1 S.D.) total crustacean abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

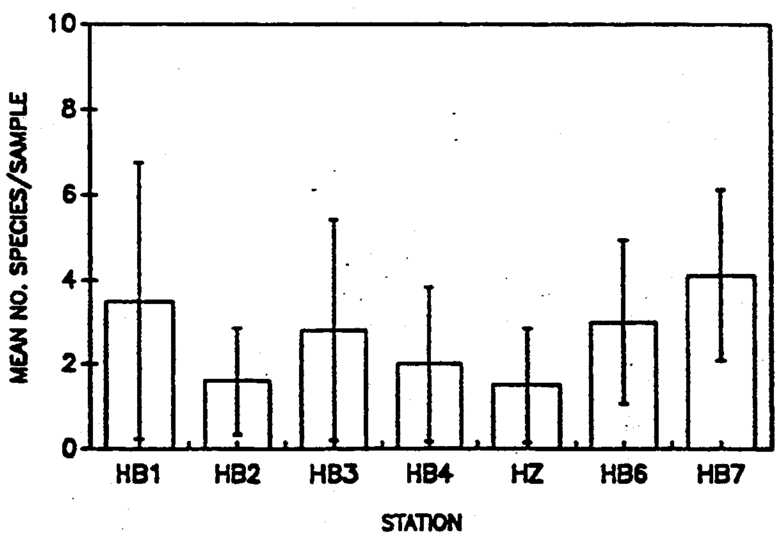

Figure 15. Mean (±1 S.D.) total number of crustacean species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

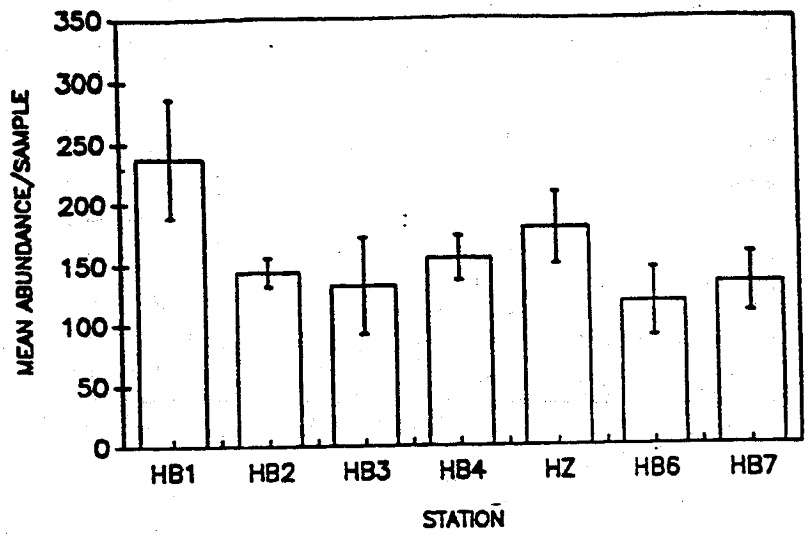

Figure 16. Mean (±1 S.D.) mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

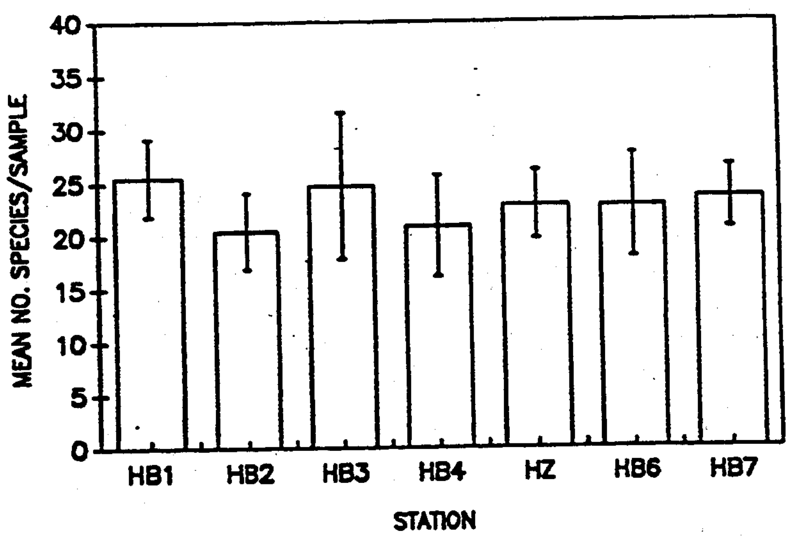

Figure 17. Mean (±1 S.D.) total number of mollusk species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

Mean number of mollusk species per sample ranged from a low of 20.5 at Station HB2 to a high of 25.5 at Station HB1 (Fig. 17). Data at all stations were normally distributed (App. Tab. C.4). Complete basic statistics on number of mollusk species at all stations are shown in Appendix Table C.4. There were no significant differences in mean mollusk species richness among stations (ANOVA, App. Tab. C.3).

H' diversity ranged from a low of 1.96 at Station HB2 to a high of 2.63 at Station HB6 (Fig. 18). Evenness (J) ranged from 0.51 at Station HB2 to 0.65 at Station HB6. Diversity and evenness values for all stations were extremely similar (Fig. 18).

Mollusks were analyzed for abundance distribution among stations according to the following categories: mollusk class (Gastropoda, Bivalvia), trophic type (grazer/parasite, algivore/detritivore, carnivore), and habitat (epifaunal, infaunal). A species list and abundance for all mollusk species for all stations and replicates are shown in Appendix Table E.1.

Gastropoda. The total gastropod component represented 93 to 97% of the total mollusk abundance seen at all stations. Variances were heterogeneous (App. Tab. C.5.1) and could not be corrected by transformation. Mean gastropod abundance (no./10 cm^3) ranged from 109.6 (Sta. HB6) to 231.8 (Sta. HB1) (Fig. 19). There were significant differences in mean gastropod abundances among stations (Games and Howell test, App. Tab. C.5.2). Mean abundance was significantly greater at Station HB1 than at the other stations except for Station HZ, and significantly greater at Station HZ than at Station HB6. No other differences in means were significant.

The gastropod taxa *Balcis* spp., *Cerithidium perparvulum*, *Diala scopulorum*, and *Scaliola* spp. were abundant at all stations. An additional species, *Finella pupoides*, was abundant at Station HZ.

Bivalvia. The total bivalve component represented only 3 to 7% of the total mollusk abundance seen at all stations. Variances were heterogeneous (App. Tab. C.6), but were made homogeneous by square-root transformation. Mean bivalve abundance (no./10 cm^3) ranged from 3.3 (Sta. HB7) to 9.2 (Sta. HB4) (Fig. 20). There were significant differences in mean bivalve abundance among stations (ANOVA, App. Tab. C.6). Bivalve abundance was significantly greater at Stations HB4, HB2, HB6, and HB3 than at Station HB7. No other differences were significant.

Faunal Grazers and Parasites. Mean faunal grazer and parasite abundance (no./10 cm^3) ranged from 14.7 (Sta. HB3) to 30.7 (Sta. HB6) (Fig. 21). Variances were homogeneous (App. Tab. C.7). There were significantly more faunal grazers and parasites at Station HB6 than at all other stations except Station HZ (ANOVA, App. Tab. C.7). No other differences were significant.

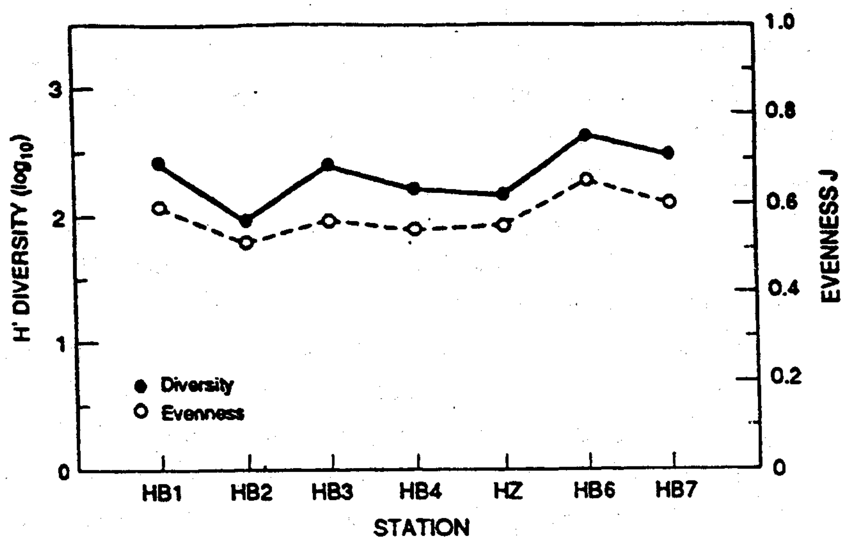

Figure 18. Shannon-Wiener H' diversity (log_{10}) and evenness (J) for mollusks, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

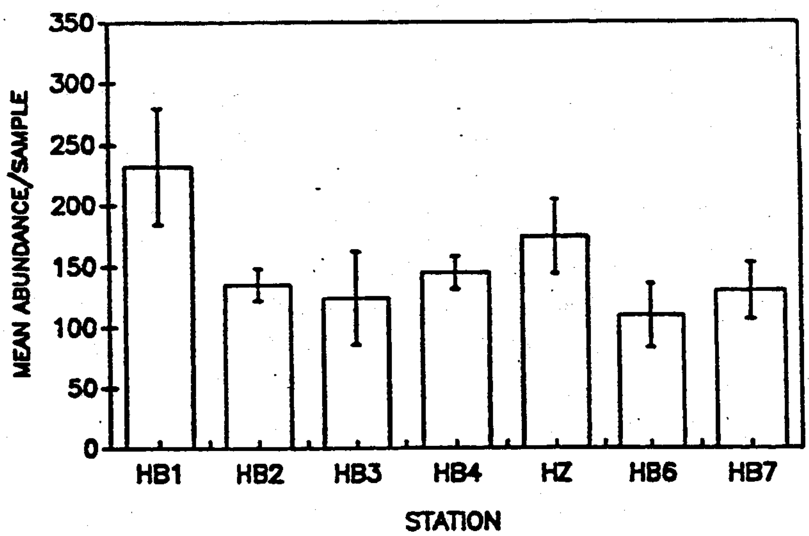

Figure 19. Mean (±1 S.D.) gastropod abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

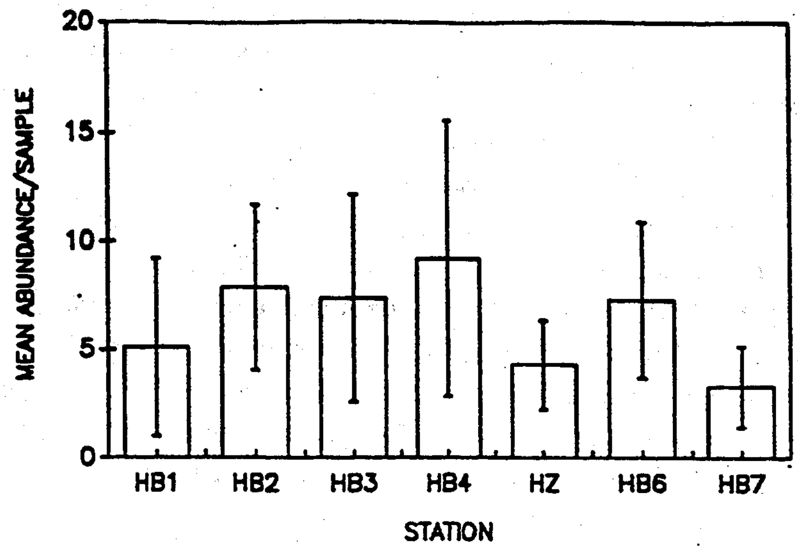

Figure 20. Mean (±1 S.D.) bivalve abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

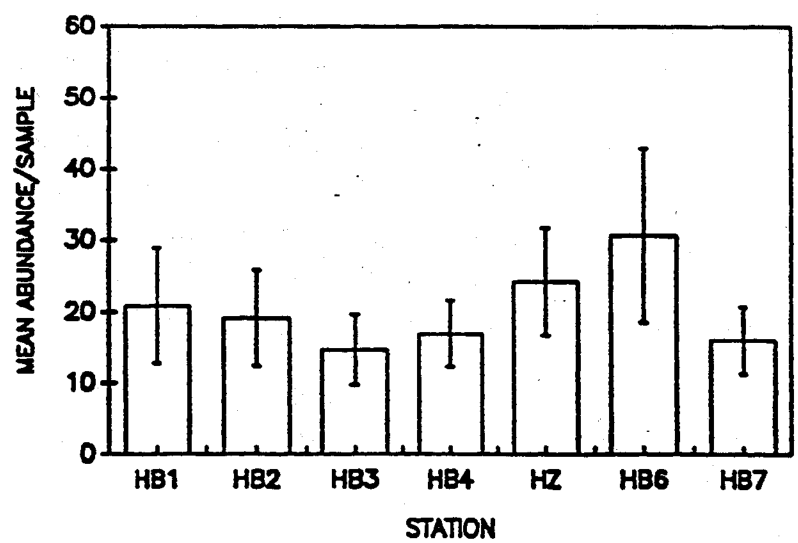

Figure 21. Mean (±1 S.D.) faunal grazer/parasite mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

Faunal grazers were a relatively minor constituent of this mollusk category at all stations, making up only 1% or less of total mollusk abundance at most stations. Parasites made up a maximum of 25% of mollusk abundance at Station HB6, while at all other stations, the percentage was approximately 10%. The dominant parasite taxon was *Balcis* spp.

Algivores and Detritivores (A/D). Mean A/D abundance (no./10 cm^3) ranged from 74.6 (Sta. HB6) to 208.2 (Sta. HB1) (Fig. 22). Variances were heterogeneous (App. Tab. C.8.1) and could not be corrected by standard transformations. Mean A/D abundance differed significantly among stations (Games and Howell test, App. Tab. C.8.2). A/D abundance was significantly higher at Station HB1 than at all other stations except Station HZ, and significantly greater at Stations HZ, HB4, and HB2 than at Station HB6. No other differences were significant.

Algivores represented a very small portion of the A/D mollusk category, constituting 1% or less of total mollusk abundance at all stations. *Cerithidium perparvulum*, *Diala scopulorum*, and *Scaliola* spp., all epifaunal detritivorous gastropods, were very abundant at all stations.

Carnivores. Mean carnivore abundance (no./10 cm^3) ranged from 1.9 (Sta. HB7) to 8.9 (Sta. HB2) (Fig. 23). Variances were homogeneous (App. Tab. C.9). Mean carnivore mollusk abundance differed significantly among stations (ANOVA, App. Tab. C.9). Carnivore abundance at Station HB2 was significantly greater than at all other stations; abundance at Station HZ was greater than at Stations HB4 and HB7; and abundance at Station HB6 was greater than at Station HB7 (SNK test, App. Tab. C.9).

Carnivorous mollusks represented between 1.2% (Sta. HB7) and 6.2% (Sta. HB2) of total mollusk abundance. No trend in this parameter relative to station location was observed.

Epifaunal Mollusks. Mean epifaunal mollusk abundance (no./10 cm^3) ranged from 49.4 (Sta. HB6) to 174.2 (Sta. HB1) (Fig. 24). Variances were heterogeneous (App. Tab. C.10), but were corrected by square-root transformation. Mean epifaunal mollusk abundance differed significantly among stations (ANOVA, App. Tab. C.10). Epifaunal mollusk abundance was significantly greater at Station HB1 than at all other stations (SNK test, App. Tab. C.10). Abundance at Station HB6 was less than at all other stations. No other differences among stations were significant.

Epifaunal species made up the great majority of mollusks at most stations. The gastropod taxa *Balcis* spp., *Cerithidium perparvulum*, *Diala scopulorum*, and *Scaliola* spp. were the dominant epifaunal mollusk species at all stations. *Finella pupoides* was also abundant at Station HZ.

Infaunal Mollusks. Mean infaunal mollusk abundance (no./10 cm^3) ranged from 21.4 (Sta. HB7) to 52.8 (Sta. HZ) (Fig. 25). Variances were homogeneous (App. Tab. C.11). Mean infaunal mollusk abundance differed significantly among stations (ANOVA, App. Tab. C.11). There were significantly more infaunal mollusks at Station HZ than at all other stations except

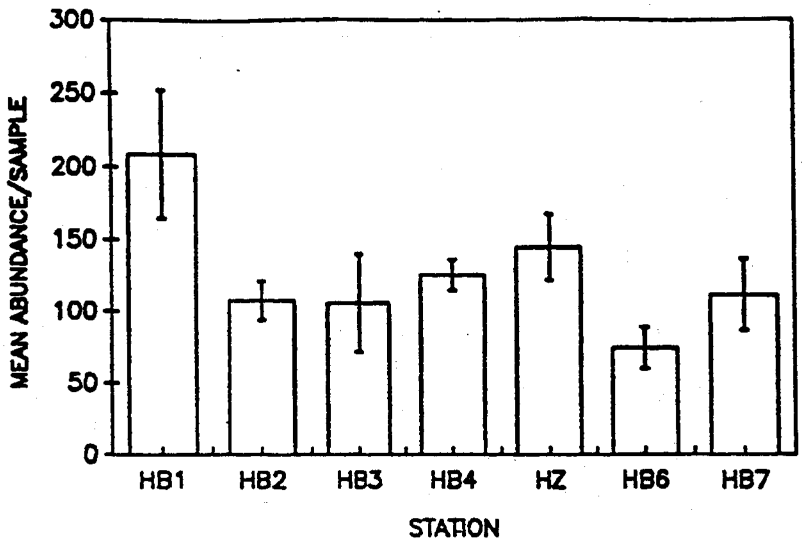

Figure 22. Mean (±1 S.D.) algivore/detritivore mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

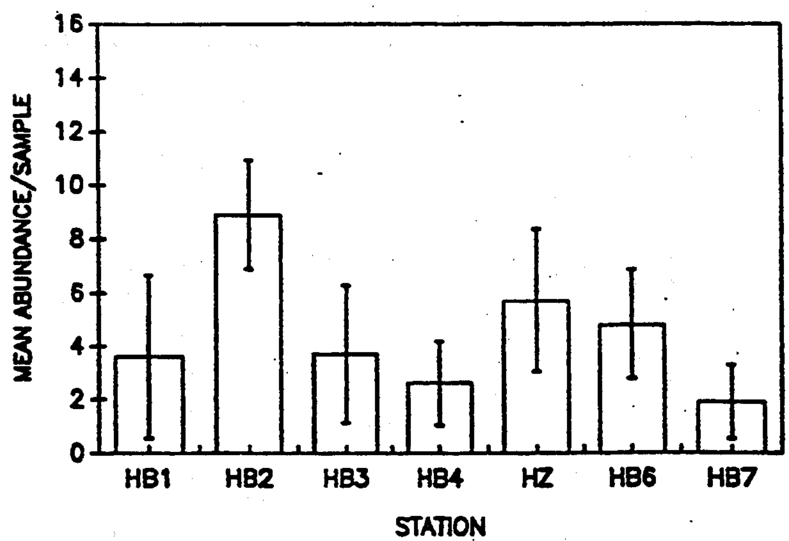

Figure 23. Mean (±1 S.D.) carnivore mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

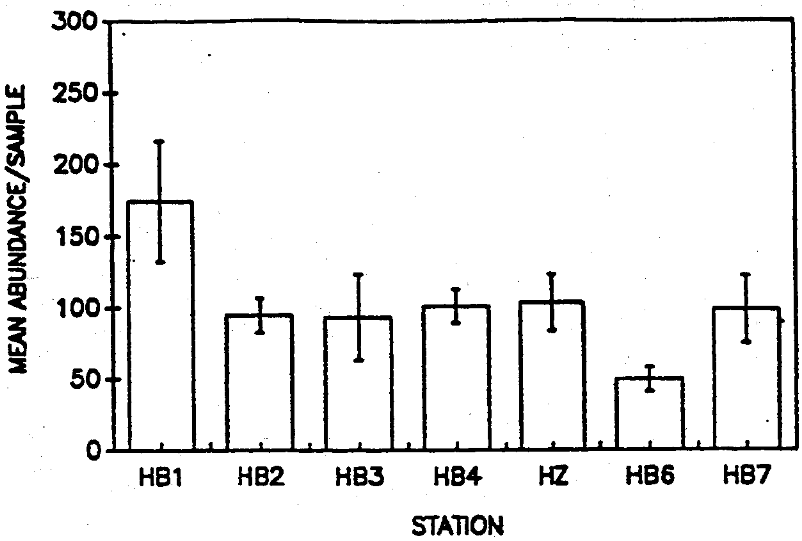

Figure 24. Mean (±1 S.D.) epifaunal mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

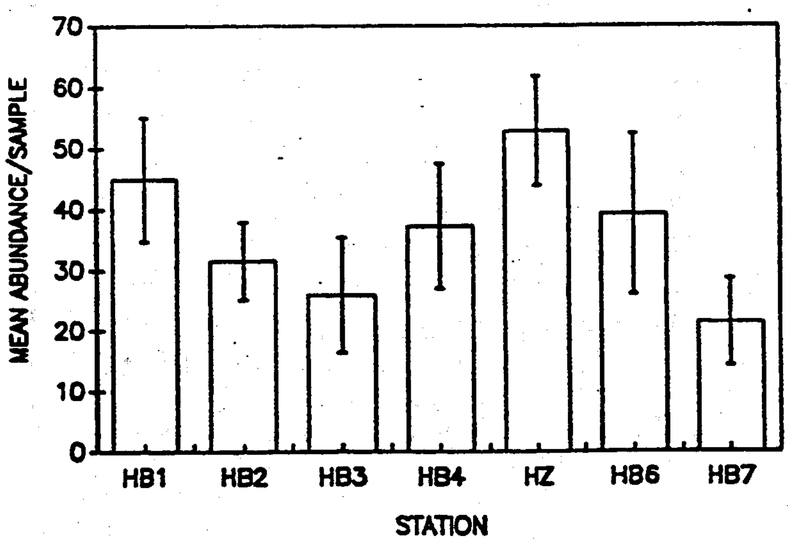

Figure 25. Mean (±1 S.D.) infaunal mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1990

Station HB1 (SNK test, App. Tab. C.11). Other groupings of stations were broadly overlapping in terms of significant differences (App. Tab. C.11).

DISCUSSION

There was no clear pattern of macrofaunal abundance that could be related to the effects of the outfall diffuser. The western ZID-boundary station (Sta. HB4) had significantly more non-mollusk individuals than the eastern ZID-boundary station (Sta. HB2). Since no other stations differed significantly from one another, there was little evidence of significant spatial heterogeneity in non-mollusk macrobenthic abundance. The difference observed does not point to an effect of the outfall.

There were no significant differences among stations in terms of mean numbers of non-mollusk species per core. Diversity and evenness values were extremely similar at all stations. Thus, there is no evidence that the outfall is having any effect on species richness of the non-mollusk macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray-Curtis dissimilarity index suggested that the abundance and species composition at all stations was generally similar, although there was some suggestion of separation of stations along an east-west gradient. Cluster analysis of the 1986 stations showed no discernible pattern in the grouping of stations (Nelson et al. 1987); and ZID and near-ZID stations were not grouped together in either 1986 or 1990. Cluster analysis therefore indicates that the outfall has not had a discernible effect on community composition of the non-mollusk component of the benthos.

As was the case in the 1986 study, sediment-grain sizes generally were quite similar among stations. The percentage of fine sediments at the ZID and ZID-boundary stations showed no increase from 1986. Sediment oxidation-reduction potential showed no evidence of reducing sediment conditions at the surface of sediments at any station. There was no evidence of a trend in sediment "oil and grease" values related to effects of the diffuser. Sediment organic content was relatively higher at some ZID stations (Stas. HB2, HB4, HZ), but not all (Sta. HB3). However, maximum sediment organic content (0.33%) constitutes a relatively low value within a range typical for sandy sediments. As an example of the potential range of values, extremely high organic loadings such as those found near fish farms may typically fall in the range of 20 to 40% (measured as loss on ignition*).

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*E. Bonsdorff: personal communication.

July 1991 Benthic Monitoring Program Results

(Nelson et al., 1992)

BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O'AHU, HAWAI'I, JULY 1991

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SPECIAL REPORT 04.08:92

April 1992

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(1987, App. D). Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained by CCH for six years.

Data Analysis

All data were tested for assumptions of normality (Kolmogorov-Smirnov test) and heterogeneity of variances (F_{max} test) prior to statistical analysis (Sokal and Rohlf 1981). Corrections to heterogeneity of variances were achieved by square-root or $\log_{10}$ transformation. Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following ANOVA, the a posteriori Student-Newman-Keuls (SNK) test was used to determine which differences among stations were significant.

An overall comparison of species composition among stations was carried out using cluster analysis (Pielou 1984). The Bray-Curtis similarity index (Bloom 1981) on untransformed data was performed using the flexible sorting strategy. To make the analysis more manageable, only those nonmollusk species that contributed at least 0.09% of the total abundance were included in the analysis. As a result of adhering to this criterion, only species represented by a total of more than three individuals were included in the analysis, and the analysis data set was reduced from 162 to 95 species. The Cluster program developed by the EPA Corvallis Environmental Research Laboratory (Mathews 1981) was used to compute the similarity matrix.

The Shannon-Wiener diversity index (H') ($\log_{10}$) and evenness index (J) were calculated for all stations (all replicates pooled), as recommended by EPA procedures. Calculations of these parameters were carried out with Quattro Pro spreadsheet software.

RESULTS

Sediment Parameters

Results of sediment-grain-size analysis are given in Appendix Table A.2. The mean sediment compositions, based on three grain-size categories, at the sampling stations are compared in Figure 3. The grain-size categories (Folk 1968) were as follows: medium and coarse sand, retained on a +2-phi sieve; fine sand, passed through a +2-phi but retained on a +4-phi sieve; and silt and clay, passed through a +4-phi sieve.

Sediments at all stations were generally similar in grain-size distribution, although both Stations HB3 and HB7 had a higher percentage of medium and coarse sand and a lower percentage of fine sand than the other stations. The sediment at all stations was more than 93% sand (App. Tab. A.2). Replicate sediment samples at all seven stations indicated homogeneity in grain size within stations (App. Tab. A.2).

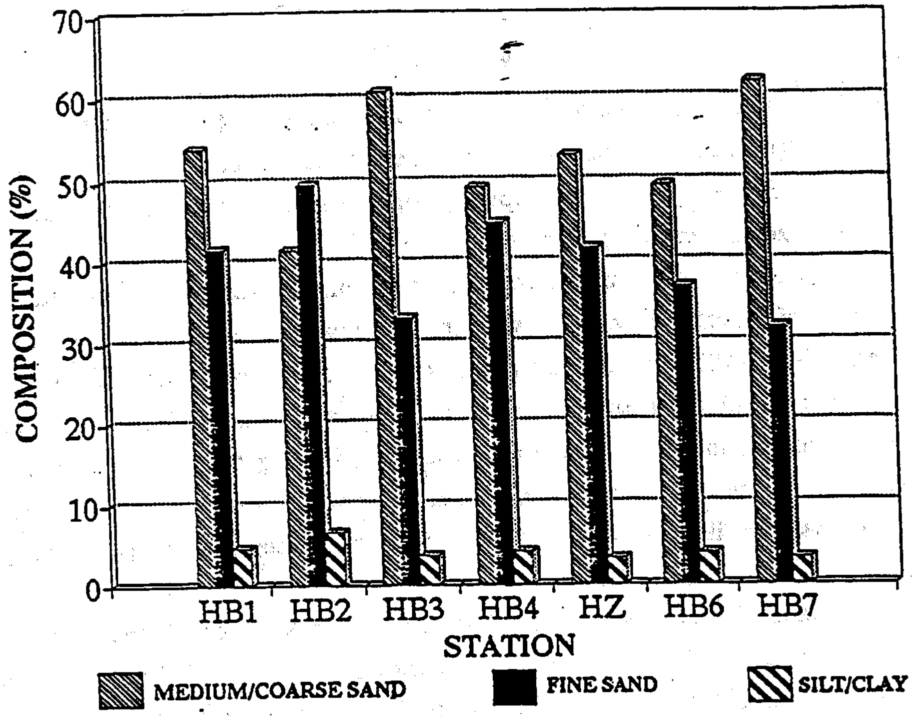

Figure 3. Sediment-grain-size characteristics, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

Direct electrode measurements of ORP (App. Tab. A.3) were positive in the range of +24 to +187 mV. These readings show no evidence of strongly reducing conditions in the surface sediments at any station. There was a statistically significant difference (one-way ANOVA, $F_{6,14} = 5.6$, n.s.) among the seven stations (App. Tab. A.3). ORP values at Station HB7 were significantly higher than at all other stations. Sediment oil and grease (O&G) values were in the range of 149 to 616 mg/dry kg (App. Tab. A.3). Mean O&G values showed no trend in relation to the diffuser, with values at stations near the diffuser being similar to those at reference stations. For example, maximum values were obtained at Station HB7, a farfield reference site, and Station HB2, a ZID-boundary site. Sediment cyanide concentrations were below the limit of detection (0.5 mg/kg) for all replicates from all stations (App. Tab. A.3.).

Values for sediment TOC (App. Tab. A.3) were in the range of less than 0.05% to 0.33% at all stations. TOC values were highest at Stations HB1 and HB6, both reference stations. There was thus no pattern of elevation of TOC at the ZID and ZID-boundary stations. The highest levels of TOC recorded at the Barbers Point stations are still indicative of relatively low organic content.

Biological Parameters

TOTAL NONMOLLUSK COMPONENT. The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, sipunculans, echinoderms, nematodes, nemerteans, priapulids, phoronids, a chordate species, amphipods, copepods, cumaceans, decapods, isopods, ostracods, pycnogonids, and tanaidaceans.

The 4,227 nonmollusk specimens counted and identified for all stations and replicates represent a total of 162 taxa. Polychaetes were the dominant nonmollusk taxon both in terms of abundance (1,692 or 40%) and species richness (92 species). Nematodes were the second most dominant nonmollusk taxon in terms of abundance (27.6%). Oligochaetes constituted 14% of numerical abundance, with crustaceans contributing an additional 17% of total nonmollusk abundance. The 51 crustacean taxa, 21 of which were amphipods, represented 13% of the total species list. Abundance estimates for each species in each replicate are given in Appendix Tables D.1 and D.2.

Basic statistics for the nonmollusk data, including 95% confidence limits and a Kolmogorov-Smirnov test for normality of distribution, are provided in Appendix Tables B.1 (number of individuals) and B.2 (number of species). Data were normal for all stations. Variances were heterogeneous for number of species (App. Tab. B.2), and $\log_{10}$ transformation of the data was carried out before analysis.

Mean total nonmollusk abundance ranged per sample from 28.2 individuals (6,215/m^2) at Station HB3 to 165.4 individuals (36,454/m^2) at Station HB4 (Fig. 4). There were significant differences in mean abundance among stations (ANOVA, App. Tab. B.3). Station HB3 had significantly fewer individuals than did Stations HB4, HB6, HB1, and HB2 (SNK test, App. Tab. B.3). No other differences were significant.

The mean number of nonmollusk species per sample ranged from a low of 14.6 species at Station HB3 to a high of 45.6 species at Station HB6 (Fig. 5). There were significant differences in mean number of species per sample among stations (ANOVA, App. Tab. B.4). Station HB3 had significantly fewer nonmollusk species than all other stations. No other differences were significant.

Composite station diversity (H') and evenness (J) are shown in Figure 6. Patterns of variation in diversity and evenness were highly similar among stations. Values for both parameters were similar at all stations. Values for H' ranged between 2.57 at Stations HB2 and HB4 and 3.89 at Station HB6. This range of values was extremely similar to that for samples taken in 1990 (Nelson et al. 1991). Evenness ranged between 0.62 (Stas. HB2, HB4) and 0.82 (Sta. HB6). This range of values was also comparable to that observed in previous

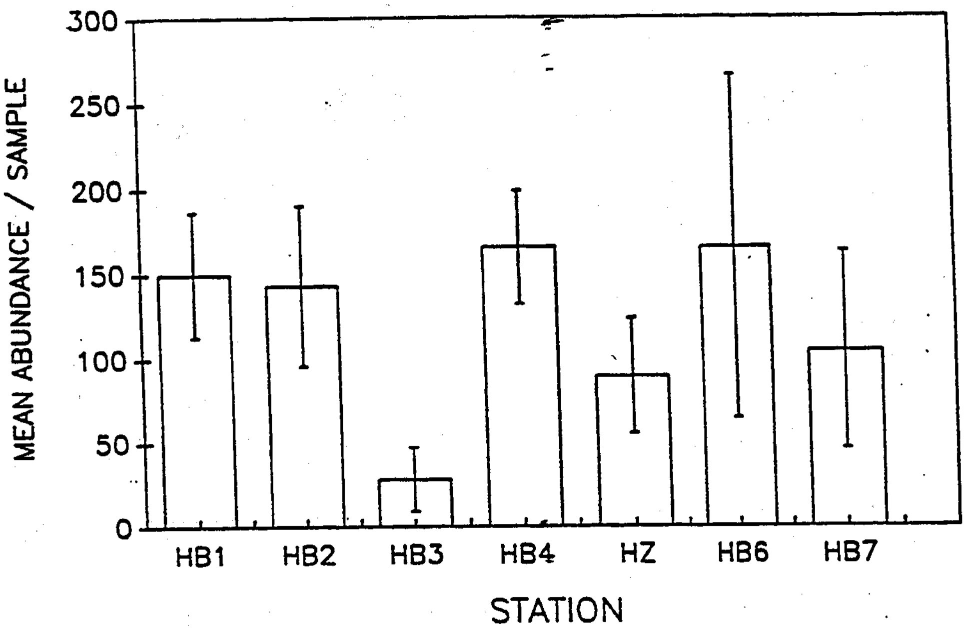

Figure 4. Mean (±1 S.D.) nonmollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

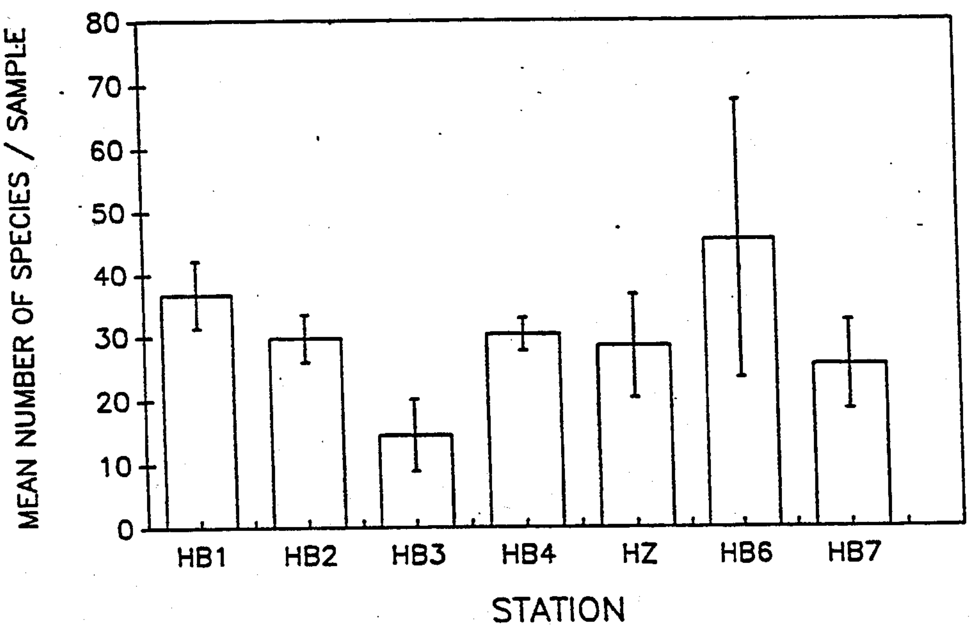

Figure 5. Mean (±1 S.D.) number of nonmollusk species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

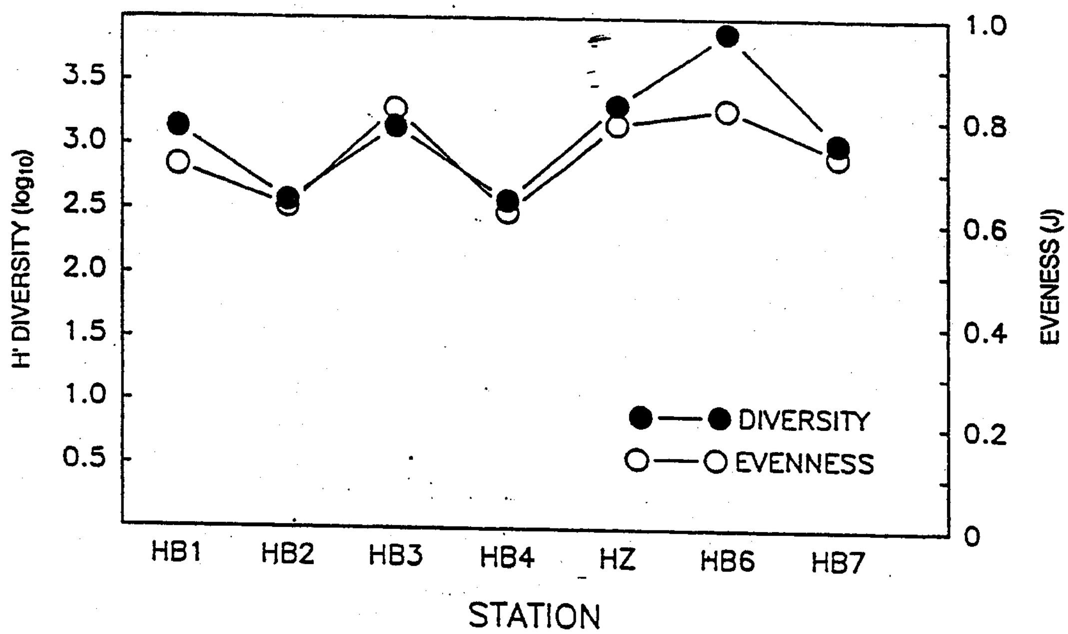

Figure 6. Shannon-Wiener H' diversity (log_{10}) and evenness (J) for nonmollusks, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

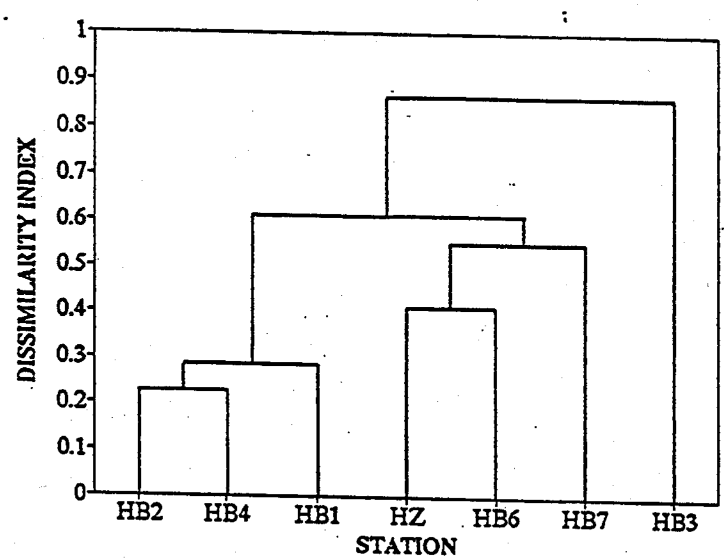

Figure 7. Dendrogram for untransformed nonmollusk data showing dissimilarity among Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

samples (Nelson et al. 1987, 1991). Relative to other stations, there was no pattern of lower diversity or evenness at ZID or near-ZID stations.

Results of cluster analysis indicating the relative similarity of stations based on the 95 most abundant nonmollusk species are shown in Figure 7. Stations clustered in three groups. There was some suggestion in the clustering pattern of the east-to-west gradient of station locations. One group included the eastern Stations HB1 and HB2, plus Station HB4, while the second consisted of Stations HZ, HB6, and HB7. The spatial pattern of stations was not perfect since Station HB4 lies to the west of Station HZ. Station HB3 showed little similarity to the other stations (Fig. 7).

POLYCHAETE AND MISCELLANEOUS INVERTEBRATE COMPONENT. Polychaetes were the dominant taxon both in terms of numbers (1,692) and species richness (92 species). Abundance of all taxa in this component was greatest at Station HB4 but most speciose at Station HB6, while the polychaetes were most abundant and species rich at Station HB6. A complete breakdown of each taxon's abundance in each replicate is provided in Appendix Tables D.1.1 to D.1.7.

Polychaetes. The most polychaetes were found at Station HB6 (329) and the fewest at HB3 (74). The stations, ranked in decreasing order according to the abundance of polychaetes, were as follows: HB6, HB1, HB4, HB7, HZ, HB2, and HB3. Polychaetes were the most species rich taxon at all stations (App. Tabs. D.1.1–D.1.7). The maximum polychaete species richness occurred at Station HB6 (63). The remaining stations, ranked in descending order according to species abundance, were as follows: HB1 (51), HB4 (45), HZ (42), HB7 (39), HB2 (37), and HB3 (32).

Dominant polychaetes were the pilargid *Synelmis acuminata* at Station HB7, the syllid *Pionosyllis gesae* at Stations HB1 and HB4, the sabellids *Augeneriella dubia* at Station HB3 and *Fabricia* sp. A at Station HB2, and the oweniid *Myriochele oculata* at Stations HB6 and HZ.

Trophic Categories. Trophic and motility categories are based on Fauchald and Jumars (1979).

Detritivores. Deposit-feeding polychaetes were most abundant and speciose at Station HB6 and were about equally distributed at ZID (four stations with 334 polychaetes) and non-ZID (three stations with 300 polychaetes) stations.

The dominant polychaetes in the deposit-feeding category were the oweniids *Myriochele* spp. and the spionids *Prionospio* spp. and *Polydora normalis*.

The detritivores comprised the most species at all stations when compared to the number of species in the other three trophic categories.

Omnivores. In terms of percentage of total polychaetes, omnivorous worms were best represented at Station HB7, which is consistent with the results of the 1986 and 1990 surveys (Nelson et al. 1986, 1990). In terms of total polychaete abundance, omnivores were most abundant at Station HB7, with the pilargid *Synelmis acuminata* dominating the omnivorous component. *Pionosyllis gesae* was the most abundant omnivore at Stations HB1 and HB4. Nereids were poorly represented; only one specimen was found at Stations HB3 and HB4 while two were collected at Station HB6.

Suspension Feeders. The highest numbers of suspension feeders (primarily the families Sabellidae and Serpulidae) were found at Stations HB4 and HB6, with Station HB6 the most speciose. Suspension feeders made up the smallest proportion of the community at all stations except Stations HB4 and HZ, where carnivores were the least abundant trophic group.

Carnivores. Carnivorous polychaetes were present at all stations, with maximum proportional representation at Stations HB1 and HB7. The percentages of carnivorous species were similar at all stations. The eunicid complex (Eunicidae, Lumbrineridae, Onuphidae, Dorvilleidae) and the amphinomid *Linopherus microcephala* comprised most of the carnivorous polychaetes.

Motility Categories. Tubicolous suspension feeding worms dominated the polychaete fauna at Stations HB2 (*Fabricia* sp. A, with 25) and HB3 (*Augeneriella dubia*, with 10). The tubicolous deposit feeder *Myriochele oculata* predominated at Stations HB6 (44) and HZ (32). Motile omnivores predominated at Stations HB7 (*Synelmis acuminata*, with 101), HB1 (*Pionosyllis gesae*, with 44), and HB4 (*P. gesae*, with 28).

The spionids (e.g., *Prionospio cirrobranchiata*, *P. cirrifera*, and *Polydora normalis*) were the most species rich and numerically dominant family in the discretely motile category. Discretely motile polychaetes made up the second largest polychaete motility category at all stations.

Tubicolous worms had their largest proportional representation in terms of abundance at Stations HB4 (105) and HB6 (104). The greatest percentage of tubicolous species was found at Station HB6. Sabellids, terebellids, and serpulids were well represented at all stations, but were never present in large numbers.

CRUSTACEANS. A total of 725 crustaceans were collected. Mean crustacean abundances (no./sample) ranged from 2.2 (485/m^2) at Station HB3 to 62.2 (13,709/m^2) at Station HB6 (Fig. 8). Variances were heterogeneous but made homogeneous with $\log_{10}$ transformation. There were significant differences in mean abundance of crustaceans among stations (ANOVA, App. Tab. B.5). Station HB3 had significantly fewer crustaceans than all other stations. Station HZ had significantly lower abundance than Station HB6. No other differences were significant.

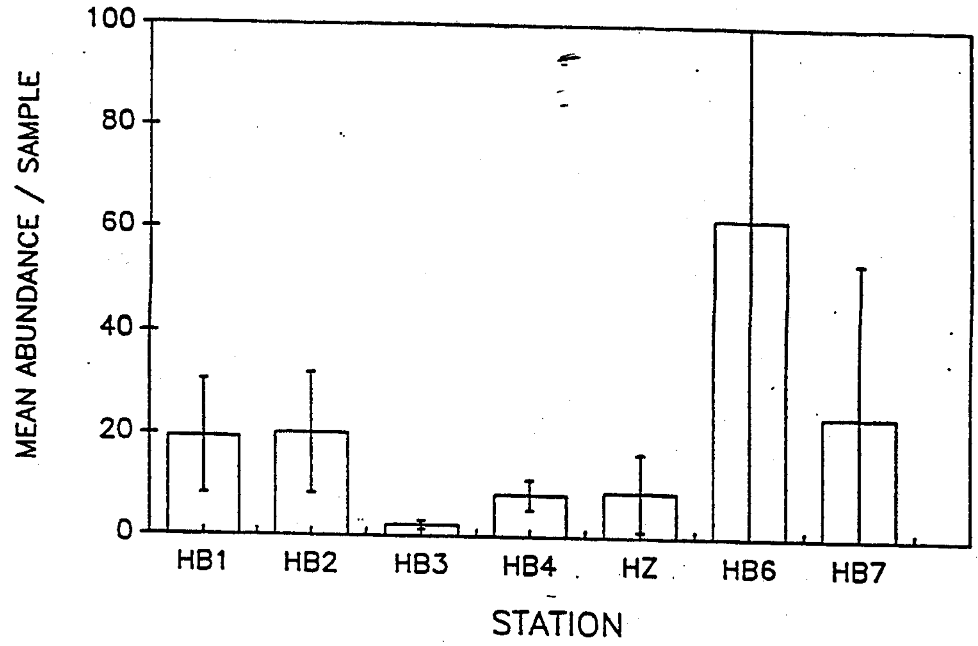

Figure 8. Mean (±1 S.D.) total crustacean abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

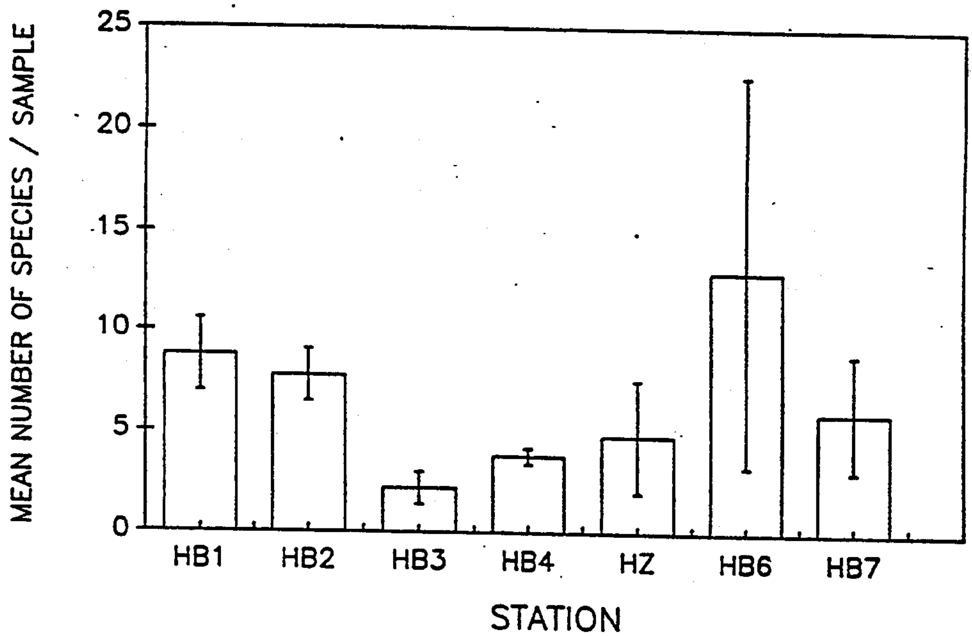

Figure 9. Mean (±1 S.D.) total number of crustacean species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

A total of 51 taxa (copepods were not identified to the species level) of crustaceans were collected, of which 21 species (51%) were amphipods. Mean number of crustacean species ranged from 2.2 (Sta. HB3) to 13.0 (Sta. HB6) (Fig. 9). Variances were heterogeneous but made homogeneous with square-root transformation. There were significant differences in mean number of crustacean species among stations (ANOVA, App. Tab. B.6). Station HB3 had significantly fewer species than Stations HB6, HB1, and HB2. Both Stations HB4 and HZ had fewer crustacean species than Station HB6. No other differences were significant.

Amphipods, tanaidaceans, and isopods were the numerically dominant taxa, comprising 50%, 20%, and 20%, respectively, of total crustacean abundance. The tanaid *Leptochelia dubia* and the amphipod *Eriopisella sechellensis* were the most abundant species at most stations. The amphipods *Gammaropsis pokipoki* and *Elasmopus piikoi* were abundant at Stations HB6 and HB7, respectively.

The meiofaunal isopod genera *Microcharon* and *Caecianiropsis* were collected at two stations. However, because samples were sorted on a 0.5-mm screen, collection of meiofauna was inadequate. Crustacean meiofaunal species are generally poorly represented in Hawaiian nearshore benthic communities, in contrast to continental shelf areas, so the discovery of these two genera is especially interesting. Decapods were present at these sites, but the small size (7.6 cm in diameter) of the subsamples taken from the Van Veen grabs precluded any accurate inventory or the showing of any pattern among stations. As in earlier years, some numbers of copepods were also found at these stations. Copepod specimens were not identified below the subclass; some appeared to be planktonic forms. A complete list of crustacean species abundance for all replicates and stations is given in Appendix Table D.2.

MOLLUSKS. Mean abundance of mollusks per sample (no./10 cm^3) ranged from a low of 80.2 at Station HB6 to a high of 174.6 at Station HB4 (Fig. 10). Data at all stations were normally distributed (App. Tab. C.2). Complete basic statistics for total mollusk data are shown in Appendix Table C.2. Variances were homogeneous (App. Tab. C.3).

There were significant differences in mean mollusk abundance among stations (ANOVA, App. Tab. C.3). Mean abundance was significantly greater at the other stations than at Stations HB3 and HB6, which did not differ significantly from each other. No other differences in means were significant.

Mean number of mollusk species per sample ranged from a low of 16.4 at Station HB6 to a high of 32.2 at Station HB7 (Fig. 11). Data at all stations were normally distributed (App. Tab. C.2). Complete basic statistics on number of mollusk species at all stations are shown in Appendix Table C.2. Variances were heterogeneous (App. Tab. C.4) and could not be corrected by application of standard transformations. Therefore, the nonparametric Games and Howell test for comparison of means was carried out in lieu of performing an ANOVA. There

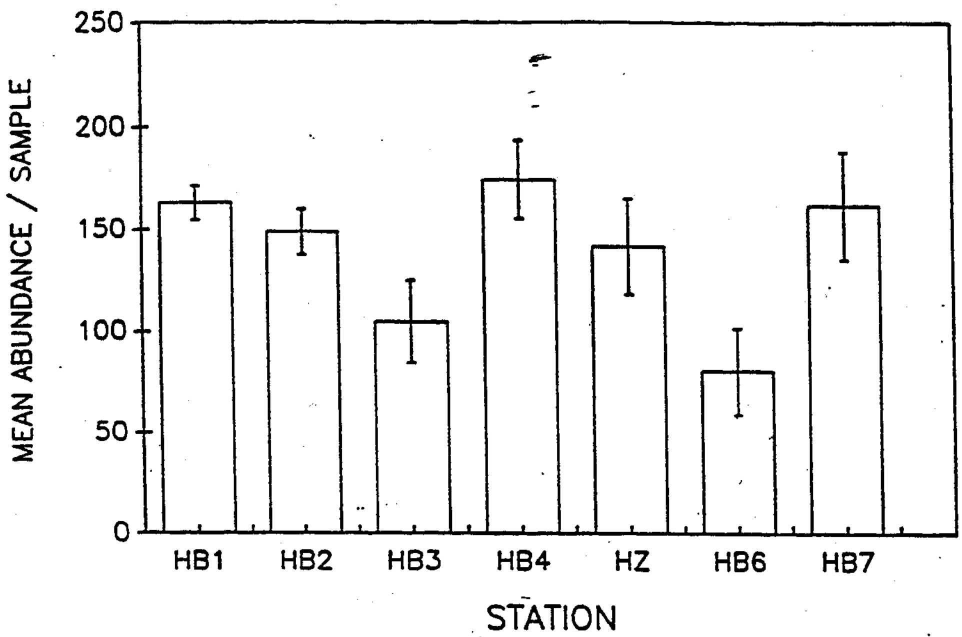

Figure 10. Mean (±1 S.D.) mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

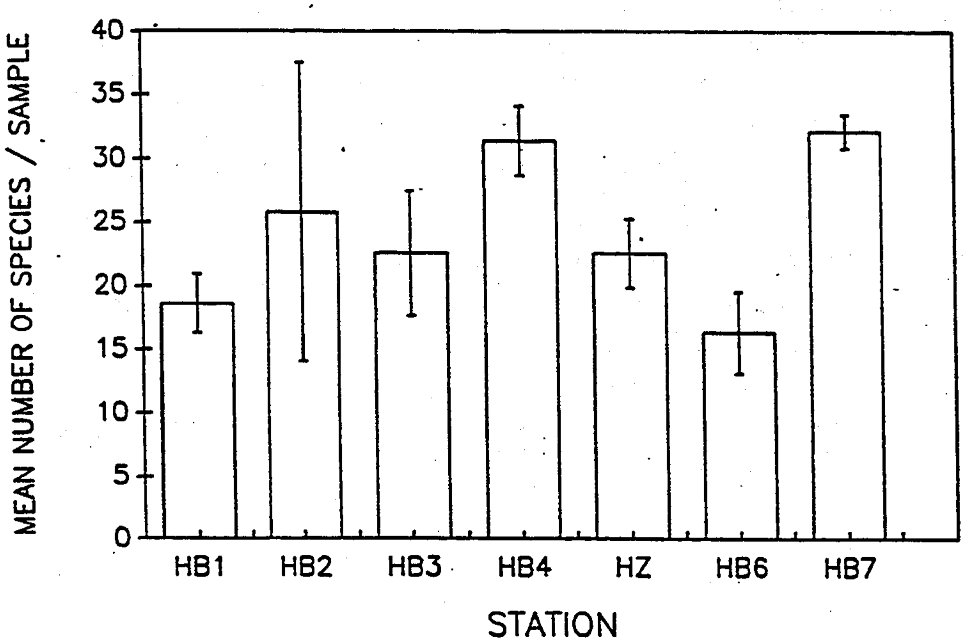

Figure 11. Mean (±1 S.D.) total number of mollusk species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

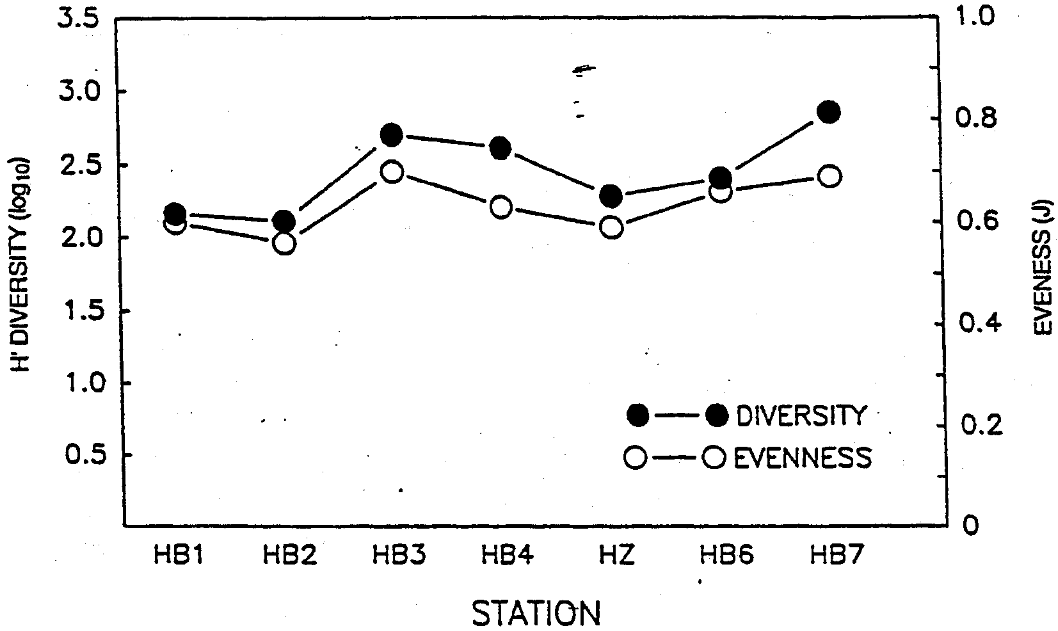

Figure 12. Shannon-Wiener H' diversity (log_{10}) and evenness (J) for mollusks, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

were significant differences in mean mollusk species richness among stations (Games and Howell test, App. Tab. C.4.). Both Stations HB6 and HB1 had significantly fewer mollusk species than Stations HB4 and HB7. Station HZ had significantly fewer mollusk species than Station HB7. No other differences were significant.

H' diversity ranged from a low of 2.11 at Station HB2 to a high of 2.85 at Station HB7 (Fig. 12). Evenness (J) ranged from 0.56 at Station HB2 to 0.70 at Station HB3. Diversity and evenness values for mollusks for all stations were extremely similar (Fig. 18).

A species list and abundances for all species of mollusks for all stations and replicates are shown in Appendix Table E.1.

The gastropod taxa *Balcis* spp., *Cerithidium perparvulum*, *Diala scopulorum*, and *Scaliola* spp. were abundant at all stations. An additional species, *Finella pupoides*, was abundant at Stations HB2 and HZ.

DISCUSSION

In terms of nonmollusk macrofaunal abundance, the only consistent significant difference at a station in proximity to the diffuser was found at Station HB3. This ZID-boundary station had significantly fewer nonmollusk individuals than most other stations, including two other ZID-boundary stations (HB2, HB4). The pattern of crustacean abundance was similar to that for total nonmollusk abundance, with abundance at Station HB3 lower than that at all other stations. ZID Station HZ also had significantly lower crustacean abundance than reference Station HB6, although it did not differ significantly from other reference stations.

Mollusk abundance values at Station HB3 and reference Station HB6 were significantly lower than at all other stations, but did not differ from each other. Such a result, together with the fact that no other stations differed from one another, indicates that there is no general, statistically significant pattern with regard to mollusk abundance and proximity to the diffuser.

The only station that differed significantly from other stations in terms of mean numbers of nonmollusk species was Station HB3, which had fewer species than all other stations. However, Station HB3 did not differ from other stations in mollusk species number. No clear pattern with regard to mollusk species richness was seen. Reference Stations HB1 and HB6 had fewer mollusk species than reference Station HB7 and ZID-boundary Station HB4. ZID Station HZ also had fewer species than Station HB7. Diversity and evenness values were both generally similar among all stations, for the nonmollusks and the mollusks. Thus, with the exception of a potential effect on nonmollusks at Station HB3, there is little evidence that the outfall is having a general effect on species richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray-Curtis dissimilarity index suggested that the abundance and species composition of the nonmollusks was broadly similar at all stations, except Station HB3. Cluster analysis of stations in previous years showed no divergence in community composition for Station HB3 (Nelson et al. 1987, 1991). Cluster analysis has consistently intermixed ZID and near-ZID stations with reference stations on all sampling dates (1991, 1990, and 1986).

As in the previous Barbers Point ocean outfall studies, sediment grain sizes in the 1991 samples were broadly similar among stations, with the exception of Stations HB3 and HB7, which had relatively lower percentages of fine sand. The percentage of fine sediments at the ZID and ZID-boundary stations showed no increase over that of samples taken in 1986 and 1990 (Nelson et al. 1987, 1991). Sediment ORP showed no evidence of reducing conditions at the sediment surface at any station. There was no evidence of a diffuser-related trend in sediment O&G values. TOC values were very similar and relatively low (<0.3%) at all stations.

The total number of nonmollusk taxa recorded in the 1991 study (162) was extremely similar to that recorded in previous studies (162 in 1986; 164 in 1990). Although there have been differences in levels of sampling effort and taxonomic resolution (Nelson et al. 1991), overall nonmollusk species richness in the study area appears to have changed little over the period 1986 to 1991.

Overall comparisons of mean nonmollusk abundance and mean crustacean abundance for the July 1991, February 1990, and September 1986 samplings are made in Figures 13 and 15. There were fewer nonmollusk individuals per core in 1990, as compared with 1991 and 1986, a pattern also seen in the crustacean component of the fauna. These differences may be the result of seasonality of abundance in the macrobenthos of this region. The strongly anomalous value of nonmollusk abundance at Station HB3 in 1991 was a pattern not present in previous samplings (Figs. 13, 15). Rank order of abundance among stations has varied from sampling date to sampling date. With the exception of Station HB3 in 1991, there has been no indication of depression in nonmollusk abundance at near-ZID stations over the sampling periods.

Overall comparisons of mean numbers of nonmollusk species and crustacean species for the July 1991, February 1990, and September 1986 samplings are made in Figures 14 and 16. There were fewer nonmollusk and crustacean species per core in 1990, as compared with 1991 and 1986. Station HB6 ranked first in mean nonmollusk species number on all three sampling dates. Rank order of all other stations varied from year to year, as it did for the mean number of crustacean species (Fig. 16). The depressed totals of nonmollusk and crustacean species at Station HB3 in 1991 were not observed in previous years (Figs. 14, 16).

The factors responsible for the low abundance and species values at Station HB3 are not clear. Station HB3 does not differ from other stations in chemical parameters such as O&G or TOC. Sediment cyanide content was below the detection limit at all stations. In terms of ORP, values were slightly higher at Stations HB3 and HB7, indicative of better oxygenation of the sediments, probably as a result of the somewhat coarser sediments at these two locations. Sediment grain sizes at Stations HB3 and HB7 were very similar, so grain-size differences cannot explain the low faunal values at Station HB3. Examination of 1991 depth readings for Station HB3 indicates that samples were taken 10 m deeper than in previous years (App. Tab. A.1.; Nelson et al. 1987, 1991). Whether or not the depth difference contributed to the lower values of faunal parameters is not known.

The dominant taxa of nonmollusk fauna differed from those in previous samplings. While the representation of oligochaetes was of similar magnitude, nematodes, which were not included in previous sample processing, formed a major component of 1991 nonmollusk abundance. However, several of the dominant polychaete species were the same as in previous samplings (Nelson et al. 1987, 1991). These included the polychaetes *Synelmis acuminata*, *Nereimyra* sp. A., *Pionosyllis gesae*, and *Myriochele oculata*. Representation of the chordate *Branchiostoma* sp. and the sipunculan *Aspidosiphon klunzingerii* decreased somewhat.

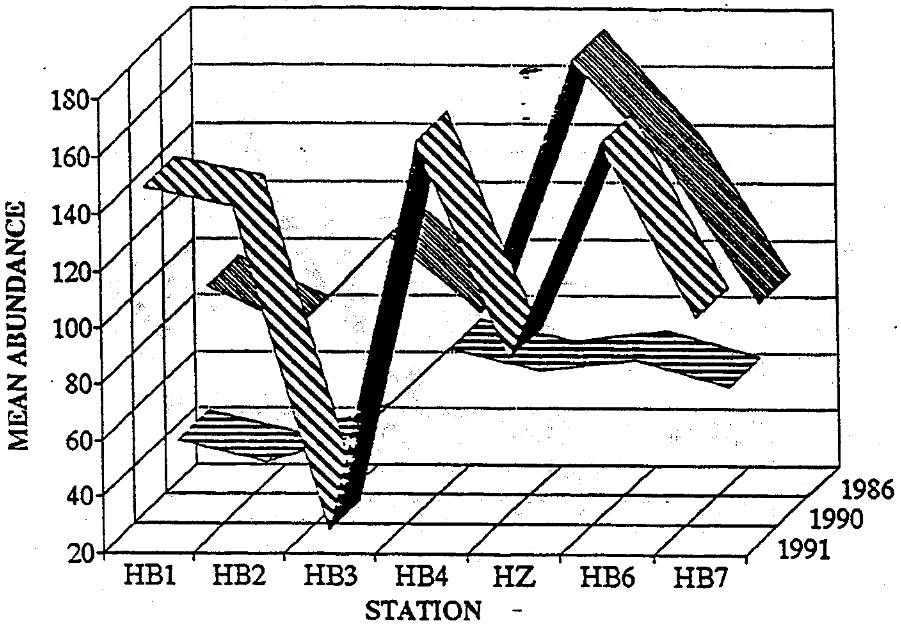

Figure 13. Comparison of mean nonmollusk abundance for samples taken in 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

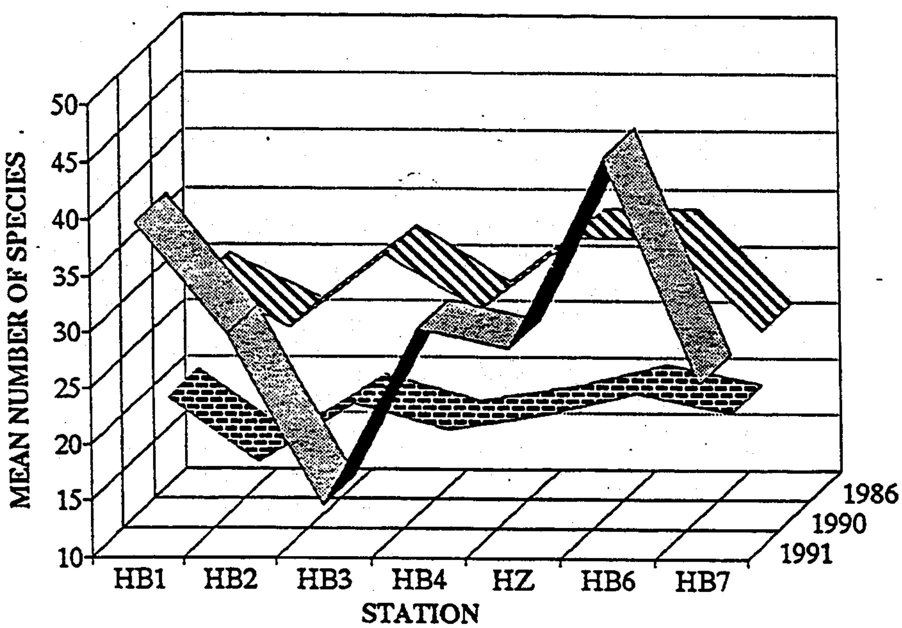

Figure 14. Comparison of mean nonmollusk species richness for samples taken in 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

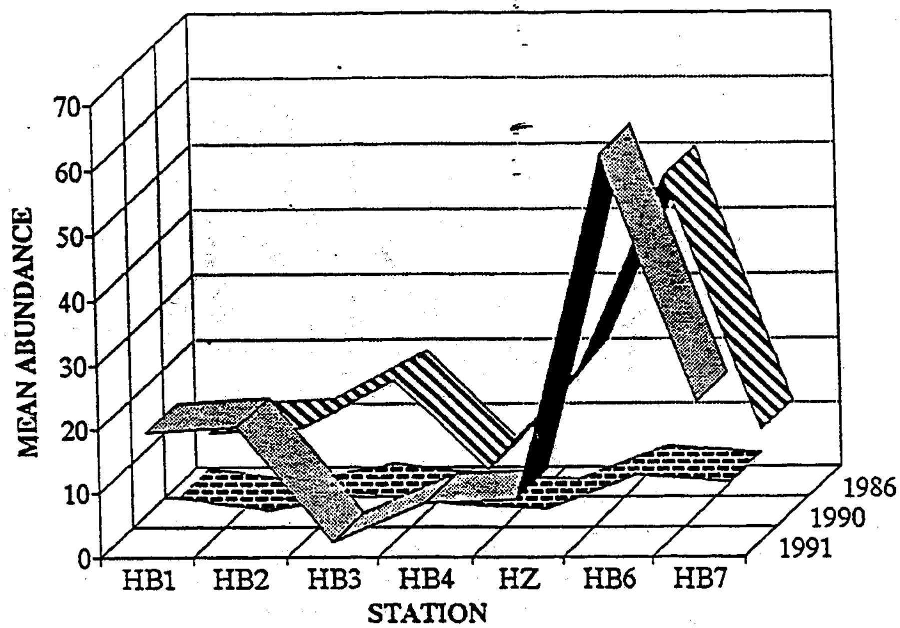

Figure 15. Comparison of mean crustacean abundance for samples taken in 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

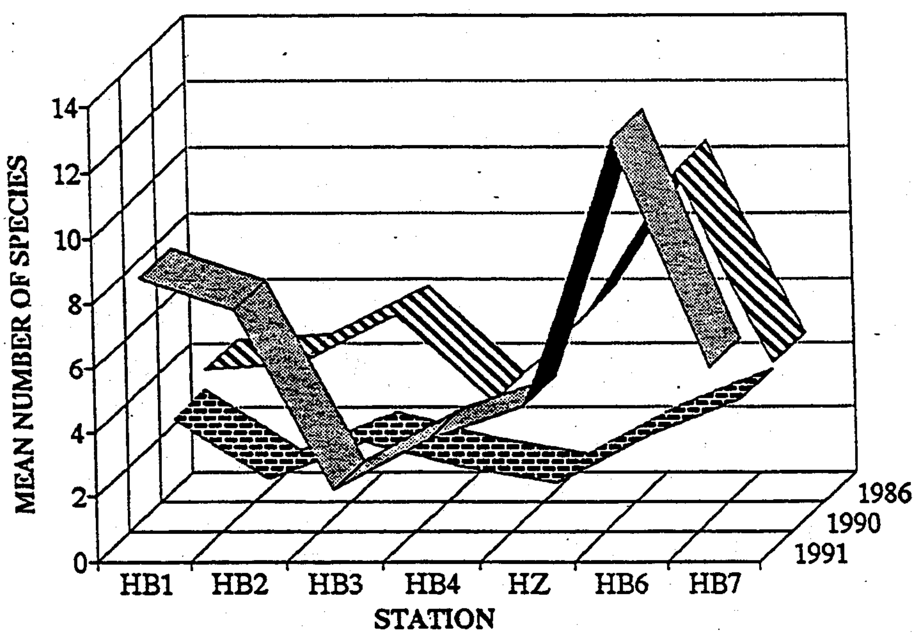

Figure 16. Comparison of mean crustacean species richness for samples taken in 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

As in 1990 and 1986, the crustacean fauna in the vicinity of the Barbers Point ocean outfall was dominated by amphipods, isopods, and tanaidaceans. These groups generally brood larvae and are therefore less likely to be affected by variable recruitment than other, planktonically recruited groups. As such, these peracarideans may be expected to be integrating indicators of the long-term status of the benthic community.

In contrast to the 1990 collections, the 1991 samples revealed a strong depression of both crustacean species richness and abundance in the vicinity of the outfall. Stations HB3 and HB4, which were located on the southern boundary of the ZID, were markedly lower than all other stations in species richness. Stations HB3, HB4, and HZ also had markedly lower abundance values than other stations, although not all pairwise comparisons of these stations with reference stations were statistically significant.

In 1991, crustacean species richness and abundance appeared to be reduced at stations adjacent to and immediately to the south of the outfall: Stations HB3, HB4, and HZ. Little effect was seen further west (Stas. HB6, HB7) or east of the outfall (Stas. HB1, HB2). This scheme is consistent with a net down-slope (south-by-southwest) flow of effluent. The effect on Stations HB3, HB4, and HZ may be due directly to the effluent plume, or may be influenced by other factors, such as interactions with the noncrustacean benthic fauna, bottom topography, or sediment differences not apparent from grain-size analysis.

Overall comparisons of mean mollusk abundance and mean number of mollusk species for the July 1991, February 1990, and September 1986 samplings are made in Figures 17 and 18. Because the mollusk collections are not separated into living and dead shell material, they represent time-averaged collections, which reflect conditions at a site over a longer period. As a consequence, temporal variability in mollusk abundance among sampling dates was much less than that for the nonmollusk fraction. The rank order of mean abundance among stations showed little correspondence among sampling dates, with the exception that Station HB6 consistently has had the fewest mollusk individuals (Fig. 17). The rank order of mean number of mollusk species showed virtually no correspondence among sampling dates.

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show no evidence of a buildup of organic matter in the vicinity of the Barbers Point ocean outfall diffuser. This conclusion is confirmed by each of the physical and chemical parameters measured. TOC values at all stations were below 0.3%. For comparison, the percentage of organic content ranged from 1.2% to 10.9% for sediments of the Kattegat (Pearson, Josefson, and Rosenberg 1985), and 0.6% to 8.9% for

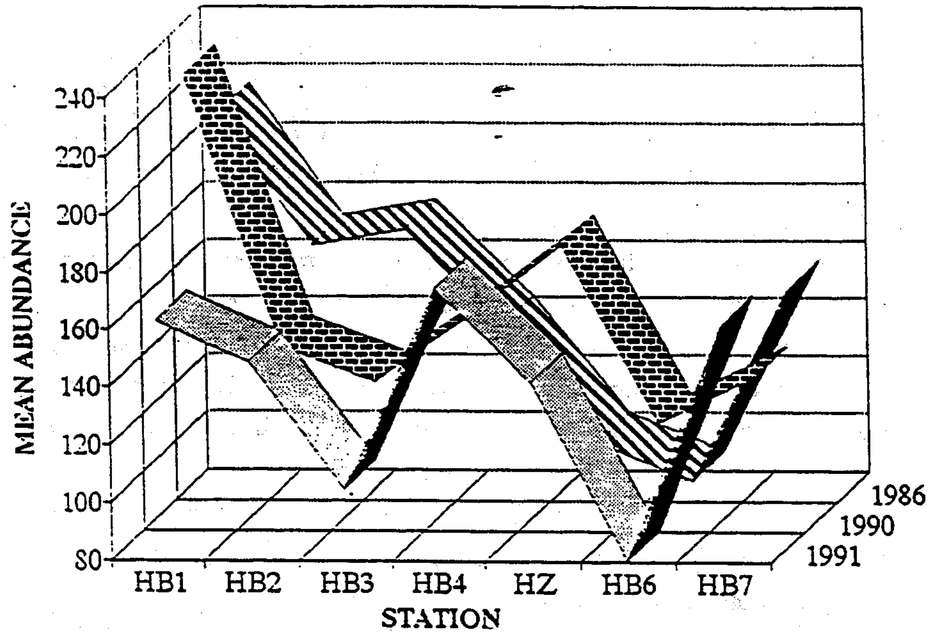

Figure 17. Comparison of mean mollusk abundance for samples taken in 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

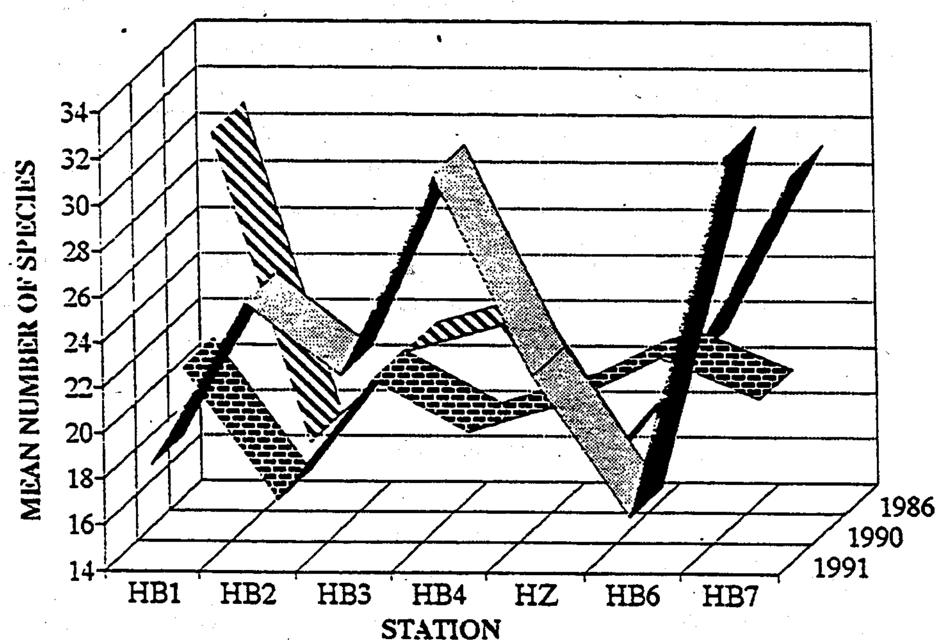

Figure 18. Comparison of mean mollusk species richness for samples taken in 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, July 1991

sediments off the coast of Maine (Bader 1954). TOC percentages ranged from 1.4% to 4.1% for stations near the Los Angeles County ocean outfalls (Swartz et al. 1986). The lack of evidence for organic buildup would suggest that little particulate matter from the diffuser ever reaches the sediment surface.

The spatial patterns of organism abundance and species richness in relation to the outfall varied depending on the taxonomic grouping. A consistent pattern for both nonmollusks and mollusks was low abundance at Station HB3, although for mollusks, abundance at Station HB6 was lowest. Cluster analysis of nonmollusk data confirmed that Station HB3 was the most different among the stations in terms of species composition and relative abundance. As Station HB3 is a ZID-boundary station, the low abundance observed may be an outfall effect. However, with the exception of the crustaceans, no effect at other ZID or ZID-boundary stations was observed. Any outfall effect is therefore of limited extent. Since Station HB3 was not anomalous in either 1990 or 1986, it appears that the change at this station occurred rather recently. It will be important to see if the deviation observed in 1991 at Station HB3 persists in the 1992 samplings.

In spite of the low abundance and species richness values at Station HB3, species diversity (H') and evenness (J) were relatively similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment proposed by Pearson and Rosenberg (1978) would suggest that in the transition zone of an enrichment gradient, a few species will increase and be extremely dominant, while overall diversity and evenness will be low. Neither the response pattern of the benthos nor the sediment TOC data would support the organic enrichment hypothesis, and the perturbation observed at Station HB3 must be due to other, as yet undetermined, factors.

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February 1992 Benthic Monitoring Program Results

(Nelson et al., 1992)

BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O'AHU, HAWAI'I, FEBRUARY 1992

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SPECIAL REPORT 06.30:92

September 1992

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All specimens were identified to the lowest taxonomic level possible. A selected bibliography on the identification of Hawaiian marine benthic species is provided in Nelson et al. (1987, App. D). Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained by CCH for six years.

Data Analysis

All data were tested for assumptions of normality (Kolmogorov-Smirnov test) and heterogeneity of variances (F_{max} test) prior to statistical analysis (Sokal and Rohlf 1981). Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following ANOVA, the a posteriori Student-Newman-Keuls (SNK) test was used to determine which differences among stations were significant. In several cases, heterogeneous variances were found that could not be corrected by application of standard transformations. The Games and Howell test of equality of means was applied in these cases (Sokal and Rohlf 1981).

An overall comparison of species composition among stations was carried out using cluster analysis (Pielou 1984). The Bray-Curtis similarity index (Bloom 1981) on untransformed data was performed using the flexible sorting strategy. To make the analysis more manageable, only those nonmollusk species that contributed at least 0.07% of the total abundance were included in the analysis. As a result of adhering to this criterion, only species represented by a total of more than three individuals were included in the analysis, and the analysis data set was reduced from 175 to 107 species. The Cluster program developed by the EPA Corvallis Environmental Research Laboratory (Mathews 1981) was used to compute the similarity matrix.

The Shannon-Wiener diversity index (H') ($\log_{10}$) and evenness index (J) were calculated for all stations (all replicates pooled) as recommended by EPA procedures. Calculations of these parameters were carried out with Quattro Pro spreadsheet software.

RESULTS

Sediment Parameters

Results of sediment-grain-size analysis are given in Appendix Table A.2. The mean sediment compositions, based on three grain-size categories, at the sampling stations are compared in Figure 3. The grain-size categories (Folk 1968) were as follows: medium and coarse sand, retained on a +2-phi sieve; fine sand, passed through a +2-phi sieve but retained on a +4-phi sieve; and silt and clay, passed through a +4-phi sieve.

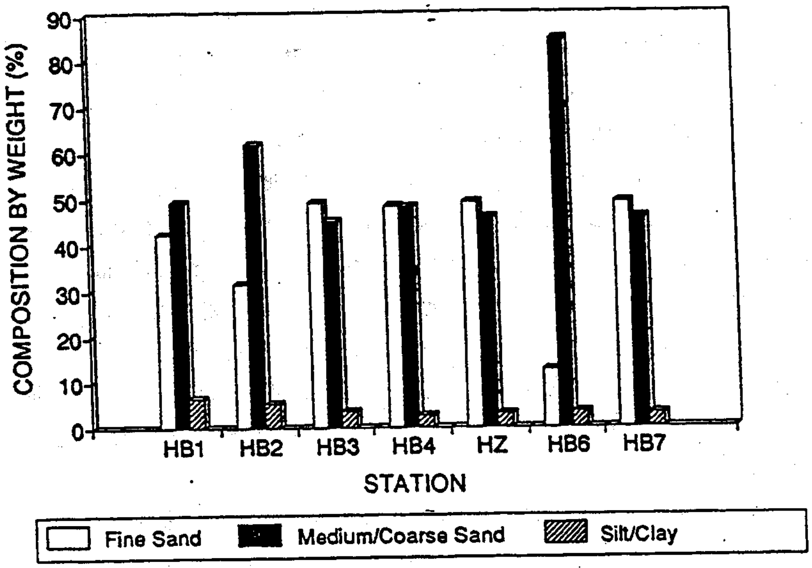

Figure 3. Sediment grain-size characteristics (Wentworth classification), Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

Sediments at all stations were generally similar in grain-size distribution, with the exception of Stations HB2 and HB6, which had a higher percentage of medium and coarse sand and a lower percentage of fine sand than the other stations (Fig. 3). The sediment at all stations was more than 93% sand (App. Table A.2). Replicate sediment samples at all seven stations indicated homogeneity in grain size within stations (App. Table A.2).

Direct electrode measurements of ORP (App. Table A.3) were positive in the range of +18 to +187 mV. These readings show no evidence of strongly reducing conditions in the surface sediments at any station. Sediment ORP values were generally similar at all stations (App. Table A.3). Sediment oil and grease (O&G) values were in the range of 60 to 362 mg/dry-kg (App. Table A.3). Mean O&G values showed no trend in relation to the diffuser, with values at stations near the diffuser being similar to those at reference stations. The maximum values of sediment O&G were found at Station HB1, a farfield reference site, and Station HB2, a ZID-boundary site.

Values for TOC (App. Table A.3) were in the range of 0.13% to 0.70% at all stations. Mean TOC values per station ranged only between 0.30% and 0.47%. There was no pattern of elevation of TOC at the ZID and ZID-boundary stations.

Biological Parameters

TOTAL NONMOLLUSK COMPONENT. The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, sipunculans, echinoderms, nematodes, nemerteans, priapulids, phoronids, anthozoans, bryozoans, hemichordates, a chordate species, amphipods, copepods, cumaceans, decapods, isopods, ostracods, and tanaidaceans.

The 5,458 nonmollusk specimens counted and identified for all stations and replicates represent a total of 175 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (2,205 or 40%) and species richness (113 species). Nematodes were the second most dominant nonmollusk taxon in terms of abundance (23.7%). Oligochaetes constituted 11% of numerical abundance, with crustaceans contributing an additional 8.6% of total nonmollusk abundance. The 35 crustacean taxa, 11 of which were amphipods, represented 20% of the total species list. Abundance estimates for each species in each replicate are given in Appendix Tables D.1 and D.2.

Basic statistics for the nonmollusk data, including 95% confidence limits and a Kolmogorov-Smirnov test for normality of distribution, are provided in Appendix Tables B.1 (number of individuals) and B.2. (number of species). Data were normal for most stations; exceptions were data on nonmollusk individuals at Stations HB4 and HZ. Deviations from normality were not deemed sufficiently extreme to require transformation. ANOVA is robust for moderate deviations from normality of data (Sokal and Rohlf 1981).

Mean total nonmollusk abundance ranged from 99.2 individuals per sample (21,863/m^2) at Station HB5 to 242.2 individuals per sample (53,381/m^2) at Station HB4 (Fig. 4). There were significant differences in mean abundance among stations (ANOVA, App. Table B.3). Station HB4 had significantly more individuals than did all other stations except Station HZ (SNK test, App. Table B.3). No other differences were significant.

The mean number of nonmollusk species per sample ranged from a low of 29.8 species at Station HB5 to a high of 46.6 species at Station HB2 (Fig. 5). There were no significant differences in mean number of species per sample among stations (ANOVA, App. Table B.4).

Composite station diversity (H') and evenness (J) are shown in Figure 6. Patterns of diversity and evenness were highly similar among stations. Values for both parameters were similar at all stations. Values for H' ranged between 2.78 at Station HB4 and 3.80 at Station HB2. This range of values was extremely similar to that of samples taken in previous years (Nelson et al. 1987, 1991, 1992). Evenness ranged between 0.61 (Sta. HB4) and 0.82 (Sta. HB2) and was comparable to that of previous samples (Nelson et al. 1987, 1991, 1992). Relative to other stations, there was no pattern of lower diversity or evenness at ZID or near-ZID stations.

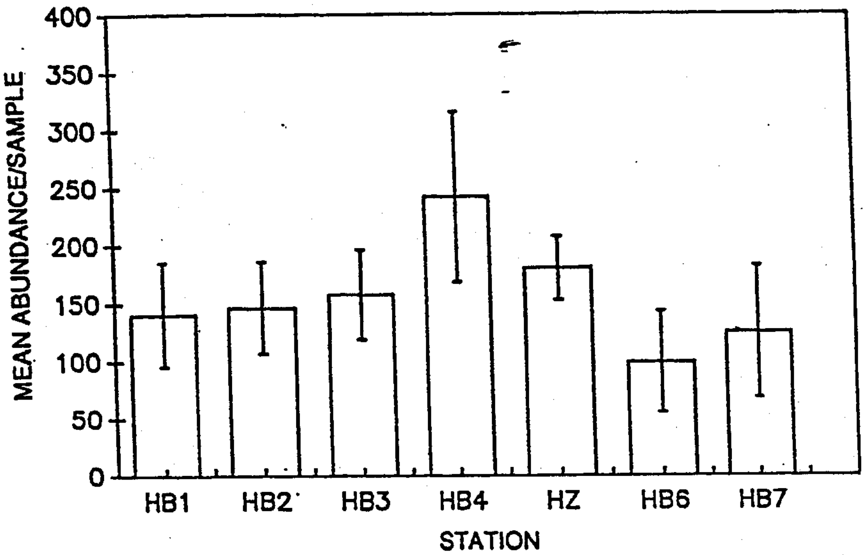

Figure 4. Mean (±1 S.D.) nonmollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

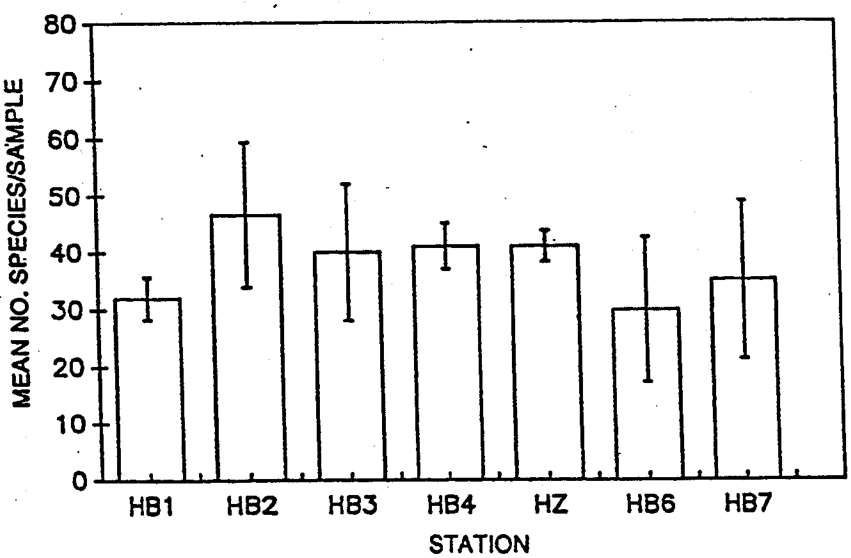

Figure 5. Mean (±1 S.D.) number of nonmollusk species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

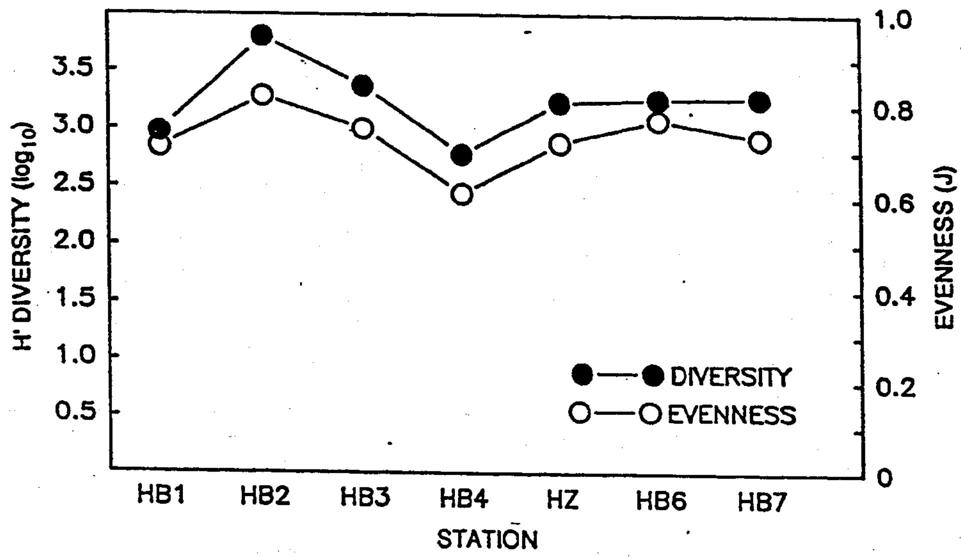

Figure 6. Shannon-Wiener H' diversity (log_{10}) and evenness (J) for nonmollusks, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

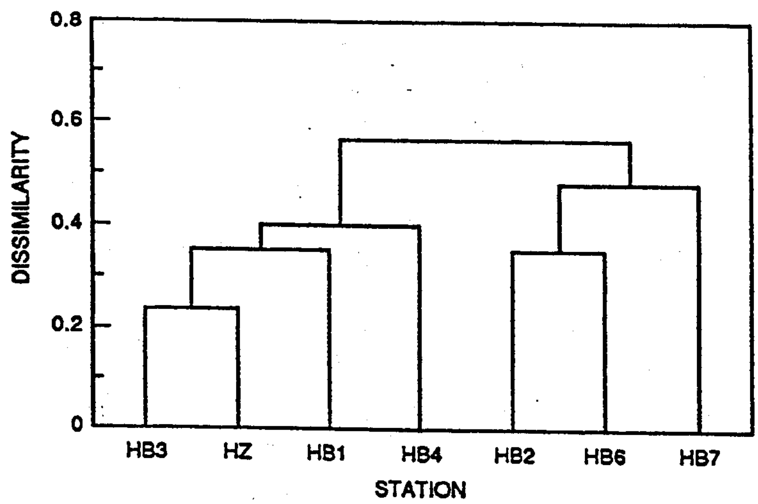

Figure 7. Dendrogram for untransformed nonmollusk data showing dissimilarity among Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

Results of cluster analysis indicating the relative similarity of stations based on the 107 most abundant nonmollusk species are shown in Figure 7. Stations were clustered in two groups. One group consisted of Stations HB1, HB3, HZ, and HB4, and the second of Stations HB2, HB6, and HB7 (Fig. 7). The coefficient of dissimilarity between the two groups was 0.56.

Polychaetes. A total of 2,205 polychaete worms, representing 40% of total nonmollusk abundance were collected. The most polychaetes were found at Station HB4 (391) and the fewest at Station HB1 (212) (Fig. 8). The stations, ranked in decreasing order according to the abundance of polychaetes, were as follows: HB4, HZ, HB2, HB3, HB7, HB6, and HB1. Polychaetes were the most species rich group at all stations (App. Table D.1). The maximum polychaete species richness occurred at Station HB2 (64); the remaining stations, ranked in descending order according to species abundance, were as follows (Fig. 9): HB4 (61), HZ (60), HB7 (59), HB3 (57), HB6 (44), and HB1 (40).

Dominant polychaetes were the pilargid *Synelmis acuminata* at Stations HB4 and HB7, the sabellid *Euchone* sp. B at Station HB1, and the oweniid *Myriochele oculata* at Stations HB2, HB3, HB6, and HZ.

TROPHIC CATEGORIES. Trophic and motility categories are based on Fauchald and Jumars (1979) and are summarized in Figures 10, 11, 12, and 13.

Detritivores. Deposit-feeding polychaetes were most abundant at Station HZ and most speciose at Stations HZ and HB4. The dominant polychaetes in the deposit-feeding category were *Prionospio cirrobranchiata* (Sta. HB1), *Myriochele oculata* (Stas. HB2, HB3, HB4, HB6, and HZ), and *Prionospio cirrifera* (Sta. HB7).

Omnivores. In terms of percentage of total polychaetes, omnivorous worms were best represented at Station HB7, which is consistent with the results of the 1986, 1990, and 1991 surveys (Nelson et al. 1987, 1991, 1992). In terms of total polychaete abundance, omnivores were most abundant at Station HB7, with the pilargid *Synelmis acuminata* dominating the omnivorous component. *Synelmis acuminata* was also the most abundant omnivore at Station HB1, HB4, HB6, and HZ. *Pionosyllis gesae* was the dominant omnivore at Station HB3.

Suspension Feeders. The highest numbers of suspension feeders (primarily the families Sabellidae and Serpulidae) were found at Stations HZ, HB2, and HB4. The most species rich station was Station HZ. Suspension feeders made up the smallest proportion of the community at Stations HB3, HB6, and HB7.

Carnivores. Carnivorous polychaetes were present at all stations, with maximum abundances at Stations HB2, HB3, and HB7. The eunicid complex (Eunicidae, Lumbrineridae, Onuphidae, and Dorvilleidae), the amphinomid *Linopherus microcephala* and the hesionids *Podarke angustifrons* and *Nereimyra* sp. A comprised most of the carnivorous

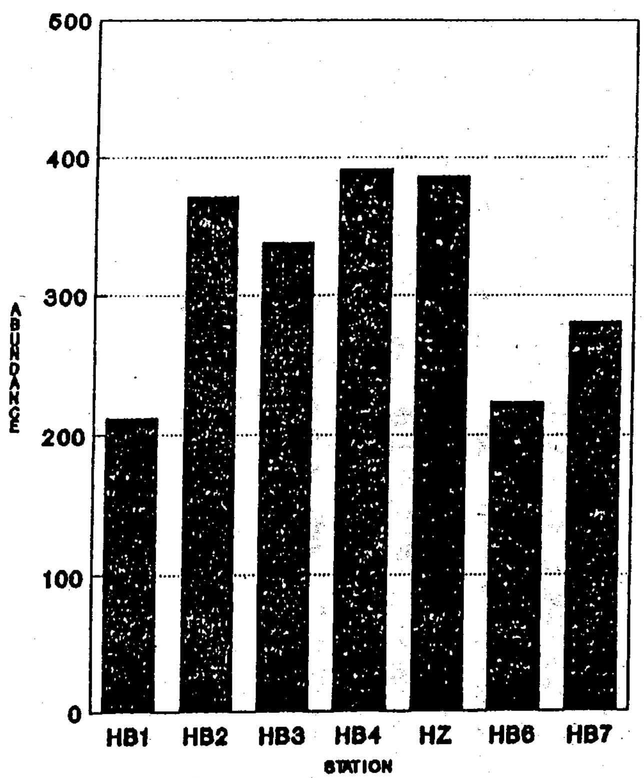

Figure 8. Total abundance of polychaetes at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

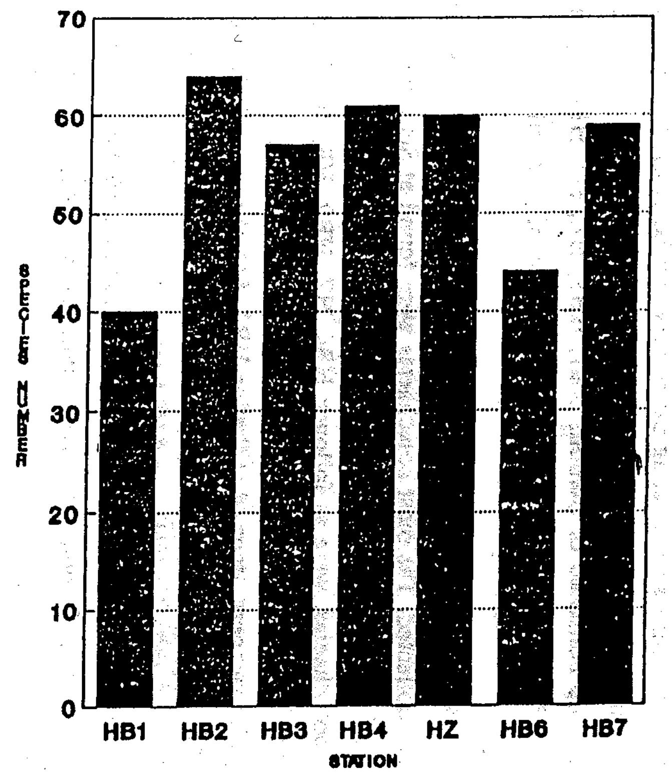

Figure 9. Total number of polychaete species at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

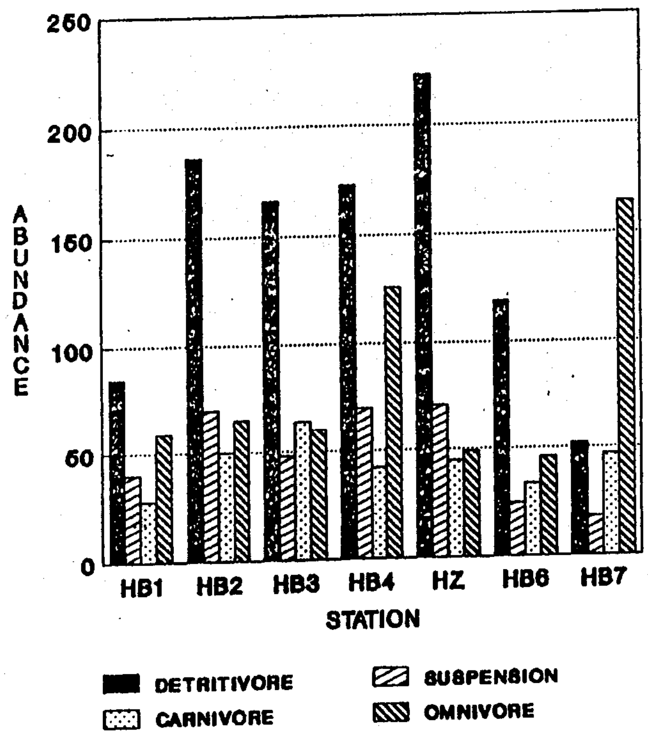

Figure 10. Total number of polychaetes in four trophic categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

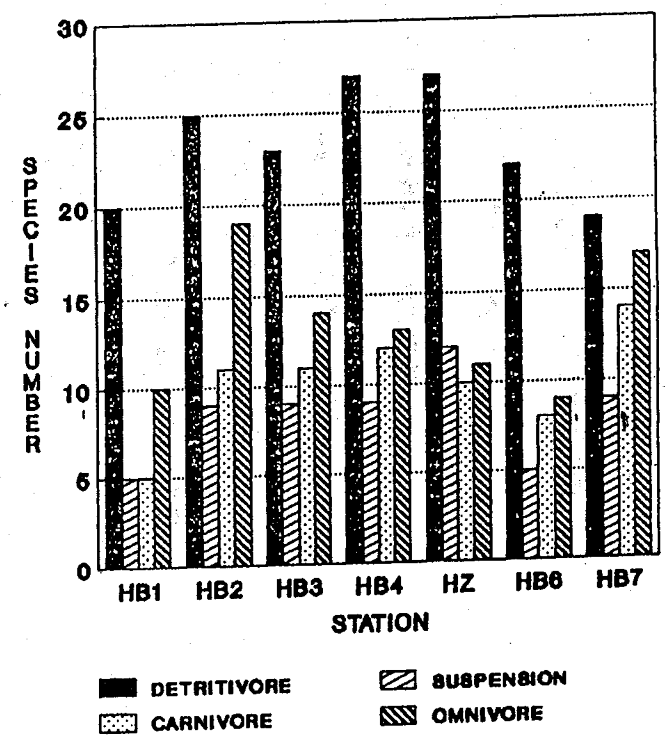

Figure 11. Total number of polychaete species in four trophic categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

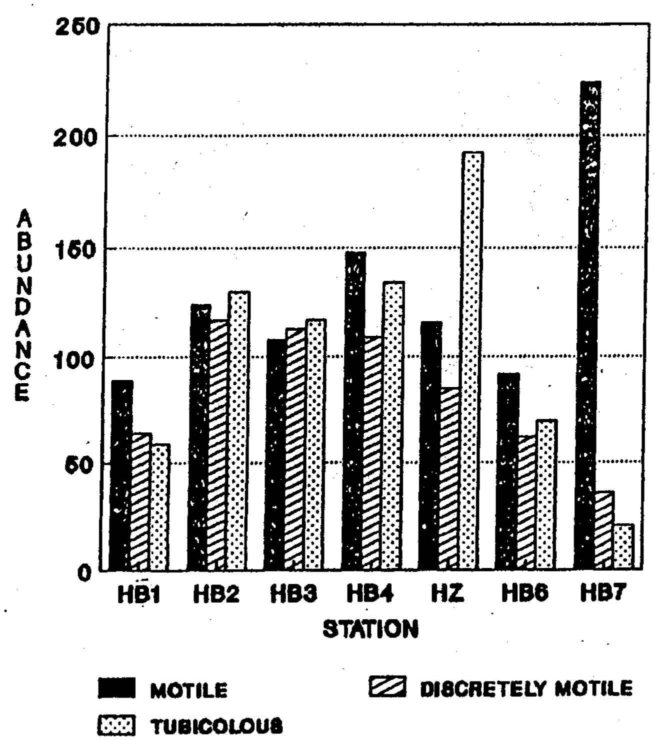

Figure 12. Total number of polychaetes in three motility categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

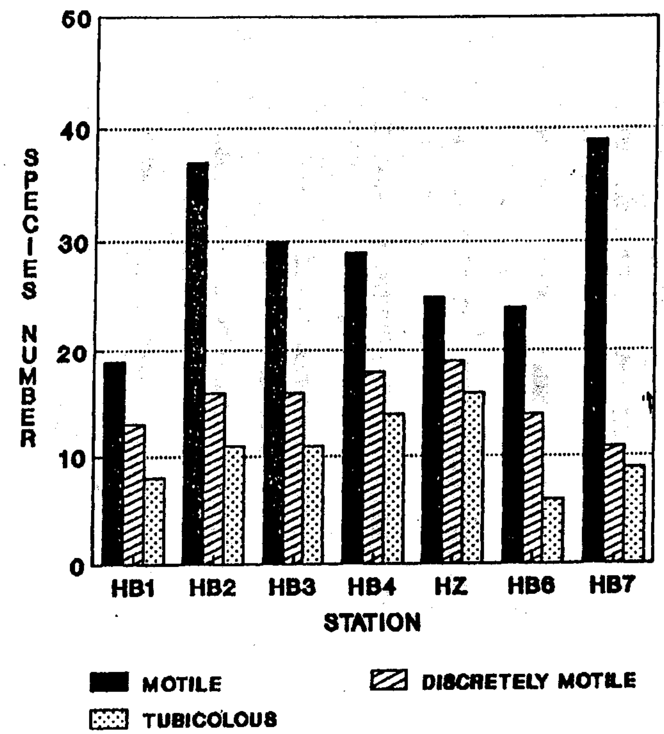

Figure 13. Total number of polychaete species in three motility categories, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

polychaetes. The greatest species richness of carnivorous worms was found at Station HB7, the next at Station HB4.

MOTILITY CATEGORIES. Tubicolous worms dominated the polychaete fauna at Stations HB2, HB3, and HZ (*Myriochele oculata* and *Myriochele* sp. A). The motile omnivore *Synelmis acuminata* dominated at Stations HB4 and HB7. The spionids (e.g., *Prionospio cirrobranchiata*, *P. cirrifera*, and *Polydora normalis*) were the most species rich and numerically dominant family in the discretely motile category.

Discretely motile polychaetes made up the second largest motility category of polychaete abundance at Stations HB2 and HB3.

Tubicolous worms had their largest proportional representation in terms of abundance at Station HZ. The greatest percentage of species in the tubicolous category was found at Stations HB4 and HB1. Sabellids and serpulids were well represented at all stations and were dominant at HB1.

Crustaceans. A total of 472 crustaceans were collected. Mean crustacean abundances (no./sample) ranged from 8.4 (1,851/m^2) at Station HB5 to 25.2 (5,554/m^2) at Station HB6 (Fig. 14). Variances were heterogeneous (App. Table B.5.1), and the Games and Howell test of equality of means was used. There were no significant differences in mean abundance of crustaceans among stations (Games and Howell test, App. Table B.5.2).

A total of 35 taxa (copepods were not identified to the species level) of crustaceans were collected, of which 11 species (31%) were amphipods. Mean number of crustacean species ranged from 4.4 (Sta. HZ) to 7.20 (Sta. HB2) (Fig. 15). Variances were heterogeneous (App. Table B.6.1), and the Games and Howell test of equality of means was used. There were no significant differences in mean number of crustacean species among stations (Games and Howell test, App. Table B.6.2).

Amphipods, tanaidaceans, and isopods were the numerically dominant taxa, making up 46%, 23%, and 7%, respectively, of total crustacean abundance. No species was most abundant at all stations. The amphipod *Eriopisella sechellensis* and the tanaids *Leptochelia dubia* and *Tanaissus* sp. A were present at most stations and were generally among the most abundant. The amphipod *Gammaropsis atlantica* was abundant at Station HB7.

The two meiofaunal isopod genera *Microcharon* and *Caecianiropsis*, present in 1991, were not present in 1992. However, because samples were sorted on a 0.5-mm screen, collection of meiofauna was generally poor. Decapods were present at these sites, but the small size (7.6 cm in diameter) of the subsamples taken from the Van Veen grabs precluded any accurate inventory or the showing of any pattern among stations. As in earlier years, some copepods were also found at these stations. Copepod specimens were not further identified below the

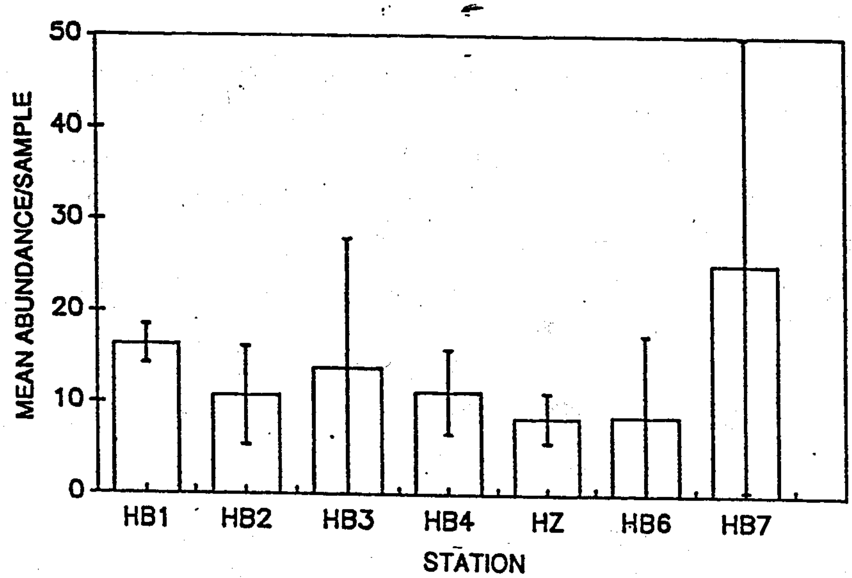

Figure 14. Mean (±1 S.D.) total crustacean abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

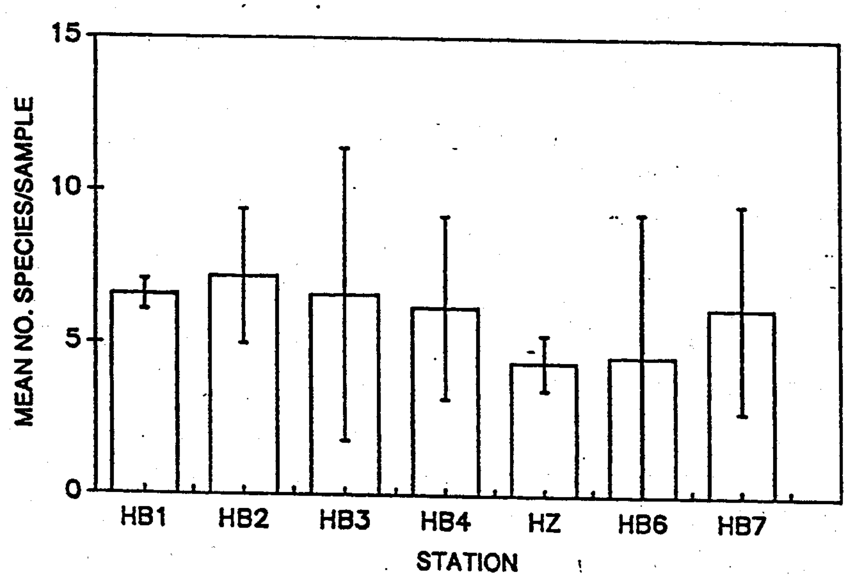

Figure 15. Mean (±1 S.D.) total number of crustacean species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

subclass; some appeared to be planktonic forms. A complete list of crustacean species abundance for all replicates and stations is given in Appendix Table D.2.

MOLLUSKS. Mean abundance of mollusks per sample (no./10 cm^3) ranged from a low of 94.4 at Station HB6 to a high of 238.4 at Station HB1 (Fig. 16). Data at all stations except Stations HB1 and HB4 were normally distributed (App. Table C.1). Deviations from normality were not deemed sufficiently extreme to require transformation. ANOVA is robust for moderate deviations from normality of data (Sokal and Rohlf 1981). Complete basic statistics for total mollusk data are shown in Appendix Table C.1. Variances were homogeneous (App. Table C.3.).

There were significant differences in mean mollusk abundance among stations (ANOVA, App. Table C.3). Mean abundance was significantly greater at Station HB1 than at all other stations. Stations HB2 and HB4 did not differ significantly from each other, but both stations had significantly greater abundance than the other stations. No other differences in means were significant.

Mean number of mollusk species per sample ranged from a low of 15.6 at Station HB2 to a high of 25.8 at Station HB1 (Fig. 17). Data at all stations were normally distributed (App. Table C.2). Complete basic statistics on number of mollusk species at all stations are shown in Appendix Table C.2. Variances were homogeneous (App. Table C.4). There were significant differences in mean mollusk species richness among stations (ANOVA, App. Table C.4). Station HB1 had significantly more mollusk species than Stations HB3, HB6, and HB2. Station HB6 had significantly more mollusk species than Stations HB3 and HB2. Station HB4 had significantly more mollusk species than Station HB2. No other differences were significant.

H' diversity ranged from a low of 1.69 at Station HB2 to a high of 2.44 at Station HB7 (Fig. 18). Evenness (J) ranged from 0.48 at Station HB2 to 0.63 at Station HB6 (Fig. 18). Diversity and evenness values for mollusks were extremely similar for all stations.

Species and abundance for all mollusks at each station and repliate are shown in Appendix Table E.1.

The gastropod taxa *Balcis* spp., *Cerithidium perparvulum*, *Diala scopulorum*, and *Scaliola* spp. were abundant at all stations. An additional species, *Finella pupoides*, was abundant at all stations except Stations HB1 and HB7.

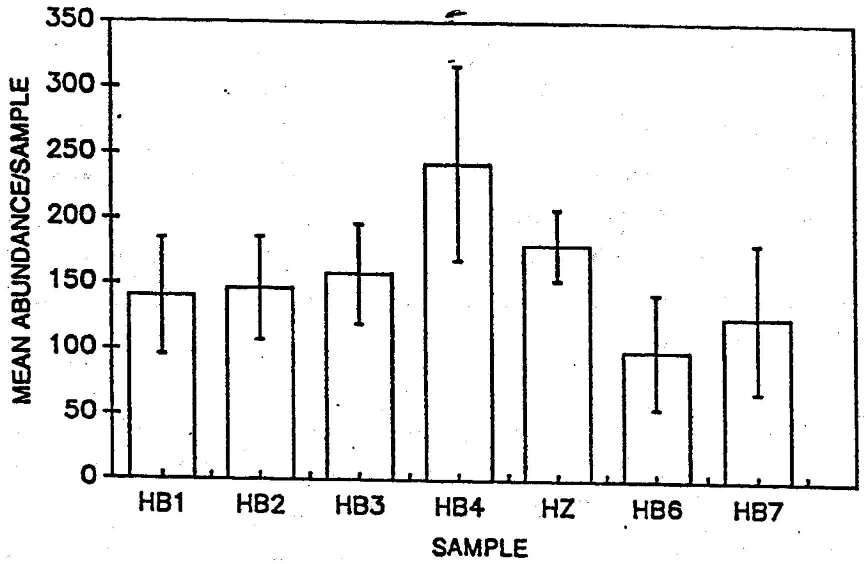

Figure 16. Mean (±1 S.D.) mollusk abundance, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

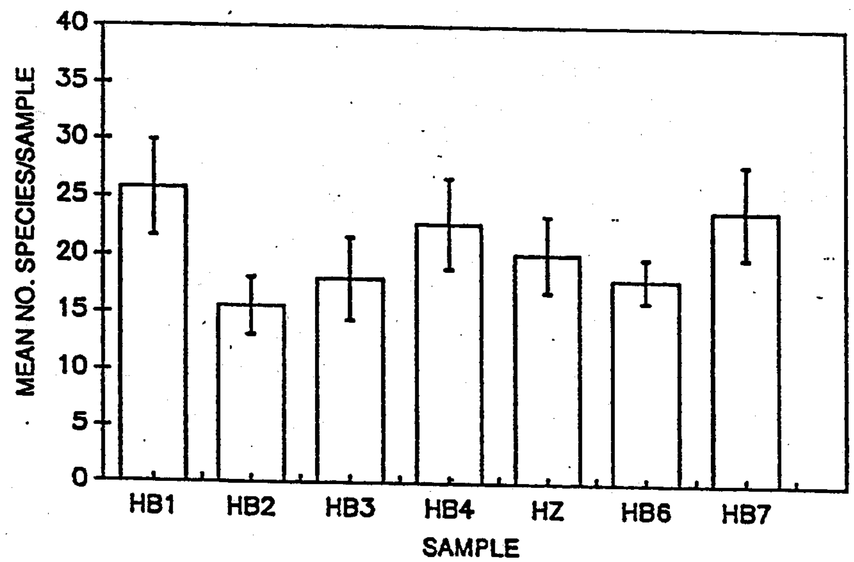

Figure 17. Mean (±1 S.D.) total number of mollusk species, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

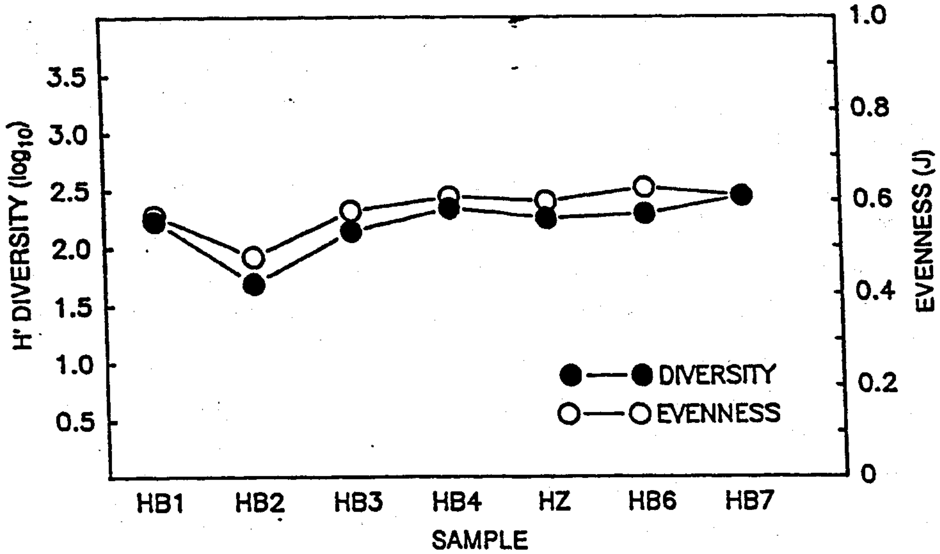

Figure 18. Shannon-Wiener H' diversity (log_{10}) and evenness (J) for mollusks, Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i, February 1992

DISCUSSION

The ZID boundary Station HB4 had significantly more nonmollusk individuals than all other stations except Station HZ. Nematode abundance at this station was 2 to 4 times greater than at other stations and is the primary reason for the elevated abundance recorded. Abundances of other taxa were very similar among stations. There were no significant differences among stations in crustacean abundance.

Mollusk abundance was significantly greater at reference Station HB1 than at all other stations. ZID-boundary Stations HB2 and HB4 did not differ from each other, but had significantly higher mollusk abundances than all other stations except Station HB1. The remaining stations, including near-ZID Stations HZ and HB3 and reference Stations HB6 and HB7, did not differ in mollusk abundance. Thus, there was no general, statistically significant pattern with regard to mollusk abundance and proximity to the diffuser.

There were no significant differences among stations in number of either nonmollusk species or crustacean species. No clear pattern with regard to mollusk species richness was seen. Reference Stations HB1 and HB7 had a greater number of mollusk species than some near-ZID stations. Reference Station HB6 did not differ significantly from the near-ZID stations. Diversity and evenness values were both generally similar among all stations for both nonmollusks and mollusks. Station HB2 had somewhat lower mollusk diversity and evenness than other stations, yet had the highest nonmollusk diversity and evenness values. Thus, there is little evidence that the outfall is having a general effect on species richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray-Curtis dissimilarity index suggested that the abundance and species composition of the nonmollusks was broadly similar at all stations. In the cluster analysis, stations near the diffuser were grouped with distant reference stations. Cluster analysis has consistently intermixed ZID, near-ZID, and reference stations on all sampling dates (1986, 1990, 1991, 1992).

As in the previous Barbers Point ocean outfall studies, sediment-grain sizes in the 1992 samples were broadly similar among stations, with the exception of Stations HB2 and HB6, which had relatively lower percentages of fine sand. There was no indication of this difference in sediment-grain size in samples taken at these stations in 1991. The variation in grain size from year to year would suggest some degree of spatial heterogeneity of sediments at these stations. The percentage of fine sediments at the ZID and ZID-boundary stations showed no increase over that of samples taken in 1986, 1990, and 1991 (Nelson et al. 1987, 1991, 1992). Sediment ORP showed no evidence of reducing sediment conditions at the sediment surface at any station. There was no evidence of a diffuser-related trend in sediment O&G values. Highest values were observed at reference Station HB1. Mean sediment TOC values were very similar, varying only by 0.5% among stations.

The total number of nonmollusk taxa recorded (175) was extremely similar to that recorded in previous studies (1986, 162; 1990, 164; 1991, 162). Although there have been differences in levels of sampling effort and taxonomic resolution (Nelson et al. 1991), overall nonmollusk species richness in the study area appears to have remained very similar over the period 1986 to 1992.

Overall comparisons of mean nonmollusk abundance and mean crustacean abundance for February 1992, July 1991, February 1990, and September 1986 samples are made in Figures 19 and 20. Nonmollusk abundances in 1992 were similar to those recorded in other years, with the exception of the somewhat higher value at Station HB4, due to abundant nematodes at this site. At most stations, crustacean abundances were similar to those of previous years. The elevated abundance of crustaceans at Station HB6 observed in 1990 and 1991 was not observed in 1992. Year-to-year differences may be partly the result of seasonality of abundance in the macrobenthos of this region. However, comparison of 1990 and 1992 samples, which were both obtained in the month of February, indicates that there are interannual variations in nonmollusk abundance that are not related solely to seasonal differences.

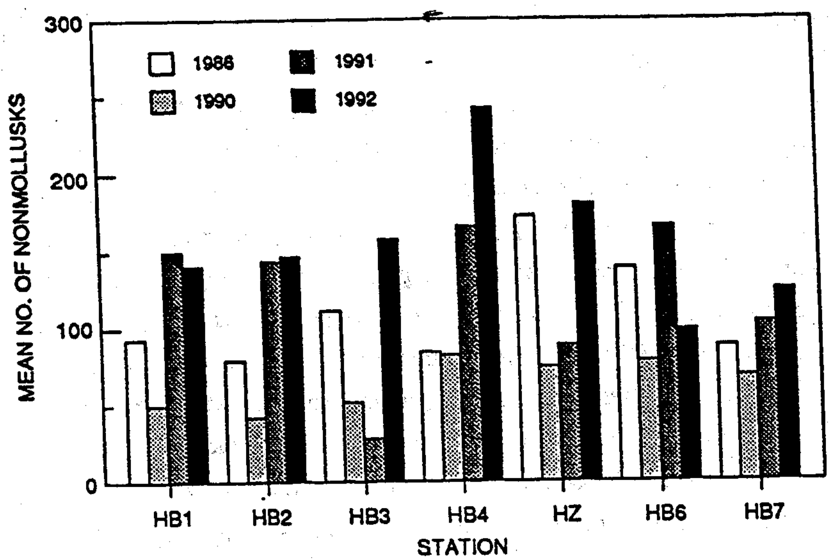

Figure 19. Comparison of mean nonmollusk abundance for samples taken in 1992, 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i

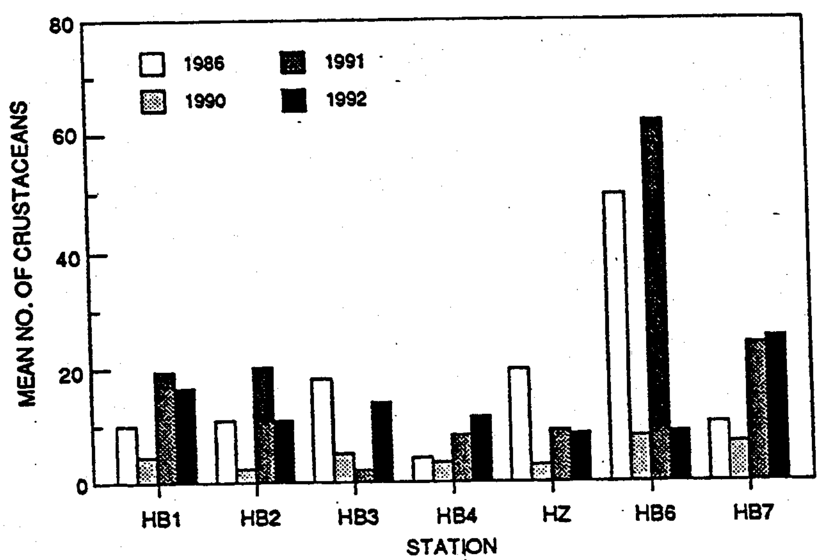

Figure 20. Comparison of mean crustacean abundance for samples taken in 1992, 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i

The strongly depressed 1991 value of nonmollusk abundance at Station HB3 was not recorded in previous years nor in 1992 (Figs. 19, 20). Rank order of abundance among stations has varied from sample date to sample date. With the exception of Station HB3 in 1991, which appears to have produced anomalous samples, there has been no indication of depression in nonmollusk abundance at near-ZID stations over the sampling period.

Overall comparisons of mean numbers of nonmollusk species and crustacean species for July 1991, February 1990, and September 1986 samples are made in Figures 21 and 22. The 1992 nonmollusk and crustacean species graphs indicate a greater similarity among stations than was the case in 1991. A general similarity of species richness among stations was the pattern observed in 1990 and 1986. Station HB6 no longer ranked first in mean nonmollusk species number, as it had on all three previous sampling dates. Rank order of stations varied from year to year for total nonmollusks, as it did for the mean number of crustacean species (Fig. 22). The depressed totals of both nonmollusk and crustacean species at Station HB3 in 1991 were not observed in 1992 (Figs. 21, 22), again suggesting the unusual nature of this site's 1991 data.

Nelson et al. (1992) suggested that a potential reason for the low readings at Station HB3 might have been that the samples were taken 10 m deeper than in previous years (App. Table A.1; Nelson et al. 1987, 1991, 1992). The 1992 samples for Station HB3 were taken from the same depth range as the 1986 and 1990 samples, suggesting that the depth difference may have been a factor.

Dominant taxa of the nonmollusk fauna were similar to those of previous samplings. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that of the 1991 samples. The dominant polychaete species in 1992 were the same as in previous samplings (Nelson et al. 1987, 1991, 1992). These included the polychaetes *Synelmis acuminata*, *Pionosyllis gesae*, and *Myriochele oculata*. Abundance of *Nereimyra* sp. A was reduced, compared to previous years. Representation of the sipunculan *Aspidosiphon klunzingerii* increased from 1991 levels to levels similar to those of earlier samplings.

The 1992 crustacean samples suggested that crustacean fauna were generally uninfluenced by proximity to the outfall, in contrast to the 1991 samples, which demonstrated a strong depression of both species richness and abundance at some stations in the vicinity of the outfall. The 1992 pattern is similar to the 1990 one. Overall abundances at all stations (except Sta. HB6) were more consistent with counts recorded in 1991 than in 1990. Stations HB3 and HB4, located on the southern boundary of the ZID, had low crustacean species richness in 1991, but in 1992 were among the stations highest in species richness.

All stations were marked by strong intrastation (replicate-to-replicate) variability. The abundance of replicate 2 of Station HB7 was more than ten times greater than the lowest

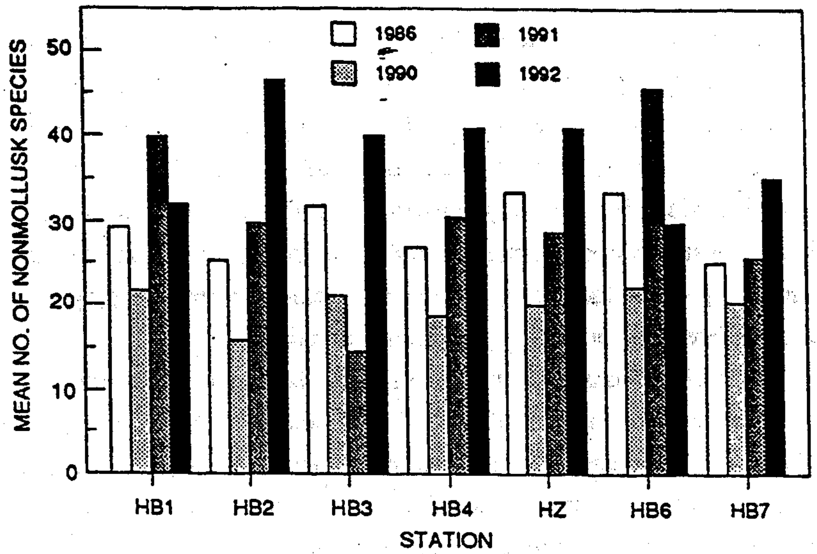

Figure 21. Comparison of mean nonmollusk species richness for samples taken in 1992, 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i

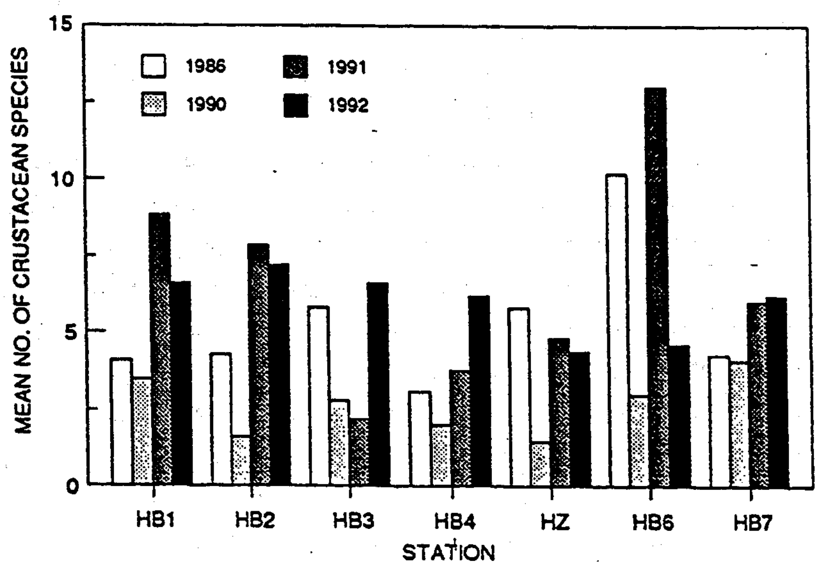

Figure 22. Comparison of mean crustacean species richness for samples taken in 1992, 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i

abundance recorded at that station (App. Table D.1.7). This intrastation variability is probably indicative of a heterogeneous benthic environment below the scale of replicate spacing.

Crustacean diversity and abundance that appeared in 1991 to be reduced adjacent to and immediately to the south of the outfall (Stas. HB3, HB4, and HZ) are now generally indistinguishable across what appears to be a rather heterogeneous bottom. The patterns of species richness and overall abundance shifting from year to year appear to be more strongly influenced by other factors, such as small-scale bottom topography and perhaps subtle sediment differences not apparent in grain-size analysis.

Overall comparisons of mean mollusk abundance and mean number of mollusk species collected in February 1992, July 1991, February 1990, and September 1986 are made in Figures 23 and 24. Because the mollusk collections are not separated into living and dead shell material, they represent time-averaged collections, which integrate conditions at a site over a longer period. As a consequence, temporal variability in mollusk abundance among sample dates is much less than for the nonmollusk fraction. On all sampling dates, the pattern of abundance in the sample area has shown a general tendency to decrease from east to west. Station HB6 consistently has had the fewest mollusk individuals (Fig. 23). The rank order of stations in terms of mean number of mollusk species shows virtually no correspondence across sampling dates (Fig. 24).

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show no evidence of a buildup of organic matter in the vicinity of the Barbers Point ocean outfall diffuser. This conclusion is confirmed by each of the physical and chemical parameters measured. Sediment TOC at all stations was below 0.5%. For comparison, the percentage of organic content ranged from 1.2% to 10.9% for sediments of the Kattegat (Pearson, Josefson, and Rosenberg 1985), and 0.6% to 8.9% for sediments off the coast of Maine (Bader 1954). The percentage of TOC ranged from 1.4% to 4.1% for stations near the Los Angeles County ocean sewage outfalls (Swartz et al. 1986). In Kingston Harbour, Jamaica, percent total organic carbon of sediments ranged from 4% to 10.7% (Wade 1972; Wade et al. 1972) in a semi-enclosed bay subject to organic pollution. The lack of evidence for organic buildup would suggest that little particulate matter from the diffuser ever reaches the sediment surface.

The spatial patterns of organism abundance and species richness in relation to the outfall varied depending on the taxonomic grouping. No pattern of reduction of either abundance or species richness at stations near the diffuser was observed for total nonmollusks, crustaceans,

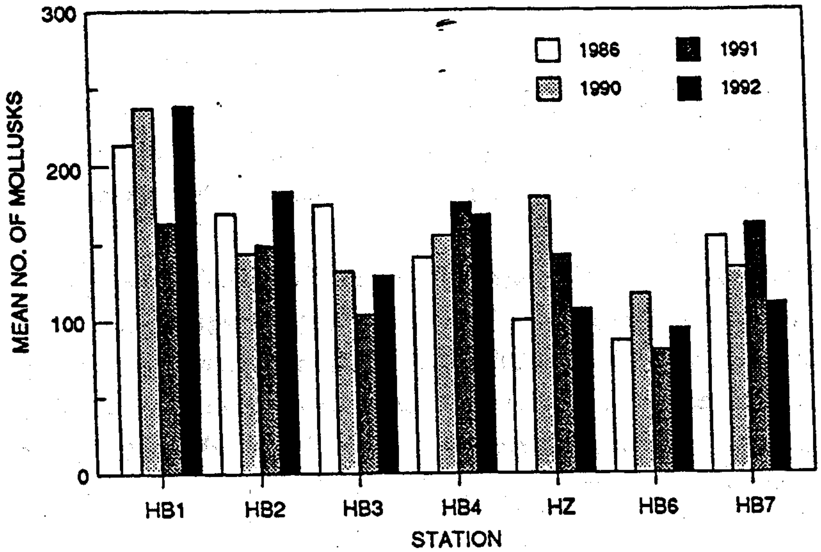

Figure 23. Comparison of mean mollusk abundance for samples taken in 1992, 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i

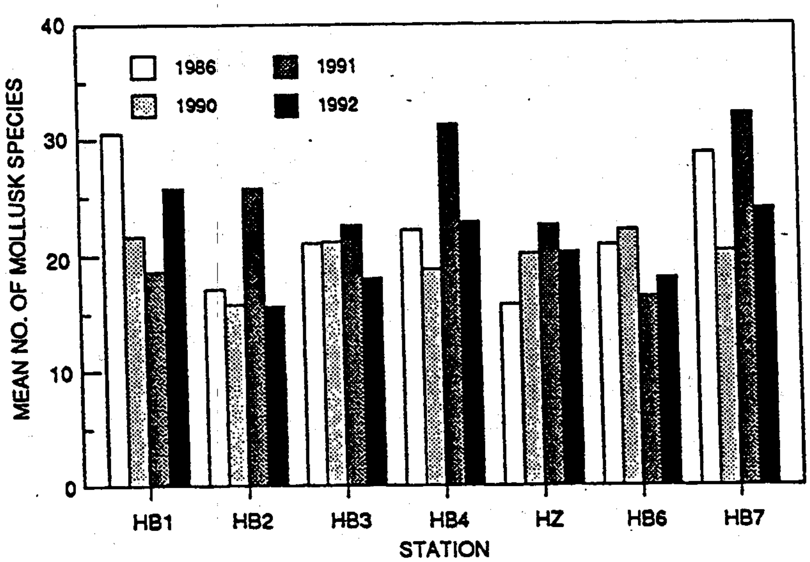

Figure 24. Comparison of mean mollusk species richness for samples taken in 1992, 1991, 1990, and 1986 at Barbers Point ocean outfall sampling stations, O'ahu, Hawai'i

or mollusks in 1992. Cluster analysis of nonmollusk data indicated that all stations were relatively similar in terms of species composition and relative abundance. The very low abundance and species richness of organisms observed in 1991 at Station HB3 did not persist in 1992. It is probable that a different location of greater depth was sampled inadvertently at Station HB3 in 1991.

Species diversity (H') and evenness (J) were relatively similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment proposed by Pearson and Rosenberg (1978) would suggest that in the transition zone on an enrichment gradient, a few species will increase and be extremely dominant, while overall diversity and evenness will be low. Neither the response pattern of the benthos nor the sediment TOC data would support the organic enrichment hypothesis.

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June 1993 Benthic Monitoring Program Results

(Nelson et al., 1994a)

BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O'AHU, HAWAI'I, JUNE 1993

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PROJECT REPORT PR-94-15

March 1994

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verification when necessary. All specimens were archived and will be maintained for six years by the City and County of Honolulu.

Data Analysis

All data were tested for assumptions of normality (Kolmogorov–Smirnov test, Sokal and Rohlf 1981) and heterogeneity of variances (Levene Median test) prior to statistical analysis. Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following ANOVA, the a posteriori Student–Newman–Keuls test was used to determine which differences among stations were significant. All statistical analyses were performed using Sigma Stat 1.1 software. Detailed statistical results are provided in Appendixes B and C.

An overall comparison of species composition among stations was carried out using cluster analysis (Pielou 1984). The Bray–Curtis dissimilarity index (Bloom 1981) on untransformed data was performed using the flexible sorting strategy. To make the analysis more manageable, only those nonmollusk species that contributed at least 0.06% of the total abundance were included in the analysis. Using this criterion, only species represented by a total of more than three individuals were included in the data set, which was reduced from 144 to 94 species. The Cluster program developed by the EPA Corvallis Environmental Research Laboratory (Mathews 1981) was used to compute the dissimilarity matrix.

The Shannon–Wiener diversity index (H') ($\log_{10}$) and evenness index (J) were calculated for all stations (all replicates pooled), as recommended in the EPA procedures. Calculations of these parameters were carried out with Quattro Pro for Windows spreadsheet software.

RESULTS

Sediment Parameters

Results of sediment grain-size analysis are given in Appendix Table A.3. The mean sediment compositions at the sampling stations, based on three grain-size categories, are compared in Figure 3. The grain-size categories (Folk 1968) were as follows: medium and coarse sand, retained on a +2-phi sieve; fine sand, passed through a +2-phi but retained on a +4-phi sieve; and silt and clay, passed through a +4-phi sieve.

All stations were generally similar in sediment grain-size distribution, except Station HB6, which had a higher percentage of medium and coarse sand and a lower percentage of fine sand than the other stations (Figure 3). Sediments at all stations were >91% sand (Appendix Table A.3). Results of replicate sediment sample analysis for all seven stations indicated homogeneity in grain size within stations (Appendix Table A.3).

Direct electrode measurements of ORP were positive in the range of +26 to +126 mV (Appendix Table A.2). These readings show no evidence of strongly reducing conditions in the surface sediments at any station. Sediment ORP values were generally similar at all stations (Appendix Table A.2). Sediment oil and grease (O&G) values were in the range of 53 to 402 mg/dry kg (Appendix Table A.2). Mean O&G values showed no trend in relation to the diffuser, with values at stations near the diffuser being similar to those at reference stations. The maximum values of sediment O&G were found at Stations HB6 and HB7, near-field and far-field reference sites, respectively.

Values for total sediment organic carbon ranged from 0.53% to 1.60% at all stations (Appendix Tables A.2). Mean TOC values per station ranged from 0.61% at Station HB3 to 1.97% at Station HB6. Thus the highest estimated values of TOC were from a reference station. There was no pattern of elevation of TOC at the ZID and ZID boundary stations.

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, sipunculans, echinoderms, nematodes, nemerteans, priapulids, phoronids, anthozoa, bryozoa, hemichordates, a chordate species, amphipods, copepods, cumaceans, decapods, isopods, ostracods, and tanaidaceans.

The 6,515 nonmollusk specimens counted and identified for all stations and replicates represent 144 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (2,464, 37.8%) and species richness (87 species). Nematodes were the second most dominant nonmollusk taxon in terms of abundance (27.5%). Oligochaetes constituted 8.1% of numerical abundance, with crustaceans contributing an additional 16.6%. The 36 crustacean taxa, 14 of which were amphipods, represented 25% of the total number of nonmollusk taxa. Abundance estimates for each species in each replicate are given in Appendix D.

Basic statistics for the nonmollusk data, including 95% confidence limits and a Kolmogorov–Smirnov test for normality of distribution are provided in Appendix Table B.1. (number of individuals) and Appendix Table B.2. (number of species). Data were normal for most stations; an exception was data on nonmollusk individuals at Station HB6. Deviations from normality were not deemed sufficiently extreme to require transformation. ANOVA is robust for moderate deviations from normality of data (Sokal and Rohlf 1981).

Mean total nonmollusk abundance ranged from 117.4 individuals per sample (25,875/m^2) at Station HB3 to 276 individuals per sample (60,830/m^2) at Station HZ

(Figure 4). There were significant differences in mean abundance among stations (ANOVA, Appendix Table B.3). Station HZ had significantly more individuals than Stations HB3, HB7, and HB2 (Student–Newman–Keuls test, Appendix Table B.3). No other differences were significant.

The mean number of nonmollusk species per sample ranged from a low of 26.0 species at Station HB2 to a high of 42.6 species at Station HB1 (Figure 5). There were no significant differences in mean number of species per sample among stations (ANOVA, Appendix Table B.4).

Composite station diversity (H') and evenness (J) are shown in Figure 6. Patterns of diversity and evenness were highly similar among stations. Values for both parameters were similar at all stations, with the exception of Station HB2, which had somewhat lower values. This was unlike the situation in 1992 when Station HB2 had the highest diversity and evenness values (Nelson et al. 1992b). In 1993, values for diversity ranged from 2.3 (Station HB2) to 3.5 (Station HB3). With the exception of Station HB2, the range of values was extremely similar to that of samples taken in previous years (Nelson et al. 1987, 1991, 1992a, 1992b). Evenness ranged from 0.57 (Station HB2) to 0.82 (Station HB3), which was comparable to the range of values observed in previous years (Nelson et al. 1987, 1991, 1992a, 1992b). Relative to other stations, there was no pattern of lower diversity or evenness at ZID or near-ZID stations.

Results of cluster analysis indicating the relative dissimilarity of stations based on the 94 most abundant nonmollusk species are shown in Figure 7. The grouping pattern of stations differed almost completely from 1992: one group included three ZID stations (HB4, HZ, and HB2) and the near-field reference station HB6; the second group included reference stations HB1 and HB7; and the third group had only the remaining ZID station, HB3, which was most dissimilar to the other six stations. Station HB3 had far lower abundances of oligochaetes and nematodes than all the other stations.

Polychaetes

A total of 2,464 polychaetes, representing 37.8% of total nonmollusk abundance, were collected. The greatest number of polychaetes were found at Station HB4 (553), followed in decreasing order by Station HZ, HB6, HB1, HB7, and HB3. The fewest were found at Station HB2 (171) (Figure 8). The polychaetes were the most species-rich group at all stations (Appendix Tables D.1 through D.7). Maximum polychaete species richness occurred at Station HB1 (56), followed by Station HZ (52), Stations HB7 and HB4 (47 each), Station HB3 (46), Station HB6 (44), and Station HB2 (34) (Figure 9).

Dominant polychaetes were different at several of the stations. The sabellid *Euchone* sp. B was a dominant species at all stations except HB7. In addition to the sabellid *Euchone* sp. B, the spionid *Polydora normalis* was equally abundant at Station HZ. Another sabellid, *Augeneriella dubia*, was dominant at Station HB4. The oweniid *Myriochele oculata* was dominant at Stations HB3, HB4, HB6, and HZ. The syllid *Pionosyllis gesae* and the pilargid *Synelmis acuminata* were the dominant species at Station HB7.

Trophic categories. Trophic categories are based on Fauchald and Jumars (1979) and are summarized in Figures 10 and 11.

1. Detritivores. Deposit-feeding polychaetes were both most abundant (239) and most speciose (23) at Station HZ. After Station HZ, species of deposit-feeding polychaetes were most numerous at Station HB7 (22), followed by Stations HB6, HB3, and HB1, all with 21 species.

The dominant polychaetes in the deposit-feeding category were *Polydora normalis* (at Station HZ), *Myriochele oculata* (at Stations HB6, HB3, HB4, and HZ), and *Prionospio cirrifera* (at Station HB1).

2. Omnivores. In terms of percentage of total polychaetes, omnivorous worms were best represented at Station HB7; this is consistent with the results of the 1986, 1990, 1991, and 1992 surveys (Nelson et al. 1987, 1991, 1992a, 1992b). The syllid *Pionosyllis gesae* and the pilargid *Synelmis acuminata* dominated the omnivorous component in the total collection. *S. acuminata* and *Nereis* sp. B were the most abundant omnivores at Station HB6, and *S. acuminata* was the dominant omnivore at Station HZ.

3. Suspension feeders. The highest numbers of suspension feeders (primarily the families Sabellidae and Serpulidae) were found at Stations HB4 and HZ. The most species-rich stations were HZ, HB4, and HB1. The fewest suspension feeders were found at Stations HB7 and HB3 and the most (*Augeneriella dubia* and *Euchone* sp. B) at Station HB4.

4. Carnivores. Carnivorous polychaetes were present at all stations, with maximum abundances at Stations HZ and HB6. The eunicid complex (Eunicidae, Lumbrineridae, Onuphidae, and Dorvilleidae), the amphinomid *Linopherus microcephala*, and the hesionids *Nereimyra* sp. A and *Podarke angustifrons* comprised most of the carnivorous polychaetes. The greatest species richness was found at Station HB1, followed by Station HB4.

Motility categories. Motility categories are based on Fauchald and Jumars (1979) and are summarized in Figures 12 and 13.

Tubicolous worms (*Myriochele oculata*, the sabellids *Augeneriella dubia* and *Euchone* sp. B, and the spionids *Prionospio cirrifera*, and *Polydora normalis*) dominated the polychaete fauna at Stations HB4, HZ, and HB6. The motile omnivore *Synelmis acuminata* dominated Stations HB4 and HB7. The spionids (e.g., *Prionospio cirrobranchiata*, *P. cirrifera* and *Polydora normalis*) were the most species-rich and numerically dominant family in the discretely motile category.

Tubicolous worms had their largest proportional representation in terms of abundance at Station HB4 (almost twice as many as any other station). The greatest percentage of species in the tubicolous category was found at Stations HZ and HB4.

Reproductive condition was evident for *Fabricia* sp. A (at Station HZ), *Sphaerosyllis taylori* (at Stations HB1, HB2, HB3, and HB4), *S. capensis* (at Stations HB1, HB2, and HB4), *S. sublaevis* (at Station HB1), and *Exogone longicornis* (at Station HB4).

Crustaceans

A total of 1,079 crustaceans were collected. Mean crustacean abundances (no./sample) ranged from 19.8 (4,364/m^2) at Station HB2 to 50.6 (11,151/m^2) at Station HB6 (Figure 14). There were no significant differences in mean abundance of crustaceans among stations (ANOVA, Appendix Table B.5).

A total of 36 taxa (copepods were not identified to the species level) of crustaceans were collected; of these, 14 species (39%) were amphipods. Mean number of crustacean species ranged from 5.6 at Station HB2 to 9.60 at Station HB1 (Figure 15). There were no significant differences in mean number of crustacean species among stations (ANOVA, Appendix Table B.6).

Tanaidaceans, amphipods, and copepods were the numerically dominant taxa, making up 47.1%, 32.2%, and 7.5%, respectively, of total crustacean abundance. No species was uniformly most abundant at all stations. The amphipod *Eriopisella sechellensis* and the tanaids *Leptochelia dubia*, *Leptochelia* sp. A, and *Tanaissus* sp. A were present at most stations and were generally among the most abundant.

Five new taxa not previously collected in the study area were added in 1993, including small marine mites (Acari, Halacaridae). Since 1990, 76 taxa have been collected at least once in the Barbers Point study area. The total number of taxa collected in the entire Barbers Point study area in 1993 was 36, which is consistent with the number collected in most of the earlier years (although in 1990, 49 taxa were collected). This constancy tends to reinforce the consistency of the benthic environment in the Barbers Point study area. Many of the rarer taxa collected in earlier years, such as the interesting meiofaunal crustaceans (*Microcharon* and *Caecianiropsis*) present in 1991, were not collected in 1993. However, since samples were sorted on a 0.5-mm screen, collection of meiofauna was generally poor. As in earlier years, some copepods were also found at these stations. Copepod specimens were not identified below the subclass level; some appeared to be planktonic forms. A complete list of crustacean species abundance for all replicates and stations is given in Appendix Tables D.8 through D.14.

Mollusks

Mean abundance of mollusks per sample (no./10 cm^3) ranged from a low of 106.4 at Station HB6 to a high of 180.1 at Station HB1 (Figure 16). Data at all stations were normally distributed (Appendix Table C.1). Complete basic statistics for total mollusk data are shown in Appendix Table C.1.

Mean number of mollusk species per sample ranged from a low of 17.2 at Station HB2 to a high of 29.2 at Station HB1 (Figure 17). Data at all stations were normally distributed (Appendix Table C.2). Complete basic statistics for number of mollusk species at all stations are shown in Appendix Table C.2. Variances for number of mollusk species data were homogeneous (Appendix Table C.4). There were significant differences in mean mollusk species richness among stations (ANOVA, Appendix Table C.4.). Station HB1 had significantly more mollusk species than all other stations. Station HB7 had significantly more mollusk species than Station HB2. No other differences were significant.

Variances for mollusk abundance data were homogeneous (Appendix Table C.3.). There were significant differences in mean mollusk abundance among stations (ANOVA, Appendix Table C.3). Mean abundance was significantly greater at Station HB1 than at all other stations. Stations HB2 and HB4 did not differ significantly from each other, but both stations had significantly greater abundance than Stations HB3, HZ, HB6, and HB7. No other differences in means were significant.

Diversity (H') ranged from a low of 2.04 at Station HB2 to a high of 2.60 at Station HB7 (Figure 18). Evenness (J) ranged from 0.45 at Station HB2 to 0.58 at Station HB1. Diversity and evenness values for mollusks were extremely similar for all stations (Figure 18).

The gastropod taxa, *Balcis* spp., *Cerithidium perparvulum*, *Diala scopulorum*, and *Scaliola* spp., were abundant at all stations. An additional species, *Finella pupoides*, was abundant at all stations except HB1 and HB7. These mollusk abundance patterns are consistent with all previous samplings (Nelson et al. 1987, 1991, 1992a, 1992b). A mollusk species abundance list for all stations and replicates is provided in Appendix E.

DISCUSSION

Station HZ (in the ZID) had significantly more nonmollusk individuals than Stations HB3 and HB2 (on the ZID boundary) and Station HB7 (far field). Station HZ did not differ from either reference stations HB1 and HB6 or ZID-boundary station HB4. Nematode abundance was greater at Station HZ than at other stations and is the primary reason for the elevated abundance recorded. Abundances of other taxa were very similar among stations. There were no significant differences in crustacean abundance among stations.

Mollusk abundance was significantly greater at reference Station HB1 than at all other stations. ZID boundary stations HB2 and HB4 did not differ from each other, but they had significantly higher mollusk abundances than reference station HB6. The remaining stations, including ZID station HZ, near-ZID station HB3, and reference station HB7, did not differ in mollusk abundance. Thus, there was no general statistically significant pattern with regard to mollusk abundance and proximity to the diffuser. The high abundance of mollusks at Station HB1 was the same as in 1992 (Nelson et al. 1992b).

There were no significant differences among stations in number of nonmollusk species, nor were there any significant differences for the crustacean component of the nonmollusks. No clear pattern with regard to mollusk species richness was seen. Reference stations HB1 and HB7 had the greatest number of mollusk species, a pattern consistent with the 1992 study (Nelson et al. 1992b). Reference station HB7 had more mollusk species than station HB2 but did not differ from other near-ZID stations. Similarly, reference station HB6 did not differ significantly from the near-ZID stations. Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. Station HB2 had somewhat lower mollusk diversity and evenness values than the other stations; it also had the lowest nonmollusk diversity and evenness values, differing from the previous year when it had the highest values (Nelson et al. 1992b). Thus, there is little evidence that the outfall is having a consistent effect on species richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis dissimilarity index indicated that nonmollusk abundance and species composition were broadly similar at most stations. In past years, cluster analysis consistently intermixed ZID, near-ZID, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b). In 1993, some separation between ZID and reference stations was observed, although near-field reference station HB6 was grouped with three of the ZID stations. Station HB3, on the ZID boundary, was shown to be the most dissimilar to the other six stations. Inspection of the data matrix indicates this was due to far lower values of both oligochaetes and nematodes at this station compared with all other sample sites.

As in previous Barbers Point outfall studies, sediment grain sizes in the 1993 samples were broadly similar among stations. An exception was the relatively lower percentage of fine sand at Station HB6. This difference was present in 1992, but there was no indication of such a difference in sediment grain size in samples taken in 1991 (Nelson et al. 1992a, 1992b). The variation in grain size from year to year would suggest some degree of spatial heterogeneity of sediments at these stations. The percentage of fine sediments at the ZID and ZID-boundary stations showed no increase over samples taken from 1986 through 1992 (Nelson et al. 1987, 1991, 1992a, 1992b). An increase in the silt/clay fraction of the sediments occurred at all stations since the precious year's sampling (for comparison see Fig. 3 in Nelson et al. 1992b). Because the increase occurred at all seven stations, it is unlikely that this was an effect of the outfall.

During visual inspection of the sediment while elutriating for biological sample processing, it was noticed that the color of samples from Station HB7 was different from that at all other stations. Samples at Station HB7 were beige, whereas samples at the other stations were gray. Also visibly apparent was the amount of the fine component in the Barbers Point sediment samples: it was higher than in previous years. Samples were more similar to previous Sand Island samples than previous Barbers Point samples. It is possible that Hurricane Iniki (September 1992) may have played a role in causing this difference. The swell associated with the storm was primarily from the south-southeast and may have moved large amounts of sediment from the Sand Island area to the west or may have brought buried fine particles up to the sediment surface. The physical impact of Iniki, if the storm stirred up previously buried sediments, may account for the gray sediment noticed at most stations.

The increased relative abundance of the tube-building sabellid polychaetes *Augeneriella dubia* and *Euchone* sp. B, the most abundant polychaetes in 1993, may be a response to the increase in fine particulate matter. These species use fine particles both for tube building and for food.

Sediment ORP showed no evidence of reducing conditions at the surface of sediments at any station. There was no evidence of a diffuser-related trend in sediment O&G values. In 1993, highest values were observed at reference station HB7, whereas in 1992, highest values were observed at reference station HB1. Mean sediment total TOC was consistently higher and more variable among stations in 1993 than in 1992. In 1993 the analytical method for TOC was changed to the determination of COD, with an approximate conversion to TOC. This change resulted from problems experienced by the contractor in the direct determination of TOC with the carbonate-rich sediments sampled from the Barbers Point Ocean Outfall area.

The total number of nonmollusk taxa recorded in the 1993 study (144) was slightly less than that recorded in previous studies (162 in 1986, 164 in 1990, 162 in 1991, and 175 in 1992). The total number of crustacean taxa collected in 1993 (36) was similar to that collected in 1992 (35). Although there have been differences in levels of sampling effort and taxonomic resolution (Nelson et al. 1991), overall nonmollusk species richness in the study area appears to have remained very similar over the period from 1986 to 1992. In 1993, fewer replicates had coral rubble in them than in 1992. The acid-bath fraction could have contributed to the somewhat higher species richness and abundance recorded in 1992, as compared to those recorded in other sampling years.

Overall comparisons of mean nonmollusk abundance and mean crustacean abundance for samples collected in June 1993, February 1992, July 1991, February 1990, and September 1986 are shown in Figures 19 and 20. Nonmollusk abundances at most stations in 1993 were similar to those recorded in other years; however, higher values were seen at Stations HZ and HB6. Abundance at Station HB4 was high in both 1992 and 1993. In all cases, elevations were due to higher abundance of nematodes at the sites.

Crustacean abundances at most stations were similar for all years (Figure 20); however, relative to previous collections, elevations were seen at Stations HB3, HB4, and HZ. The pattern of crustacean abundance at Station HB6 has varied greatly from year to year. These differences may be partly the result of seasonal variations in crustacean abundance. However, a comparison of 1990 samples with 1992 samples, both of which were taken in February, indicates that at most stations there are interannual variations in abundance that are not related solely to seasonal differences.

The strongly depressed nonmollusk abundance at Station HB3 in 1991 was not recorded in previous years nor in 1992 or 1993 (Figure 19). Rank order of abundance among stations has varied from sample date to sample date. With the exception of Station HB3 in 1991, from which an anomalous sample appears to have been taken, there has been no indication of depression in nonmollusk abundance at near-ZID stations over the sampling period.

Overall comparisons of mean number of nonmollusk species and mean number of crustacean species for samples collected in June 1993, February 1992, July 1991, February 1990, and September 1986 are presented in Figures 21 and 22. The 1993 nonmollusk and crustacean species graphs indicate a general similarity in species richness among stations. This similarity has been the case in most years sampled. The exception was for 1991, when wide differences among species numbers at stations were observed. Rank order of stations varied from year to year for mean number of nonmollusk species, as it did for the mean number of crustacean species (Figure 22). The depression in number of species for both nonmollusks and crustaceans at Station HB3 in 1991 was not recorded in 1993 (Figures 21 and 22), confirming the conclusion of the 1992 study (Nelson et al. 1992b) that the 1991 sample data at HB3 were aberrant.

Dominant taxa of the nonmollusk fauna were similar to those in previous samples. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that in previous samples. The dominant polychaete species in 1993 differed somewhat from those in previous samples (Nelson et al. 1987, 1991, 1992a, 1992b). Previous dominant species that were also dominant in 1993 included the polychaetes *Synelmis acuminata* and *Myriochele oculata*. *Euchone* sp. B. and *Augeneriella dubia* were first and second in polychaete abundance in 1993. Abundances of *Nereimyra* sp. A and *Pionosyllis gesae* were reduced somewhat from previous years. As in previous years, the crustacean fauna in the vicinity of the Barbers Point outfall was dominated by amphipods, isopods, and tanaidaceans. These groups may be integrating indicators of the long-term status of the benthic community, given their reproductive strategy of brooding larvae. Compared to the Waianae, Sand Island, and Mokapu outfall study areas (Nelson et al. 1986), the entire Barbers Point study area (both control and outfall stations) seems rather depressed in decapods.

In 1993 crustacean abundance and species richness appeared generally uninfluenced by proximity to the outfall; in contrast, in 1991 they appeared strongly depressed at some stations in the vicinity of the outfall. The 1993 sample counts were similar to the 1992 and 1990 counts, which also did not reflect outfall-related depression of crustaceans. Overall abundances at all stations in 1993 were more consistent with counts recorded in 1991 than in 1990 (corrected for the greater sampling effort in 1990). In 1993, Station HZ, located on the inshore boundary of the ZID, was the second highest station in mean abundance (Figure 20) and total species richness (Appendix Table D.12).

All stations were marked by strong intrastation (replicate-to-replicate) variability in both species counts and abundances. At Station HZ replicate 1 was over 50 times as abundant as the lowest replicate. Intrastation variability is probably indicative of a heterogeneous benthic environment below the scale of replicate spacing. Although the entire area is generally homogeneous and unaffected with respect to the presence of the outfall, small-scale patchiness (on a scale of 1 m to less than 10 m) appears to greatly affect the composition and abundance of the crustacean communities. This is reflected in the high variances among replicates within stations.

Crustacean diversity and abundance, which appeared in 1991 to be reduced adjacent to the outfall (Stations HB3, HB4, and HZ), are now generally indistinguishable across what appears to be a rather heterogeneous bottom in this general area. The patterns of species richness and overall abundance shifting from year to year appear to be more strongly influenced by other factors, such as small-scale bottom topography.

Overall comparisons of mean mollusk abundance and mean number of mollusk species collected in June 1993, February 1992, July 1991, February 1990, and September 1986 are shown in Figures 23 and 24. Because the mollusk collections are not separated into living and dead shell material, they represent time-averaged collections that integrate conditions at a site over a longer period. Temporal variability in mollusk abundance among sampling dates is much less than for the nonmollusk fraction. The pattern of abundance in the sample area on all dates has shown a general tendency to decrease from east to west. Station HB6 has consistently had the fewest mollusk individuals (Figure 23). There is little correspondence across sample dates for all stations in terms of their rank order for mean number of mollusk species, although there was a tendency for Stations HB1 and HB7 to have the greatest species numbers (Figure 24).

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show no evidence of a buildup of organic matter in the vicinity of the Barbers Point Ocean Outfall diffuser. This conclusion is confirmed by each of the physical and chemical parameters measured. Sediment TOC, estimated by COD, was higher at all stations in 1993 than in previous years, with a maximum of 1.37%. The high 1993 values are believed to be a methodological bias. Uncertainty associated with the conversion factor from COD to TOC may account for the bias. For comparison, the percentage of organic content ranged from 1.2% to 10.9% for sediments of the Kattegat (Pearson et al. 1985) and 0.6% to 8.9% for sediments off the coast of Maine (Bader 1954). The percentage of TOC ranged from 1.4% to 4.1% for stations near the Los Angeles County ocean sewage outfalls (Swartz et al. 1986). In Kingston Harbour, Jamaica, the percentage of sediment TOC ranged from 4% to 10.7% in a semi-enclosed bay subject to organic pollution (Wade 1972; Wade et al. 1972). The lack of evidence for organic buildup would suggest that little particulate matter from the diffuser ever reaches the sediment surface.

The spatial patterns of organism abundance and species richness in relation to the outfall varied depending on the taxonomic grouping. No pattern of reduction of either abundance or species richness at stations near the diffuser was observed for total nonmollusks, crustaceans, or mollusks in 1993. Cluster analysis of nonmollusk data indicated that most stations were relatively similar to one another in terms of species composition and relative abundance.

Species diversity (H') and evenness (J) were relatively similar among all stations for both total nonmollusks and mollusks, although Station HB2 had somewhat lower values of both parameters than the other stations. The model of benthic organic enrichment proposed by Pearson and Rosenberg (1978) states that in the transition zone on an enrichment gradient, a few species increase and are extremely dominant, while overall diversity and evenness are low. Station HB2 had the fewest polychaete species; this was the primary cause of the lower diversity and evenness observed. This pattern was not previously observed at this station, and in the absence of similar depressions at other ZID-boundary stations, it is unlikely that the slight depression of diversity was an outfall effect. Neither the response pattern of the benthos nor the sediment TOC data would support the organic enrichment hypothesis as a cause for the change in diversity.

January-February 1994 Benthic Monitoring Program Results

(Nelson et al., 1994b)

BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O'AHU, HAWAI'I, JANUARY–FEBRUARY 1994

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PROJECT REPORT PR-95-01

July 1994

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The Shannon–Wiener diversity index (H') (log_{10}) and evenness index (J) were calculated for all stations (all replicates pooled), as recommended in the EPA procedures. Calculations of these parameters were carried out with Quattro Pro for Windows spreadsheet software.

RESULTS

Sediment Parameters

Results of sediment grain-size analysis are given in Appendix Table A.3. The mean sediment compositions at the sampling stations, based on three grain-size categories, are compared in Figure 3. The grain-size categories (Folk 1968) were as follows: medium and coarse sand, retained on a +2-phi sieve; fine sand, passed through a +2-phi but retained on a +4-phi sieve; and silt and clay, passed through a +4-phi sieve.

Of the four stations for which sediment grain size data are available, Station HB7 had with a greater percentage of medium and coarse sand and a lower percentage of fine sand than the other three stations (Figure 3). In past collections, Station HB6 also had a much higher percentage of medium and coarse sand and a lower percentage of fine sand than the other stations. Sediments at all stations were >90% sand (Appendix Table A.3). Results of replicate sediment sample analysis indicated homogeneity in grain size within stations (Appendix Table A.3).

Direct electrode measurements of ORP were in the range of +42 to +261 mV (Appendix Table A.2). These readings show no evidence of strongly reducing conditions in the surface sediments at any station. Comparison of mean ORP per station (one way ANOVA) found highly significant ($F = 9.6$, $df = 6, 28$; $p < 0.0001$) differences among stations. Mean ORP was higher at station HB2 than at all other stations, and higher at Stations HB1 and HZ than Stations HB4 and HB6. No other comparisons were significant.

Sediment oil and grease (O&G) values were in the range of 46 to 647 mg/wet kg (Appendix Table A.2). Mean O&G values ranged from 103.7 mg/kg at Station HB2 to 367.3 mg/kg at station HB4. Mean values showed no trend in relation to the diffuser, with values at stations near the diffuser overlapping those at reference stations. The maximum values of mean sediment O&G were found at Stations HB4 (367.3 mg/kg) and HZ (322 mg/kg), a ZID-boundary site and the within-ZID site, respectively.

Values for total sediment organic carbon ranged from 0.12% to 0.60% at all stations (Appendix Table A.2). Mean TOC values per station ranged from 0.14% at Station HB7 to 0.37% at Station HB1. Thus the highest estimated values of TOC were from a far-field reference station. TOC values were very similar among stations, and there was no pattern of elevation of TOC at the ZID and ZID-boundary stations.

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, sipunculans, echinoderms, nematodes, nemerteans, priapulids, phoronids, anthozoa, bryozoa, hemichordates, a chordate species, amphipods, copepods, cumaceans, decapods, isopods, ostracods, and tanaidaceans.

The 6,246 nonmollusk specimens counted and identified for all stations and replicates represent 159 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (2,685 individuals, 43%) and species richness (90 species). Other numerically dominant taxa were crustaceans (17.9%), nematodes (17.6%), and oligochaetes (11.6%). The 44 crustacean taxa, 17 of which were amphipods, represented 27.6% of the total number of nonmollusk taxa. Abundance estimates for each species in each replicate are given in Appendix D.

Basic statistics for the nonmollusk data, including 95% confidence limits and a Kolmogorov–Smirnov test for normality of distribution are provided in Appendix Table B.1 (number of individuals) and Appendix Table B.2 (number of species). Data were normal for most stations; exceptions were data on nonmollusk individuals at Stations HB2 and HB6. Deviations from normality were not deemed sufficiently extreme to require transformation. ANOVA is robust for moderate deviations from normality of data (Sokal and Rohlf 1981).

Mean total nonmollusk abundance ranged from 140.8 individuals per sample (31,032/m^2) at Station HB7 to 211.8 individuals per sample (46,680/m^2) at Station HB4 (Figure 4). Variances were homogenous (Appendix Table B.3). There were no significant differences in mean abundance among stations (ANOVA, Appendix Table B.3).

The mean number of nonmollusk species per sample ranged from a low of 33.4 species at Station HB2 to a high of 42.2 species at Station HB3 (Figure 5). Variances were homogenous (Appendix Table B.4). There were no significant differences in mean number of species per sample among stations (ANOVA, Appendix Table B.4).

Composite station diversity (H') and evenness (J) are shown in Figure 6. Patterns of diversity and evenness were highly similar among stations. Values for both parameters were similar for all stations. Values for diversity ranged from 2.96 (Station HB2) to 3.59 (Station HB3). The range of values was extremely similar to that of samples taken in previous years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994). Evenness ranged from 0.68 (Station HZ) to 0.79 (Station HB3), which was also comparable to the range of values observed in previous years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994). Relative to the other stations, there was no pattern of lower diversity or evenness at ZID or near-ZID stations.

Results of cluster analysis indicating the relative dissimilarity of stations based on the 97 most abundant nonmollusk species are shown in Figure 7. The grouping pattern of stations was somewhat similar to that seen in 1993: one group included three ZID stations (HB4, HZ, and HB2) and the near-field reference station HB6; the second group included reference stations HB1 and HB7 and ZID station HB3. Unlike the 1993 pattern which showed that Station HB3 was least similar to all other stations, the 1994 pattern showed that Station HB3 was highly similar to Stations HB1 and HB7.

Polychaetes

A total of 2,685 polychaetes, representing 43% of total nonmollusk abundance, were collected. The greatest number of polychaetes were found at Station HB2 (525), followed in decreasing order by Stations HB6, HZ, HB4, HB3, and HB1; the fewest were found at Station HB7 (198) (Figure 8). The polychaetes were the most species-rich group of nonmollusks at all stations (Appendix Tables D.1 through D.7). Maximum polychaete species richness occurred at Station HB3 (63), followed by Station HZ (52), Station HB7 (51), Station HB1 (45), Stations HB2 and HB4 (43 each), and Station HB6 (38) (Figure 9).

Dominant polychaetes were different at several of the stations. The sabellid *Euchone* sp. B was a dominant species at Stations HB1, HB2, and HB6. The spionid *Prionospio cirrobranchiata* was dominant at Station HB3 and the oweniid *Myriochele oculata* at Station HB4. The pilargid *Synelmis acuminata* and the syllid *Pionosyllis* cf. *gesae* were the dominant species at Station HB7, whereas the spionid *Polydora normalis* continued to be the dominant species at Station HZ.

Trophic categories. Trophic categories are based on Fauchald and Jumars (1979) and are summarized in Figures 10 and 11.

1. Detritivores. Deposit-feeding polychaetes were most abundant at Station HZ (305) and most speciose (28) at Station HB3. After Station HB3, species of deposit-feeding polychaetes were most numerous at Station HZ (25), followed by Stations HB1 and HB4 (21 each) and Stations HB2 and HB7 (18 each).

The dominant polychaetes in the deposit-feeding category were *Polydora normalis* (at Station HZ), *Myriochele oculata* (at Stations HB1, HB4, and HB6), *Prionospio cirrifera* (at Station HB7), and *Prionospio cirrobranchiata* (at Stations HB2 and HB3).

2. Omnivores. In terms of percentage of total polychaetes, omnivorous worms were best represented at Station HB7; this is consistent with the results of the 1986, 1990, 1991, 1992, and 1993 surveys (Nelson et al. 1987, 1991, 1992a, 1992b, 1994). In terms of total polychaete abundance, omnivores comprised the largest trophic group at Station HB7, with the syllid *Pionosyllis* cf. *gesae* and the pilargid *Synelmis acuminata* dominating this component, as

in 1993. *S. acuminata* was also the dominant omnivore at Station HZ, whereas *Pionosyllis* cf. *gesae* was the most abundant omnivore at Station HB4.

3. Suspension feeders. The highest abundance of suspension feeders (primarily the families Sabellidae and Serpulidae) were found at Stations HB2 and HB6. Suspension feeders made up the smallest proportion of the community at Stations HB4 and HB7. The largest proportion of suspension feeders (55%) was found at Station HB2 (primarily *Euchone* sp. B).

4. Carnivores. Carnivorous polychaetes were present at all stations, with maximum abundances at Station HB4, followed by Stations HB2 and HB3. The eunicid complex (Eunicidae and Lumbrineridae), the goniadid *Goniada emerita*, and the hesionids *Nereimyra* sp. A and *Podarke angustifrons* comprised most of the carnivorous polychaetes. The greatest species richness occurred at Stations HB3 and HB7, followed by Station HB2.

Motility categories. Motility categories are based on Fauchald and Jumars (1979) and are summarized in Figures 12 and 13.

Tubicolous worms (*Myriochele oculata* and the sabellid *Euchone* sp. B) dominated the polychaete fauna at Stations HB2, HZ, and HB6. The motile omnivore *Synelmis acuminata* dominated Station HB7. The syllid *Pionosyllis* cf. *gesae* and the hesionid *Podarke angustifrons* were the dominant motile polychaetes at Stations HB3, HB4, and HB6. The spionids (e.g., *Prionospio cirrobranchiata*, *Aonides* sp. A, and *Polydora normalis*) were the most species-rich and numerically dominant family in the discretely motile category.

Reproductive condition was evident for *Sphaerosyllis taylori* (one individual with eggs at each of Stations HB2, HB4, and HB6), and three juvenile *Prionospio cirrobranchiata* were found at Station HB3.

Crustaceans

A total of 1,121 crustaceans were collected. Mean crustacean abundances (no./sample) ranged from 13.2 (2,909/m^2) at Station HZ to 53.6 (11,813/m^2) at Station HB7 (Figure 14). Variances were homogeneous. There were no significant differences in mean abundance of crustaceans among stations (ANOVA, Appendix Table B.5).

A total of 44 taxa (copepods were not identified to the species level) of crustaceans were collected; of these, 17 species (38%) were amphipods. Mean number of crustacean species ranged from 6.4 at Station HB2 to 13.6 at Station HB6 (Figure 15). Variances were homogeneous and data for all stations were normally distributed. There was a significant difference in mean number of crustacean species among stations, with Station HB6 having significantly more species than Station HB2 (ANOVA, Appendix Table B.6). No other comparisons among stations were significant.

Amphipods, tanaidacea, and copepods were the numerically dominant taxa, making up 58%, 25%, and 4.3%, respectively, of total crustacean abundance. No species was uniformly most abundant at all stations. The amphipod *Eriopisella sechellensis* and the tanaids *Leptochelia dubia, Leptochelia* sp. A, and *Tanaissus* sp. A were present at most stations and were generally among the most abundant.

Nine new taxa not previously collected in the study area were added in 1994. The rarer meiofaunal crustacean taxa (*Microcharon* and *Caecianiropsis*) and the marine mites collected earlier were not collected. However, since initial sorting is done at the 0.5-mm screen level, consistent collection of meiofaunal species should not be expected. Since 1990, 85 taxa have been collected at least once in the Barbers Point study area. The total number of taxa collected in the entire Barbers Point study area in 1994 was 44, second only to 1990, when 49 taxa were collected. Generally, between 36 and 49 taxa are collected each year across the entire outfall study area. This constancy reinforces the view that the Barbers Point outfall study area is not subject to large swings in benthic community composition or consistency and generally represents a rather stable environment. This should aid in identifying any impacts associated with the outfall itself. A complete list of crustacean species abundance for all replicates and stations is given in Appendix Tables D.8 through D.14.

Mollusks

Mean abundance of mollusks per sample (no./10 cm^3) ranged from a low of 129.8 at Station HB2 to a high of 277.2 at Station HB1 (Figure 16). Data at all stations were normally distributed (Appendix Table C.1). Complete basic statistics for total mollusk data are shown in Appendix Table C.1.

Mean number of mollusk species per sample ranged from a low of 16.2 at Station HB2 to a high of 27.8 at Station HB1 (Figure 17). Data at all stations were normally distributed (Appendix Table C.2). Complete basic statistics for number of mollusk species at all stations are shown in Appendix Table C.2. Variances for mollusk abundance data were homogeneous (Appendix Table C.3). There were significant differences in mean mollusk abundance among stations (ANOVA, Appendix Table C.3). Mean abundance was significantly greater at Station HB1 than at all other stations. Stations HB3 and HZ did not differ, but both had significantly greater abundances than the remaining stations. No other differences in means were significant.

Variances for number of mollusk species data were homogeneous (Appendix Table C.4). There were significant differences in mean mollusk species richness among stations (ANOVA, Appendix Table C.4). Station HB1 had significantly more mollusk species than Stations HB2 and HB6. Station HB3 had significantly more mollusk species than Station HB2. No other differences were significant.

Diversity (H') ranged from a low of 1.91 at Station HZ to a high of 2.40 at Station HB7 (Figure 18). Evenness (J) ranged from 0.41 at Station HZ to 0.52 at Station HB1. Diversity and evenness values for mollusks were similar for all stations (Figure 18).

The gastropod taxa *Balcis* spp., *Cerithidium perparvulum*, *Diala scopulorum*, and *Scaliola* spp. were abundant at all stations. An additional species, *Finella pupoides*, was abundant at all stations except HB1 and HB7. These mollusk abundance patterns are consistent with those for all previous samplings (Nelson et al. 1987, 1991, 1992a, 1992b, 1994). A mollusk species abundance list for all stations and replicates is provided in Appendix E.

DISCUSSION

There were no significant differences in either total nonmollusk abundance or crustacean abundance among stations. In 1993, nematode abundance was greater at Station HZ than at the other stations, resulting in a significantly elevated number of total nonmollusks at this station. In 1994, abundances of all taxa were generally similar among stations.

Mollusk abundance was significantly greater at reference station HB1 than at all other stations, as was the case in 1993. ZID station HZ and near-ZID station HB3 did not differ from each other, but they had significantly higher mollusk abundances than all other stations. The remaining stations did not differ in mollusk abundance. Thus there was no general statistically significant pattern with regard to mollusk abundance and proximity to the diffuser. The highest abundance of mollusks at Station HB1 has been the case since 1992 (Nelson et al. 1992b, 1994).

There were no significant differences among stations in number of nonmollusk species, nor were there any significant differences for the crustacean component of the nonmollusks. No clear pattern with regard to mollusk species richness was seen. Reference station HB1 had the greatest number of mollusk species, a pattern consistent with the 1992 and 1993 studies (Nelson et al. 1992b, 1994). The only statistically significant differences were for reference station HB1 versus ZID-boundary station HB2 and reference station HB6, and for ZID-boundary station HB3 versus Station HB2. Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. The lower nonmollusk diversity and evenness values recorded at Station HB2 in 1993 did not persist in 1994 (Nelson et al. 1994). Thus, there is little evidence that the outfall is having a consistent effect on species richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis dissimilarity index indicated that nonmollusk abundance and species composition were broadly similar at most stations. In most past years, cluster analysis consistently intermixed ZID, near-ZID, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b). In 1993, some separation between ZID and reference stations was observed, although near-field reference station HB6 was grouped with three of the ZID stations. The cluster analysis for 1993 showed Station HB3 (on the ZID boundary) to be most dissimilar to the other six stations; this was due to far lower numbers of both oligochaetes and nematodes at this station. In 1994, values of both oligochaetes and nematodes at Station HB3 were very similar to those at all other sampling sites; hence, the cluster analysis showed a high degree of similarity between Station HB3 and all other stations.

The loss of sediment grain-size samples makes a complete comparison among stations impossible for 1994. Comparison of the 1994 data to the 1993 data (Nelson et al., 1994) shows that the relative grain-size makeup at each station was relatively consistent between the two years. Sediment grain sizes in the 1994 samples were broadly similar among stations, with the exception of Station HB7. A relatively lower percentage of fine sand was found at Station HB6 in 1992 and 1993, but there was no indication of such a difference in grain size in sediment samples taken in 1991 (Nelson et al. 1992a, 1992b). The variation in grain size from year to year would suggest some degree of spatial heterogeneity of sediments at these stations. No increase in the percentage of fine sediments at ZID station HZ was seen in samples taken from 1986 through 1993 (Nelson et al. 1987, 1991, 1992a, 1992b, 1994). The increase in the silt and clay fraction of the sediments first observed in 1993 for all stations persisted in 1994 (for comparisons see figure 3 in Nelson et al. 1992b, 1994). Because the increase occurred at all seven stations, it is unlikely that this was an effect of the outfall.

Sediment ORP showed no evidence of reducing conditions at the surface of sediments at any station. There was no evidence of a diffuser-related trend in sediment O&G values. In 1994 significantly higher values were observed at ZID-boundary station HB2 as compared to all other stations, whereas in 1993 highest values were observed at reference station HB7.

Mean sediment total TOC in 1994 was within the range found in 1992 and earlier sampling years. This contrasts with the 1993 data which were consistently higher and more variable among stations than in 1992. In 1993 the analytical method for TOC was changed to the determination of COD, with an approximate conversion to TOC. This change was made because of problems experienced by the contractor in the direct determination of TOC with the carbonate-rich sediments sampled from the Barbers Point Ocean Outfall area. It appears that due to methodological problems the 1993 sediment TOC may have been overestimated by up to an order of magnitude. The 1994 data did not indicate any buildup of organic matter in the sediments throughout the sampling area.

The total number of nonmollusk taxa recorded in the 1994 study (159) was well within the range recorded in previous studies (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, and 144 in 1993). The total number of crustacean taxa collected in 1994 (44) was higher than that collected in 1993 (36). Although there have been differences in levels of sampling effort and taxonomic resolution (Nelson et al. 1991), overall nonmollusk taxa richness in the study area appears to have remained very similar over the period from 1986 to 1994. In 1993, fewer replicates had coral rubble in them than in 1992. The acid-bath fraction could have contributed to the somewhat higher taxa richness and abundance recorded in 1992, as compared to those recorded in other sampling years.

Overall comparisons of mean nonmollusk abundance and mean crustacean abundance for samples collected in September 1986, February 1990, July 1991, February 1992, June 1993, and January–February 1994 are shown in Figures 19 and 20. Nonmollusk abundances at all stations in 1994 were within the range of values recorded in other years.

Crustacean abundances at most stations have been variable from year to year (Figure 20). In particular, the pattern of crustacean abundance at Station HB6 has varied greatly. These differences may be partly the result of seasonal variations in crustacean abundance. However, a comparison of 1990, 1992, and 1994 samples, all of which were taken in February, indicates that at most stations there are interannual variations in abundance that are not related solely to seasonal differences.

The strongly depressed nonmollusk abundance at Station HB3 in 1991 was not recorded in 1994 (Figure 19). Rank order of abundance among stations has varied from sampling date to sampling date. With the exception of Station HB3 in 1991, from which an anomalous sample appears to have been taken, there has been no indication of a depression in nonmollusk abundance at near-ZID stations over the sampling years.

Overall comparisons of mean number of nonmollusk taxa and mean number of crustacean taxa for samples collected in September 1986, February 1990, July 1991, February 1992, June 1993, and January–February 1994 are presented in Figures 21 and 22. For both nonmollusks and crustaceans, a general similarity in taxa richness among stations is indicated. This similarity has been the case in most sampling years. The exception is 1991, when wide differences among taxa numbers at stations were observed. Rank order of stations varied from year to year for mean number of nonmollusk taxa, as it did for the mean number of crustacean taxa (Figure 22). The depression in number of taxa for both nonmollusks and crustaceans at Station HB3 in 1991 was not repeated in 1994 (Figures 21 and 22), confirming the conclusion of the 1992 study (Nelson et al. 1992b) that the 1991 sample data for Station HB3 were aberrant.

Dominant taxa of the nonmollusk fauna were similar to those in previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude as that in previous sampling years. The dominant polychaete species in 1994 showed some variation from those recorded in previous years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994). Dominant polychaete species in 1994 included *Euchone* sp. B., *Myriochele oculata, Polydora normalis, Prionospio cirrobranchiata,* and *Podarke angustifrons*.

Abundance of *Augeneriella dubia* was less than in 1993. As in previous years, the crustacean fauna in the vicinity of the Barbers Point outfall was dominated by amphipods, isopods, and tanaidaceans. These groups may be integrating indicators of the long-term status of the benthic community, given their reproductive strategy of brooding larvae. Compared to the Waianae, Sand Island, and Mokapu outfall study areas (Nelson et al. 1986), the entire Barbers Point study area (both control and outfall stations) seems rather depressed in decapods.

The 1994 crustacean samples appeared generally uninfluenced by proximity to the outfall, except for some depression in abundance at Station HZ, which is located at the outfall. Crustacean density at this station in 1993 was high, however. This is in contrast to the 1991 samples, which demonstrated a strong depression of both crustacean taxa richness and abundance in the vicinity of the outfall. Overall abundances at all stations in 1994 were more consistent with counts recorded in 1991 than in 1990 (corrected for the greater sampling effort in 1990). Four of the seven stations in the study area had the highest abundances since 1990.

All stations were marked by strong intrastation (replicate-to-replicate) variability. Crustacean abundance at Station HB7 showed order-of-magnitude variation among replicates. Intrastation variability is probably indicative of a heterogeneous benthic environment below the scale of replicate spacing.

Crustacean taxa richness and abundances, which appeared in 1991 to be reduced near the outfall (Stations HB3, HB4, and HZ; Figures 20 and 22), are now generally indistinguishable across what may be a bottom with much small-scale heterogeneity. The shifting patterns of taxa richness and overall abundances from year to year may be more strongly influenced by factors such as small-scale bottom topography or subtle sediment differences not apparent in grain-size analysis than by the effects of effluent discharged by the diffuser. Variations in sediment size composition in small (10- to 30-cm) pockets of finer or coarser sediment may not be apparent in a bulk sediment analysis.

Overall comparisons of mean mollusk abundance and mean number of mollusk species collected in September 1986, February 1990, July 1991, February 1992, June 1993, and January–February 1994 are shown in Figures 23 and 24. Because the mollusk collections are not separated into living and dead shell material, they represent time-averaged collections that integrate conditions at a site over a longer period. Temporal variability in mollusk abundance among sampling dates is much less than for the nonmollusk fraction. The pattern of abundance in the sample area on all dates has shown a general tendency to decrease from east to west. Station HB6 has consistently had the fewest mollusk individuals (Figure 23). There is little correspondence across sampling dates for all stations in terms of their rank order for mean number of mollusk species, although there is a tendency for Stations HB1 and HB7 to have the greatest species numbers (Figure 24).

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show no evidence of a buildup of organic matter in the vicinity of the Barbers Point Ocean Outfall diffuser. This conclusion is confirmed by each of the physical and chemical parameters measured. Mean sediment TOC, estimated by COD, was in the range of 0.14% to 0.37%, comparable to values in all previous years except 1993. The high 1993 values are believed to have resulted from problems with the methods used to process the samples. For comparison, the percentage of organic content ranged from 1.2% to 10.9% for sediments of the Kattegat (Pearson et al. 1985) and 0.6% to 8.9% for sediments off the coast of Maine (Bader 1954). The percentage of TOC ranged from 1.4% to 4.1% for stations near the Los Angeles County ocean sewage outfalls (Swartz et al. 1986). In Kingston Harbour, Jamaica, the percentage of sediment TOC ranged from 4% to 10.7% in a semi-enclosed bay subject to organic pollution (Wade 1972; Wade et al. 1972). The lack of evidence for organic buildup would suggest that little particulate matter from the diffuser ever reaches the sediment surface.

The spatial patterns of organism abundance and species richness in relation to the outfall varied depending on the taxonomic grouping. No pattern of reduction of either abundance or species richness at stations near the diffuser was observed for total nonmollusks, crustaceans, or mollusks in 1994. Cluster analysis of nonmollusk data indicated that all stations were very similar to one another in terms of species composition and relative abundance.

Species diversity (H') and evenness (J) were very similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment proposed by Pearson and Rosenberg (1978) states that in the transition zone on an enrichment gradient, a few species increase and are extremely dominant, while overall diversity and evenness are low. The response patterns of the benthic fauna and the sediment chemical analyses show no indications of the types of changes in the bottom predicted by the organic enrichment hypothesis.

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January 1995 Benthic Monitoring Program Results

(Nelson et al., 1995)

BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O'AHU, HAWAI'I, JANUARY 1995

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May 1995

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RESULTS

Sediment Parameters

Results of sediment grain-size analysis are given in Appendix Table A.3. The mean sediment compositions at the sampling stations, based on three grain-size categories, are compared in Figure 3. The grain-size categories (Folk 1968) were as follows: medium and coarse sand, retained on a +2-phi sieve; fine sand, passed through a +2-phi sieve but retained on a +4-phi sieve; and silt and clay, passed through a +4-phi sieve.

Station HB7, with a greater percentage of medium and coarse sand, differed most from the other six stations (Figure 3). Sediments at all stations were >91% sand (Appendix Table A.3). Results of replicate sediment sample analysis for all seven stations indicated reasonable homogeneity in grain size within stations (Appendix Table A.3).

Direct electrode measurements of ORP ranged from +22 to +175 mV (Appendix Table A.2). These readings show no evidence of strongly reducing conditions in the surface sediments at any station. Comparison of mean ORP per station (one-way ANOVA) showed no significant ($F = 1.29$, $df = 6, 28$; $p = 0.323$) differences among stations.

Sediment oil and grease (O&G) values ranged from 90 to 619 mg/wet kg (Appendix Table A.2). Mean O&G values ranged from 199.3 mg/wet kg at Station HB7 to 568.3 mg/wet kg at Station HB4. In contrast to 1994 when mean O&G values showed no trend in relation to the diffuser, Station HB4 had a significantly higher value than all other stations except Station HZ (ANOVA, $F = 7.06$, $p = 0.0013$). The mean O&G value at Station HZ was significantly higher than at Stations HB1 and HB7 but did not differ significantly from the other stations.

Individual sample values for total sediment organic carbon ranged from 0.17% to 0.48% at all stations (Appendix Tables A.2). Mean TOC values per station ranged only from 0.27% at Station HB6 to 0.36% at Station HZ. There was no statistically significant difference among stations in TOC values ($F = 0.446$, $p = 0.836$). There was no pattern of TOC elevation at the ZID and ZID-boundary stations.

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, sipunculans, echinoderms, nematodes, nemerteans, priapulids, phoronids, hydrozoa, bryozoa, hemichordates, a chordate species, amphipods, copepods, cumaceans, decapods, isopods, ostracods, mysids, tanaidaceans, and a pycnogonid.

The 5,980 nonmollusk specimens counted and identified for all stations and replicates represent 151 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (2,527 individuals, 42.3%) and species richness (87 species, 57.6%). Nematodes were the second most dominant nonmollusk taxon in terms of abundance (21.5%). Oligochaetes constituted 14.5% of numerical abundance, and crustaceans contributed 11.9%. The 43 crustacean taxa, 13 of which were amphipods, represented 28.5% of the total number of nonmollusk taxa. Abundance estimates for each species in each replicate are given in Appendix D.

Basic statistics for the nonmollusk data, including 95% confidence limits and a Kolmogorov–Smirnov test for normality of distribution are provided in Appendix Table B.1 (number of individuals) and Appendix Table B.2 (number of species). Data were normal for most stations; an exception was data on nonmollusk individuals at Station HB6. That this deviation from normality was not sufficiently extreme to require transformation was confirmed by the fact the entire data set passed the test for normality prior to ANOVA. ANOVA is robust for moderate deviations from normality of data (Sokal and Rohlf 1981).

Mean total nonmollusk abundance ranged from 96.2 individuals per sample (17,669/m^2) at Station HB7 to 229.4 individuals per sample (42,133/m^2) at Station HB4 (Figure 4). Variances were homogeneous (Appendix Table B.3). There were significant differences in mean abundance among stations (ANOVA, Appendix Table B.3). Stations HB4 and HB6 had significantly greater mean abundances than Station HB7. No other means were significantly different.

The mean number of nonmollusk species per sample ranged from 26.4 species at Station HB7 to 39.0 species at Stations HB1 and HB6 (Figure 5). Variances were homogeneous (Appendix Table B.4). There were no significant differences in mean number of species per sample among stations (ANOVA, Appendix Table B.4).

Composite station diversity (H') and evenness (J) are shown in Figure 6. Patterns of diversity and evenness were highly similar among stations. Values for both parameters were similar for all stations. Values for diversity ranged from 2.86 (Stations HB4 and HZ) to 3.48 (Station HB1). The range of values was extremely similar to that of samples taken in previous years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b). Evenness ranged from 0.67 (Station HB4) to 0.78 (Station HB1), which was also comparable to the range of values observed in previous years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b). Relative to other stations, there was no pattern of lower diversity or evenness at ZID or near-ZID stations.

Results of cluster analysis indicating the relative dissimilarity of stations based on the 85 most abundant nonmollusk species are shown in Figure 7. All stations were grouped at a maximum dissimilarity value of <0.6, indicating generally similar species composition and abundance among stations. The grouping pattern of stations formed one group which placed the ZID and ZID-boundary stations (HB4, HZ, HB3, and HB2) together with near-field reference station HB6 and a second group with far-field reference stations HB1 and HB7. This pattern was generally similar to that seen in 1994, with the exception that in 1994 Station HB3 was grouped with the far-field stations.

Polychaetes

A total of 2,527 polychaetes, from 87 species, representing 42% of total nonmollusk abundance, were collected. The greatest number of polychaetes were found at Station HB6 (580), followed in decreasing order by Stations HB2, HB4, HZ, HB3, HB1 and HB7 (Figure 8). Polychaetes were the most species-rich group at all stations (Appendix Tables D.1 through D.7). Maximum polychaete species richness occurred at Station HB1 (50), followed by Station HB4 (47), Station HB3 (43), Station HB6 (40), Station HZ (39), Station HB7 (38), and HB2 (36) (Figure 9).

Different polychaetes were dominant at several of the stations. The syllid *Pionosyllis heterocirrata* (formerly *Pionosyllis* cf. *gesae*) was the dominant species at Stations HB1 and HB7. The sabellid *Euchone* sp. B was a dominant species at Stations HB2 and HB6. The oweniid *Myriochele oculata* was dominant at Stations HB3 and HB4, whereas the spionid *Polydora normalis* was the dominant species at Station HZ, as it had been in 1993 and 1994.

Trophic categories. Trophic categories are based on Fauchald and Jumars (1979) and are summarized in Figures 10 and 11.

1. Detritivores. Deposit-feeding polychaetes were most abundant at Station HZ (195 individuals) and most speciose (24 species) at Station HB1. After Station HB1, species of deposit-feeding polychaetes were most numerous at Stations HB3 and HB4 (22 each), followed by Station HZ (18) and then by Stations HB2, HB6, and HB7 (16 each).

The dominant polychaetes in the deposit-feeding category were *Prionospio cirrobranchiata* (at Station HB1), *Myriochele oculata* (at Stations HB2, HB3, HB4, and HB6), *Polydora normalis* (at Station HZ), and *Prionospio cirrifera* (at Station HB7).

2. Omnivores. In terms of percentage of total polychaetes, omnivorous worms were best represented at Station HB4; this is consistent with the results of all Barbers Point surveys since 1986 (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b). At Station HB7, the syllid *Pionosyllis heterocirrata* and the pilargid *Synelmis acuminata* dominated the omnivorous component in the total collection, as in 1993 and 1994. *Pionosyllis heterocirrata* was also the most abundant omnivore at Stations HB1 and HB6, whereas *Synelmis acuminata* was the most abundant omnivore at Stations HB2, HB3, HB4, and HZ.

3. Suspension feeders. In terms of total polychaete abundance, suspension feeders dominated Stations HB2 and HB6. This was primarily due to the sabellid *Euchone* sp. B, which accounted for 50% of the species at these stations. This species was also the dominant suspension feeder at Stations HB3 and HB4. The serpulid *Salmacina dysteri* was the dominant suspension feeder at Station HZ. Suspension feeders made up the smallest proportion of the community at Stations HB1, HB4, and HB7.

4. Carnivores. Carnivorous polychaetes were present at all stations, with maximum abundance occurring at Station HB4. The hesionid *Podarke angustifrons* was the dominant carnivore at Stations HB3, HB4, HZ, HB6, and HB7. This species also was the co-dominant carnivore with the lumbrinerid *Lumbrineris latreilli* at Station HB2. Another hesionid, *Nereimyra* sp. A, was the dominant carnivore at Station HB1. In terms of total abundance, carnivores made up the smallest proportion at Stations HB2, HB3, HZ, and HB6.

Motility categories. Motility categories are based on Fauchald and Jumars (1979) and are summarized in Figures 12 and 13.

Tubicolous worms dominated the polychaete fauna at Stations HB2 and HB6 (*Myriochele oculata* and the sabellid *Euchone* sp. B). *Salmacina dysteri* was the dominant tubicolous worm at Station HZ. The syllid *Pionosyllis heterocirrata* was the dominant motile worm at Stations HB1, HB6, and HB7. At Stations HB3 and HZ the pilargid *Synelmis acuminata* was the dominant motile worm, whereas the hesionid *Podarke angustifrons* was dominant at Station HB4. In the discretely motile category, the spionids were dominant as follows: *Prionospio cirrobranchiata* at Station HB1, HB2, and HB3; *Polydora normalis* at Station HZ; and *Prionospio cirrifera* at Station HB7.

Syllids continued to be reproductively active at both ZID and non-ZID stations, with egg-carrying and epitoke-bearing *Sphaerosyllis taylori* being present at Stations HB1, HB4, and HZ. At Station HB3, one *Exogone longicornis* was found with two epitokes, and another individual had four. Two *Polydora normalis* were found with eggs in their tubes at Station HZ.

Crustaceans

A total of 714 crustaceans were collected. Mean crustacean abundances (no./sample) ranged from 9.0 (1,984/m^2) at Station HZ to 33.6 (7,405/m^2) at Station HB1 (Figure 14). Crustacean abundances were $\log_{10}$ transformed for ANOVA. After transformation, variances were homogeneous and data were normally distributed. There were significant differences in mean abundance of crustaceans among stations (ANOVA, Appendix Table B.5). Crustacean abundances at Stations HB1, HB4, and HB6 were significantly greater than at Station HZ. No other comparisons among stations were significant.

A total of 43 taxa (copepods were not identified to the species level) of crustaceans were collected; of these, 13 species (30%) were amphipods. Mean number of crustacean species ranged from 4.8 at Station HZ to 10.0 at Station HB1 (Figure 15). Crustacean species were log_{10} transformed for ANOVA. After transformation, variances were homogeneous and data were normally distributed. There was a significant difference in mean number of crustacean taxa among stations, with Station HB6 having significantly more taxa than Station HZ (ANOVA, Appendix Table B.6). No other comparisons among stations were significant. Although mean number of crustacean species at Station HB1 was slightly greater than at Station HB6, the higher variance associated with Station HB1 caused it to fail to test as significantly different from Station HZ.

Tanaidaceans, amphipods, and copepods were the numerically dominant taxa, making up 39%, 37%, and 10.8%, respectively, of total crustacean abundance. No species was uniformly most abundant at all stations. The amphipod *Eriopisella sechellensis* and the tanaids *Leptochelia dubia*, *Leptochelia* sp. A, and *Tanaissus* sp. A were present at most stations and were generally among the most abundant taxa.

The total number of crustacean taxa collected within the Barbers Point study area in 1995 (43) was slightly above the mean of 41 taxa collected annually from 1990 though 1994. Between 36 and 49 taxa have been collected each year from within the outfall study area. This constancy reinforces the view that the Barbers Point outfall study area is not subject to large swings in benthic crustacean composition or consistency and generally represents a rather stable environment. This should aid in identifying any impacts associated with the outfall itself. Crustacean species abundance for all replicates and stations is provided in Appendix Tables D.8 through D.14.

Four new taxa not previously collected in the study area, including 3 taxa of shrimp, were added in 1995. Since 1990, 86 taxa have been collected at least once in the Barbers Point study area. Reexamination of earlier collections against additional material has allowed better identifications to be made, resulting in some consolidation of previously separated taxa and thus in a reduction of the numbers of total taxa collected in earlier years. Four to nine new taxa have been collected each year since the first two years of sampling when a total of 62 taxa were collected. This relatively low and consistent level of additions to the crustacean fauna in the study area is reflective of an efficient collection program, which is now effectively collecting even the rarer species and those which occur intermittently in the study area. However, since initial sorting is done at the 0.5-mm level, consistent collection of meiofaunal species or small specimens of these benthic taxa should not be expected.

An interesting collection in 1995 was a specimen of the commensal shrimp *Periclemenes galene*, which is known to be commensal on arborescent hydroids. It had previously been reported from Indonesia and East Africa. Although an account of its presence in Hawaii had not previously been published, it was known to exist here on the basis of specimens collected from the hydroid *Halocordyle disticha* off Waialua. Its collection suggests that arborescent hydroids are present on the hard substrates in the outfall study area.

Mollusks

A total of 5,835 mollusks representing 98 species were collected. Mean abundance of mollusks per sample (no./10 cm^3) ranged from 129.8 at Station HB2 to 238.0 at Station HB1 (Figure 16). Data at all stations except Station HB1 were normally distributed (Appendix Table C.1). However, the composite mollusk abundance data set passed the test for normality prior to ANOVA. Complete basic statistics for total mollusk data are shown in Appendix Table C.1.

Mean number of mollusk species per sample ranged from a low of 17.8 at Station HB2 to 28.4 at Station HB1 (Figure 17). Data at Stations HB2, HB6, and HB7 were not normally distributed (Appendix Table C.2). Complete basic statistics for number of mollusk species at all stations are shown in Appendix Table C.2.

Variances for mollusk abundance data were homogeneous (Appendix Table C.3). There were significant differences in mean mollusk abundance among stations (ANOVA, Appendix Table C.3). Mean abundance was significantly greater at Station HB1 than at all other stations. Station HZ had significantly greater abundance than the remaining stations. Station HB4 had significantly greater abundance than Station HB2. No other differences in means were significant.

Although variances for number of mollusk species data were homogeneous, this data set failed the test for normality prior to ANOVA (Appendix Table C.4). Routine transformations failed to correct this problem; therefore, the nonparametric Kruskal–Wallis ranked comparisons test was carried out. There were significant differences in mean mollusk species richness among stations (Kruskal–Wallis test, Appendix Table C.4). Station HB2 had significantly fewer mollusk species than all other stations. No other differences were significant.

Diversity (H') ranged from 2.15 at Station HB3 to 2.44 at Station HB1 (Figure 18). Evenness (J) ranged from 0.59 at Station HB3 to 0.63 at Station HB7. Diversity and evenness values for mollusks were generally similar for all stations (Figure 18).

The gastropod taxa *Balcis* spp., *Cerithidium perparvulum*, *Diala scopulorum*, and *Scaliola* spp. were abundant at all stations. An additional species, *Finella pupoides*, was abundant at all stations except HB1 and HB7. These mollusk abundance patterns are consistent with those of all previous samplings (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b). Mollusk species abundance for all stations and replicates is provided in Appendix E.

DISCUSSION

Total nonmollusk abundance was significantly higher at ZID-boundary station HB4 and reference station HB6 as compared to reference station HB7. Most nonmollusk species had relatively lower abundances at Station HB7 as compared to the other stations. For the crustacean component of the nonmollusks, reference stations HB1 and HB6 and ZID-boundary station HB4 were significantly greater in abundance than ZID station HZ. No single crustacean species was responsible for the differences in abundance among stations.

Mollusk abundance was significantly greater at reference station HB1 than at all other stations. ZID station HZ had significantly higher mollusk abundance than all remaining stations, and ZID-boundary station HB4 had significantly greater mollusk abundance than ZID-boundary station HB2. The remaining stations did not differ significantly in mollusk abundance. Thus there was no general statistically significant pattern with regard to mollusk abundance and proximity to the diffuser. The occurrence of highest abundance of mollusks at Station HB1 has been the case since 1992 (Nelson et al. 1992b, 1994a, 1994b).

There were no significant differences among stations in number of nonmollusk species. For the crustacean component of the nonmollusks, only reference station HB6 had significantly more crustaceans compared to ZID station HZ. With regard to mollusk species richness, ZID-boundary station HB2 had significantly fewer mollusk species than all other stations. Although not statistically significant, Station HB1 had the highest number of mollusk species, a pattern consistent with the 1992 through 1994 studies (Nelson et al. 1992b, 1994a, 1994b).

Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. The lower nonmollusk diversity and evenness values seen at Station HB2 in 1993 did not occur in either 1994 or 1995 and thus appears to have been an anomalous event (Nelson et al. 1994a, 1994b). Thus there is little evidence that the outfall is having a consistent effect on species richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis dissimilarity index indicated that nonmollusk abundance and species composition were broadly similar at most stations. In most past years, cluster analysis consistently intermixed ZID, near-ZID, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b). In 1995, some separation between stations in or near the ZID and far-field reference stations was observed, although near-field reference station HB6 was grouped with the stations in or near the ZID. This pattern was relatively similar to that seen in 1994 (Nelson et al. 1994b). The primary differences between Stations HB1 and HB7 and the other stations in 1995 were due to the relatively lower abundances of the polychaetes *Euchone* sp. B and *Myriochele oculata* and of the oligochaetes and nematodes at the far-field reference stations. These taxa were the four most abundant in the overall study area.

Comparison of the 1995 grain-size data to the 1994 data (Nelson et al. 1994b) shows that the makeup was relatively consistent between the two years at stations for which data were available in 1994. Sediment grain sizes in the 1995 samples were broadly similar among stations, except at Station HB7, which had a higher percentage of coarse sand. The percentage of fine sediments at ZID station HZ showed no increase over that in samples taken in 1986 and from 1990 through 1994 (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b). The increase in the silt and clay fraction of the sediments, which was first observed in 1993 for all stations, persisted in 1995 (for comparison see figure 3 in Nelson et al. 1992b, 1994a, 1994b). Because the increase occurred at all seven stations, it is unlikely that it was an effect of the outfall discharge.

ORP analysis showed no evidence of reducing conditions at the surface of sediments at any station. There was a significant elevation in sediment O&G values at ZID-boundary station HB4 and ZID station HZ. In 1994, significantly higher values were observed at ZID-boundary station HB2, as compared to all other stations (Nelson et al. 1994b). In 1993, highest values were observed at reference station HB7 (Nelson et al. 1994a). The year-to-year variation in stations possessing the highest sediment O&G values makes it difficult to clearly attribute the 1995 pattern to an effect of the diffuser effluent.

Mean sediment TOC in 1995 was within the range found in all study years except 1993. It is believed that the 1993 sediment TOC was overestimated by up to an order of magnitude due to methodological problems (Nelson et al. 1994b). The 1995 data showed no significant differences in TOC among stations and do not indicate any buildup of organic matter in the sediments at any station within the sampling area.

The total number of nonmollusk taxa recorded in the 1995 study (151) was within the range recorded in previous studies (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, 144 in 1993, and 159 in 1994). The total number of crustacean taxa collected in 1995 (43) was very similar to that collected in 1994 (44). Although there have been differences in levels of sampling effort and taxonomic resolution (Nelson et al. 1991), overall nonmollusk species richness in the study area appears to have remained very similar over the period from 1986 to 1995.

Overall comparisons of mean nonmollusk abundance and mean crustacean abundance for samples collected in September 1986 February 1990, July 1991, June 1993, January–February 1994, and January 1995 are shown in Figures 19 and 20. Nonmollusk abundances at all stations in 1995 were within the range of values recorded for other sampling years.

Crustacean abundance at most stations has varied from year to year (Figure 20). In particular, crustacean abundance at Station HB6 has varied greatly. The differences may be partly the result of seasonal variations. However, a comparison of the results for the 1990, 1992, 1994, and 1995 samples, all of which were taken in January or February, indicates that at most stations there are interannual variations in abundance that are not related solely to seasonal differences.

The strongly depressed nonmollusk abundance found at Station HB3 in 1991 has not been repeated (Figure 19), confirming the conclusion that this was an anomalous sample (Nelson et al. 1994b). Rank order of abundance among stations has varied from year to year. There has been no indication of a depression in nonmollusk abundance at near-ZID stations over the sampling years.

Overall comparisons of mean number of nonmollusk taxa and mean number of crustacean taxa for samples collected in 1986 and from 1990 through 1995 are presented in Figures 21 and 22. The 1995 nonmollusk and crustacean data continue to indicate a general similarity in taxa richness among stations. This similarity has been the case for most sampling years; however, an exception occurred in 1991, when wide differences among taxa numbers at stations were observed. Rank order of stations has varied from year to year for mean number of nonmollusk taxa, as it has for mean number of crustacean taxa (Figure 22). The depression in number of taxa for both nonmollusks and crustaceans at Station HB3 in 1991 has not been repeated (Figures 21 and 22), confirming the conclusion of the 1992 study (Nelson et al. 1992b) that the 1991 sampling data for Station HB3 were aberrant.

Dominant taxa of the nonmollusk fauna were similar to those in previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that in previous sampling years. The dominant polychaete species in 1994 showed some variation from previous years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). Dominant species in 1995 were similar to those found in 1994 (Nelson et al. 1994b) and included the polychaetes *Euchone* sp. B., *Myriochele oculata*, *Pionosyllis heterocirrata*, *Polydora normalis*, *Prionospio cirrobranchiata*, *Podarke angustifrons*, and *Synelmis acuminata*.

As in previous years, the crustacean fauna in the vicinity of the Barbers Point outfall was dominated by amphipods, isopods, and tanaidaceans. Compared to the Waianae, Sand Island, and Mokapu outfall study areas, the entire Barbers Point study area (both control and outfall stations) seems rather depressed in decapods.

The 1995 crustacean samples appeared generally uninfluenced by proximity to the outfall. Stations tended to be divided into two groups on the basis of total taxa richness: a group of diverse stations (HB1, HB3, and HB6), each with 19 or more taxa; and another group of lower-diversity stations (HB2, HB4, HB7, HZ), each with 10 to 15 taxa. This pattern is in contrast to the 1994 pattern in which Stations HB7 and HZ were both in the group of diverse stations.

High within-station variance in both taxa richness and abundance suggests that although the study area is generally homogeneous and unaffected by proximity to the outfall, very small-scale patchiness in sediment characteristics (on a scale of 1 to 10 m) greatly affects the composition and abundance of the crustacean community.

Crustacean taxa richness and abundances cannot be significantly and consistently related to direct proximity to the Barbers Point outfall. Although in some previous years (e.g., 1991, Nelson et al. 1992a) species richness appeared to be reduced adjacent to and immediately south of the outfall (Stations HB3, HB4, and HZ), this pattern has not been seen for several years. The shifting patterns of taxa richness and overall abundances from year to year appear to be more strongly influenced by other factors, such as small-scale bottom topography or a subtle variation in sediment composition.

Overall comparisons of mean mollusk abundance and mean number of mollusk species collected in 1986 and from 1990 through 1995 are presented in Figures 23 and 24. Because the mollusk collections are not separated into living and dead shell material, they represent time-averaged collections that integrate conditions at a site over a longer period. Temporal variability in abundance among sampling dates is much less for the mollusk fraction than for the nonmollusk fraction. The pattern of abundance in the sampling area on all dates has shown a general tendency to decrease from east to west. Station HB6 has consistently had the fewest and Station HB1 the greatest number of mollusk individuals (Figure 23). There is little correspondence across sampling dates for all stations in terms of their rank order for mean number of mollusk species, although there is a tendency for Stations HB1 and HB7 to have the greatest and Station HB2 to have the lowest mollusk species numbers (Figure 24).

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show no evidence of a buildup of organic matter in the vicinity of the Barbers Point Ocean Outfall diffuser. This conclusion is confirmed by each of the physical and chemical parameters measured. Mean sediment TOC was in the narrow range of 0.27% to 0.35%, comparable to values from all previous sampling years except 1993 when methodological problems were experienced with the analyses. For comparison, the percentage of organic content ranged from 1.2% to 10.9% for sediments of the Kattegat (Pearson et al. 1985) and 0.6% to 8.9% for sediments off the coast of Maine (Bader 1954). The percentage of TOC ranged from 1.4% to 4.1% for stations near the Los

Angeles County ocean sewage outfalls (Swartz et al. 1986). In Kingston Harbour, Jamaica, the percentage of sediment TOC ranged from 4.0% to 10.7% in a semi-enclosed bay subject to organic pollution (Wade 1972; Wade et al. 1972). The lack of evidence for organic buildup would suggest that little particulate matter from the diffuser ever reaches the sediment surface.

The spatial patterns of organism abundance and species richness in relation to the outfall varied depending on the taxonomic grouping. No pattern of reduction of either abundance or species richness at stations near the diffuser was observed for total nonmollusks, crustaceans, or mollusks in 1995. Cluster analysis of nonmollusk data indicated that all stations were relatively similar to one another in terms of species composition and relative abundance (maximum dissimilarity <0.6).

Species diversity (H') and evenness (J) were very similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment proposed by Pearson and Rosenberg (1978) states that in the transition zone on an enrichment gradient, a few species increase and are extremely dominant, while overall diversity and evenness are low. The response patterns of the benthic fauna and the sediment chemical analyses show no indications of the types of changes in the bottom communities which are predicted by the organic enrichment hypothesis.

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