BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O‘AHU, HAWAI‘I, JANUARY 1996

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Project Report PR-96-08

May 1996

PREPARED FOR
City and County of Honolulu
Department of Wastewater Management
Project Report
for
"The Assessment of the Impact of Ocean Sewer Outfalls on the Marine Environment Off Oahu, Hawaii"
Project Period: 1 January 1995–30 September 1997
Principal Investigator: Roger S. Fujioka

WATER RESOURCES RESEARCH CENTER
University of Hawai'i at Mā noa
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The taxa abundance and richness counts for benthic organisms and the data calculations in this publication are the responsibility of the authors. The Water Resources Research Center staff is responsible for publication production activities.

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ABSTRACT

Benthic infauna in the vicinity of the Barbers Point Ocean Outfall was sampled at seven stations on 30 and 31 January and 4 February 1997 with a modified van Veen grab sampler. The stations were located along the diffuser isobath (61 m) as follows: Station HZ within the zone of initial dilution (ZID); Stations HB2, HB3, and HB4 on the ZID boundary; Station HB6 at 0.5 km from the ZID; and Stations HB1 and HB7 at 3.5 km from the ZID.

Sediments were predominantly (>90%) fine to coarse sands. Stations HB1 and HB7 had relatively coarser sediments, and Station HB2 had a higher percentage of silt and clay than the other stations. Total organic carbon in the sediments at all stations was below the detection limit of the analytical method used. Values for oxidation-reduction potential and sediment oil and grease showed no indication of significant organic buildup in sediments at any station.

A total of 6,865 nonmollusk individuals from 138 taxa were collected. Polychaetes represented 41.0%, nematodes 28.2%, oligochaetes 13.4%, sipunculans 9.0%, and crustaceans 4.2% of total nonmollusk abundance. Mean total nonmollusk abundance ranged from 122.8 individuals per sample (22,554/m^2) at Station HB2 to 259.4 individuals per sample (47,643/m^2) at Station HB4. Mean crustacean abundances ranged from 4.2 (926/m^2) at Station HB2 to 12.4 (2,733/m^2) at Station HB4. Mollusks were analyzed separately because they represent time-averaged collections of live and dead shells. Mean mollusk densities ranged from 152.0 at Station HB2 to 308.0 at Station HB1. From comparisons of nonmollusk abundance among stations, ZID-boundary station HB4 had significantly greater mean abundances than ZID-boundary station HB2. There has been a significant trend of increased abundance for nonmollusks within the entire study area since 1990. Since 1994, there has been a trend of decreased abundance for crustaceans and a trend of increased abundance for mollusks. Significantly elevated abundances of nonmollusks over the entire study period have occurred at two stations near the diffuser relative not only to two of the reference stations but also to a third near-diffuser station.

There were no significant differences among stations in number of nonmollusk or crustacean species. Although there were significant differences among stations in number of species for the mollusks, no clear pattern of differences related to proximity to the diffuser was seen among stations. Crustacean taxa richness averaged over the entire study period was lower at stations near the diffuser relative to reference stations. Although not all station differences were significant, the pattern may indicate a trend related to the diffuser. Both diversity and evenness values were generally similar among all stations in 1997 for both nonmollusks and mollusks. Cluster analysis of nonmollusk data confirmed that all stations were relatively similar to one another in terms of species composition and relative abundance. There is no indication of any marked alteration of the benthic community composition related to station proximity to the diffuser.

INTRODUCTION

The Honouliuli Wastewater Treatment Plant is a primary treatment system. Wastewaters of mainly domestic origin are treated at the plant prior to discharge in Mo(¯,a)mala Bay through an 84-in. (2.13-m) diameter outfall located off the southern coast of O'ahu, Hawai'i.

A waiver of secondary treatment for sewage discharge through the Barbers Point Ocean Outfall has been granted to the City and County of Honolulu (CCH) by the Region 9 office of the U.S. Environmental Protection Agency (EPA). This report provides the results of the ninth survey in an ongoing series of studies of the macrobenthic, soft-bottom community in the vicinity of the discharge. The first benthic survey took place in 1986. The samples on which this report is based were collected on 30 and 31 January and 4 February 1997. Because of bad weather, the survey was not conducted by 10 January 1997, in accordance with the agreement between CCH and Water Resources Research Center (WRRC). For this reason and because of delays in finalizing the five-year biomonitoring contract, this report is being submitted late, even though sampling was conducted during the two-month monitoring period specified by EPA.

PROJECT ORGANIZATION

General coordination for this project is provided by James E.T. Moncur, assistant director of the Water Resources Research Center of the University of Hawai'i at Mo(¯,a)noa and project principal investigator. The principal members of the project team (listed in alphabetical order) and their contributions to this study are as follows:

Julie H. Bailey–Brock	Polychaete, oligochaete, and sipunculan analysis and report
William J. Cooke	Crustacean analysis and report
E. Alison Kay	Mollusk analysis and report
Walter G. Nelson	Statistical analysis and final report preparation
Ross S. Tanimoto	City and County of Honolulu project representative and coordinator for sediment grain-size, total volatile solids, and oxidation-reduction potential analyses

MATERIALS AND METHODS

Specific locations of the sampling stations are provided in Figure 1, and a general vicinity map for the area serviced by the Honouliuli Wastewater Treatment Plant is provided in Figure 2. Seven stations previously established along the approximate diffuser isobath (61 m) were surveyed. In 1990 survey station names were changed from those used in the 1986 survey (Nelson et al. 1987). Survey stations (1986 station names are in parenthesis) and their locations are as follows:

Station HB1 (A)	Approximately 3.5 km east of the zone of initial dilution (ZID) boundary to evaluate effects far-field and beyond the ZID
Station HB2 (B)	On the northeast ZID boundary
Station HB3 (C)	On the southeast ZID boundary
Station HB4 (D)	On the southwest ZID boundary
Station HZ (Z)	Within the ZID to evaluate diffuser effects
Station HB6 (E)	Approximately 0.5 km southwest of the ZID boundary as a near-field reference station
Station HB7 (F)	Approximately 3.5 km southwest of the ZID boundary as a far-field reference station

Station Positioning

The exact positioning of each station was determined using the Motorola Mini-ranger navigation system. Station locations in relation to latitude, longitude, and bathymetric contours are shown in Figure 1. Ranges for each replicate grab sample at each station are given in Appendix Table A.1. Depths for all stations fell within the range of 59.1 to 67.4 m. Station positions within and at the boundaries of the ZID were located precisely during the original sampling using the submersible *Makali ʻi* in coordination with its mother ship (Nelson et al. 1987).

Sampling Methods

The sampling methodology used in this study generally follow the recommendations of Swartz (1978) and guidelines of the U.S. Environmental Protection Agency (1987a, 1987b), hereafter referred to as EPA procedures. The previous reports on the benthic monitoring adjacent to the Barbers Point Ocean Outfall (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b, 1995, 1996) will be hereafter referred to as "Nelson et al. reports."

In 1994, the modified 0.1-m^2 van Veen grab sampler previously used was replaced by a 0.16-m^2 van Veen grab sampler. The new grab, which was deployed from a stern-mounted A-frame on the City's research vessel *Noi I Kai*, was used to obtain bottom samples at all seven stations. Sampling dates were 30 and 31 January and 4 February 1997. Penetration of the sampler was adequate for all replicates. The minimum penetration depth was 6.0 cm, and the maximum was 14.5 cm (Appendix Table A.2).

Five replicate grab samples were taken at each station. From each replicate sample, a subsample 7.6 cm in diameter by 5 cm deep was taken for infaunal analysis and a subsample 4.8 cm in diameter by 5 cm deep for mollusk analysis. Subsampling was necessary because the epifauna and infauna in the area are known to be both small and abundant (Nelson 1986; Russo et al. 1988). Replicated grab samples at each station, rather than replicated subsamples from one grab sample, were taken to provide information on intrastation variability. All five biological subcores for nonmollusk analysis were processed on a 0.5-mm screen and the organisms retained and preserved as appropriate for subsequent identification.

Samples for geochemical analyses (total organic carbon [TOC], oxidation-reduction potential [ORP], oil and grease [O&G], and grain size) were obtained from the grabs from which the biological subcores were taken because each replicate grab contained more than enough sediment for both purposes (methods established by National Pollutant Discharge Elimination System permit no. HI0020877). Three subsamples (one from each of three different grab samples) were taken for all stations. The top 2 cm of sediment of each subsample were used for geochemical analysis. Samples for TOC and sediment O&G analyses were put in screw-cap jars, which were placed on ice, and taken to the laboratory for analysis. Sediment ORP was measured on board the research vessel immediately after each sample was obtained. Laboratory analyses of sediment grain size and sediment ORP followed EPA procedures. Analysis of TOC was carried out using EPA procedures by Intertek Testing Services (formerly Inchcape Testing Services), Environmental Laboratories (Colchester, Vermont). It performed the analysis using a modification of the Lloyd Kahn method which utilizes an infrared detector to detect carbon dioxide.

Sample Processing

Handling, processing, and preservation of the biological samples followed EPA procedures. Nonmollusk samples were fixed with buffered 10% formalin for a minimum of 24 hours. Following fixation, all samples were placed in 70% ethanol. Mollusk samples were placed in labeled jars in the field, then placed on ice and transported to the laboratory where they were refrigerated. Samples were washed in freshwater (to minimize loss of fine sediments), fixed in 75% isopropyl alcohol for 24 hours, and then air dried. A subsample in a 10-cm^3 aliquot was removed from each mollusk sample for sorting.

The fixed nonmollusk samples were elutriated using the technique of Sanders et al. (1965). This method successfully removes from the sediment all organisms that are not heavily calcified (Nelson et al. 1987). Samples were washed several times, and the water from each was poured through 0.5-mm-mesh sieves. Polychaetes and other invertebrates retained on the sieve were transferred to alcohol, stained with rose bengal solution, and stored in 70% ethanol. Samples from some replicates (Station HB1 [replicates 3 and 5], Station HB2 [replicates 3 and 5], Station HB3 [replicates 2, 3, and 5], Station HB4 [replicates 3 and 5], Station HZ [replicates 3 and 5], Station HB6 [replicates 3 and 5] and Station HB7 [replicates 3 and 5]) contained rubble pieces, which were acid-dissolved to remove endolithic and cryptic species. From zero to several hundred additional organisms were collected from the rubble fragments, depending on the replicate.

Because the biological subcores had to be processed using two different procedures—one for mollusks and the other for all other organisms—the two components of the fauna were not directly comparable and thus were analyzed separately. Because the mollusk specimens were not separated into living and dead shell fractions, they represent time-averaged samples. Mollusks have been extensively analyzed by Kay (1975, 1978, 1979, 1982), Kay and Kawamoto (1980, 1983), Nelson (1986), and Russo et al. (1988).

All specimens were identified to the lowest taxonomic level possible. A selected bibliography for the identification of marine benthic species in Hawai'i is provided in Nelson et al. (1987, appendix D). An additional source used for the identification of polychaetes in Hawai'i is Blake et al. (1995). Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained for six years at the University of Hawai'i.

In previous benthic sampling reports for Barbers Point, several polychaete species were redesignated. The 1995 report presented Dr. Maria Jimenez and Dr. Guillermo San Martin's redesignation of *Pionosyllis* cf. *gesae* and *Pionosyllis* sp. E as *Pionosyllis heterocirrata* (Hartmann–Schröeder, 1959) and *Pionosyllis spinisetosa* (San Martin, 1990), respectively, and both *Pionosyllis* sp. B and *Pionosyllis* sp. D as *Pionosyllis weismanni* (Langerhans, 1897). For further information on these species see Hartmann–Schröeder (1977, 1992) and San Martin (1990). The present report includes species redesignations made in 1996 by Dr. Frederik Pleijel, noted specialist who kindly examined some of the hesionid and phyllodocid polychaete specimens. To date, he has identified the hesionid *Nereimyra* sp. A as *Micropodarke* sp. A (Okuda, 1938) and the phyllodocid Phyllodocidae sp. F as *Mystides* nr. *caeca* (Langerhans, 1880). For further information see Fauchald (1977) and Pleijel and Dales (1991). The species previously identified as Capitellidae sp. D was redesignated as *Questa* sp. A, based on the polychaete reference collection of the Department of Zoology at the University of Hawai'i at Mo(¯,a)noa. These taxonomic changes have been incorporated in the nonmollusk species lists used by the biomonitoring team.

Data Analysis

All data for both nonmollusks and mollusks were tested for assumptions of normality (Kolmogorov–Smirnov test; Sokal and Rohlf 1995) 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). The nonparametric Kruskal–Wallis procedure was used when standard ($\log_{10}$, square root) transformations failed to correct significant deviations from the assumptions of the parametric analysis. Following a significant result using ANOVA, a posteriori Bonferroni t-tests were used to determine which differences in means among stations were significant. All statistical analyses were performed using Sigma Stat for Windows 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 similarity index (Bloom 1981) on double square root transformed data was performed using the group-average sorting strategy. To make analysis more manageable, only those nonmollusk species that contributed at least 0.05% to the total abundance were included. Using this criterion, only species represented by a total of more than three individuals were included in the data set, which was reduced from 138 to 79 species. The PRIMER benthic analysis software (Carr 1993) was used to compute the similarity matrix and carry out the cluster analysis.

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 using the Quattro Pro for Windows spreadsheet software.

To examine trends over the entire study period, comparisons were made among mean values for all sampling dates and sampling stations using two-way ANOVA without replication and a posteriori Bonferroni t-tests.

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) are 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.

Sediment grain-size patterns were similar to those found in 1996. Stations HB1 and HB7, with a greater percentage of medium and coarse sand, and Station HB2, with a higher percentage of silt and clay, differed most from the other stations (Figure 3). Stations HB2 and HB3 had higher percentages of fine sand than medium and coarse sand, while Stations HZ and HB6 had approximately equal percentages of the two sand-size components. Sediments at all stations were >90% 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). Analysis of duplicate samples at Stations HB2, HZ, and HB6 indicated consistency of analytical techniques.

Direct electrode measurements of ORP ranged from +25 to +245 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, Bonferroni t-tests) showed that Station HB2 had a significantly lower value than all other stations, while the ORP value at Station HB4 was significantly less than that at Station HB3 ($F = 85.44$, $df = 6, 28$; $p < 0.0001$). Unlike the case in 1996 when a single, anomalously low reading at Station

HB2 apparently caused the station to differ from the other stations, all replicates were consistently low at this station in 1997.

Sediment O&G values ranged from 59 to 447 mg/wet kg (Appendix Table A.2). Mean O&G values ranged from 116.7 mg/wet kg at Station HZ to 258.3 mg/wet kg at Station HB3. Comparison of mean O&G per station (one-way ANOVA, Bonferroni t-tests) showed that there were no significant differences among stations ($F = 1.22$, $df = 6, 14$; $p = 0.35$).

Total organic carbon in the sediments at all stations was below the detection limit (100 mg/kg) of the analytical method used. Therefore, no comparison among stations is possible.

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, sipunculans, echinoderms, nematodes, nemerteans, priapulids, phoronids, anthozoans, hydrozoans, platyhelminths, bryozoans, chaetognaths, a kinorhynch species, a chordate species, copepods, ostracods, cumaceans, tanaidaceans, amphipods, isopods, and decapods.

The 6,582 nonmollusk specimens counted and identified for all stations and replicates represent 138 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (2,811 individuals, 41.0%) and species richness (93 species, 67.4%). Nematodes were the second most dominant nonmollusk taxon in terms of abundance (1,934 individuals, 28.2%). Oligochaetes constituted 13.4% (918 individuals) of numerical abundance, sipunculans contributed 9.0% (614 individuals), and crustaceans contributed 4.2% (289 individuals). The 27 crustacean taxa, 9 of which were amphipods, represented 19.6% of the total number of nonmollusk taxa. Abundance estimates for each species from each replicate are given for each of the seven stations 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 all stations except that for nonmollusk individuals at Station HB6 (Appendix Table B.1).

Mean total nonmollusk abundance ranged from 122.8 individuals per sample ($22{,}554/m^2$) at Station HB2 to 259.4 individuals per sample ($47{,}643/m^2$) at Station HB4 (Figure 4). Variances were homogeneous (Appendix Table B.3). According to the ANOVA on untransformed data, there were significant differences in mean abundance among stations (Appendix Table B.3). However, a posterior tests were not sufficiently powerful to distinguish differences among stations. The data were therefore $\log_{10}$ transformed and the a posteriori analysis was performed again. Station HB2 had significantly lower mean abundance than Station HB4. No other pairwise comparisons of means were significantly different.

The mean number of nonmollusk species per sample ranged from 19.2 species at Station HB2

INTRODUCTION

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A waiver of secondary treatment for sewage discharge through the Barbers Point Ocean Outfall has been granted to the City and County of Honolulu (CCH) by the Region 9 office of the U.S. Environmental Protection Agency (EPA). This report provides the results of the eighth survey in an ongoing series of studies of the macrobenthic, soft-bottom community in the vicinity of the discharge. The first benthic survey took place in 1986. The samples on which this report is based were collected on 11 and 12 January 1996.

PROJECT ORGANIZATION

General coordination for this project is provided by Roger S. Fujioka, director of the Water Resources Research Center (WRRC) of the University of Hawai'i at Mā noa and project principal investigator. The principal members of the project team (listed in alphabetical order) and their contributions to this study are as follows:

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Figure 2. Seven stations previously established along the approximate diffuser isobath (61 m) were surveyed. In 1990 survey station names were changed from those used in the 1986

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Station Positioning

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Sampling Methods

The sampling methodology used in this study generally followed the recommendations of Swartz (1978) and U.S. EPA guidelines (1987a, 1987b), hereafter referred to as EPA procedures. The previous reports on the benthic monitoring adjacent to the Barbers Point Ocean Outfall (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b, 1995) will be hereafter referred to in bibliographic citations as "Nelson et al. reports."

In 1994, the modified 0.1-m^2 Van Veen grab sampler previously used was replaced by a 0.16-m^2 Van Veen grab sampler. The new grab, which was deployed from a stern-mounted A-frame on the City's research vessel *Noi I Kai*, was used to obtain bottom samples at all seven stations. Sampling dates were 11 and 12 January 1996. Penetration of the sampler was adequate for all replicates. The minimum penetration depth was 7 cm, and the maximum was 11 cm (Appendix Table A.2).

Five grab samples were taken at each station. From each replicate core, a subsample 7.6 cm in diameter by 5 cm deep was taken for infauna analysis and a subsample 4.8 cm in diameter by 5 cm deep for mollusk analysis. Subsampling was necessary because the epifauna and infauna in the area are known to be both small and abundant (Nelson 1986; Russo et al. 1988). Replicated grab samples at each station, rather than replicated subsamples from one grab sample, were taken to provide information on intrastation variability. All five biological subcores for nonmollusk analysis were processed on a 0.5-mm screen.

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Sample Processing

Handling and processing of biological samples followed EPA procedures. Nonmollusk samples were fixed with buffered 10% formalin for a minimum of 24 hours. Following fixation, all samples were placed in alcohol. Mollusk samples were placed in labeled jars in the field, then placed on ice and transported to the laboratory where they were refrigerated. Samples were washed in fresh water (to minimize loss of fine sediments), fixed in 75% isopropyl alcohol for 24 hours, and then air dried. A subsample in a 10-cm^3 aliquot was removed from each mollusk sample for sorting.

The fixed nonmollusk samples were elutriated using the technique of Sanders et al. (1965). This method successfully removes from the sediment all organisms that are not heavily calcified (Nelson et al. 1987). Samples were washed several times, and the water from each was poured through 0.5-mm-mesh sieves. Some replicates (one each at Stations HB1 [replicate 3] and HB7 [replicate 3]) contained rubble pieces, which were acid-dissolved to remove endolithic and cryptic species. However, no additional organisms were collected from the rubble fragments.

Because the biological subcores had to be processed using two different procedures—one for mollusks and the other for all other organisms—the two components of the fauna were not directly comparable and thus were analyzed separately. Because the mollusk specimens were not separated into living and dead shell fractions, they represent time-averaged samples. The mollusks have been extensively analyzed by Kay (1975, 1978, 1979, 1982), Kay and Kawamoto (1980, 1983), Nelson (1986), and Russo et al. (1988).

All specimens were identified to the lowest taxonomic level possible. A selected bibliography for the identification of marine benthic species in Hawai'i is provided in Nelson et al. (1987, appendix D). Blake et al. (1995) provides additional assistance with the identification of polychaetes in Hawai'i. Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained for six years by the University of Hawai'i.

Pionosyllis cf. *gesae* and *Pionosyllis* sp. E recorded in previous reports have been redesignated as *Pionosyllis heterocirrata* (Hartmann–Schrö eder, 1959) and *Pionosyllis spinisetosa* (San Martin, 1990), respectively. Specimens formerly referred to as *Pionosyllis* sp. B and *Pionosyllis* sp. D have both been identified as specimens of *Pionosyllis weismanni* (Langerhans, 1897). For further information on these species see Hartmann–Schrö eder (1977, 1992) and San Martin (1990).

Data Analysis

All data were tested for assumptions of normality (Kolmogorov–Smirnov test, Sokal and Rohlf 1995) 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). The nonparametric Kruskal–Wallis procedure was used when deviations from the assumptions of ANOVA were detected. Following a significant result using ANOVA,
a posteriori Bonferroni t-tests were used to determine which differences among stations were significant. All statistical analyses were performed using Sigma Stat for Windows 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 similarity index (Bloom 1981) on double square root transformed data was performed using the group-average sorting strategy. To remove species which contributed little information to the analysis, only those nonmollusk species that contributed at least 0.06% of the total abundance were included. Using this criterion, only species represented by a total of more than five individuals were included in the data set, which was reduced from 147 to 83 species. The PRIMER benthic analysis software (Carr 1993) was used to compute the similarity matrix and carry out the cluster analysis.

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.

To examine trends over the entire study period, comparisons were made among all sampling dates and sampling stations using two-way ANOVA and a posteriori Bonferroni t-tests.

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.

Sediment grain-size patterns were similar to those found in 1995. Station HB7, with a greater percentage of medium and coarse sand, and Station HB2, with a higher percentage of silt and clay, differed most from the other stations (Figure 3). Stations HB2, HB3, HZ, and HB6 all had higher percentages of fine sand than medium and course sand, while the reverse was the case at the remaining stations. Sediments at all stations were >90% 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). Analysis of duplicate samples at Station HB7 indicated consistency of analytical techniques.

Direct electrode measurements of ORP ranged from +25 to +245 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, Bonferroni t-tests) showed that Station HB2 had a significantly lower value than Stations HB3 and HB7 ($F = 4.28$, $df = 6, 28$; $p = 0.0035$). A single, anomalously low reading from Station HB2 was the apparent cause of this difference.

Sediment O&G values ranged from below detection (<1) to 294 mg/wet kg (Appendix Table A.2). Mean O&G values ranged from 3.3 mg/wet kg at Station HB7 to 196.0 mg/wet kg at Station HB6. Variability among replicate measurements of O&G at stations was very high, although mean values were generally lower than those found in 1995. The O&G data failed the test for normality of data distribution and were analyzed with the nonparametric Kruskal–Wallis test. There were no significant differences among stations.

Total organic carbon in the sediments at all stations was below the detection limit (100 mg/kg) of the analytical method used. No comparison among stations is therefore possible.

Biological Parameters

Nonmollusks

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

The 8,727 nonmollusk specimens counted and identified for all stations and replicates represent 147 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (3,836 individuals, 44.0%) and species richness (95 species, 64.6%). Nematodes were the second most dominant nonmollusk taxon in terms of abundance (2,497 individuals, 28.6%). Oligochaetes constituted 13.2% (1,156 individuals) of numerical abundance, and crustaceans and pycnogonids contributed 7.5% (651 individuals). The 34 crustacean and pycnogonid taxa, 10 of which were amphipods, represented 23.1% 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 all stations.

Mean total nonmollusk abundance ranged from 121.2 individuals per sample (22,371/m^2) at Station HB7 to 347.0 individuals per sample (64,246/m^2) at Station HZ (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 HZ had significantly greater mean abundances than Station HB7. No other means were significantly different.

The mean number of nonmollusk species per sample ranged from 34.6 species at Station HB6 to 42.2 species at Station HB1 (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 2.50 (Stations HB2) to 3.29 (Stations HB1 and HB7). The range of values was extremely similar to that of samples taken in previous years (Nelson et al. reports). Evenness ranged from 0.59 (Station HB2) to 0.76 (Station HB7), which was also comparable to the range of values observed in previous years (Nelson et al. reports). 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 83 most abundant nonmollusk species are shown in Figure 7. All stations were grouped at similarity values of greater than 70%, indicating similar species composition and abundance among all stations. There was very little sorting among stations with regard to proximity to the diffuser. For example, reference station HB7 and ZID-boundary station HB4 were grouped as most similar.

Polychaetes

A total of 3,836 polychaetes, from 95 species, representing 44.0% of total nonmollusk abundance, were collected. These numbers were higher than those of previous years: 2,685 polychaetes from 90 species in 1994 (Nelson et al. 1994b) and 2,527 polychaetes from 87 species in 1995 (Nelson et al. 1995). The greatest number of polychaetes were found at Station HB2 (823), followed in decreasing order by Stations HB4, HZ, HB6, HB1, HB3, 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 HZ (54), followed by Stations HB1 and HB3 (53 each), Station HB7 (49), Station HB4 (46), Station HB6 (45), and Station HB2 (42) (Figure 9).

Different polychaetes were dominant at several of the stations. The syllid *Pionosyllis heterocirrata* was a dominant species at Stations HB1 and HB7. The sabellid *Euchone* sp. B was a dominant species at Stations HB1, HB2, and HB6. The pilargid *Synelmis acuminata* was dominant at Station HB7, and the dorvilleid *Ophryotrocha* sp. A was dominant at Stations HB3 and HB4. The spionid *Polydora normalis* was the dominant species at Station HZ, as it had been every year since 1993.

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 Stations HB3, HB4, HZ, and HB6 and were the most speciose of the four trophic categories. The maximum number of deposit feeding polychaete species was 29 at Station HB3.

The dominant polychaetes in the deposit-feeding category were *Prionospio cirrobranchiata* (at Stations HB1, HB3, and HB7), *Myriochele oculata* (at Stations HB2, HB4, and HB6), and *Polydora normalis* (at Station HZ). The dorvilleid *Ophryotrocha* sp. A was the dominant polychaete at ZID-boundary stations HB3 and HB4. In addition, *Ophryotrocha* sp. A was found with less abundance at Stations HB2 and HZ.

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. reports). At Station HB7, the syllid *Pionosyllis heterocirrata* and the pilargid *Synelmis acuminata* dominated the omnivorous component in the total collection, as in 1993, 1994, and 1995. *Pionosyllis heterocirrata* was also the most abundant omnivore at Stations HB1, HB2, HB3, HB4, HZ, and HB6, whereas *Synelmis acuminata* was the most abundant omnivore at Stations HB7.

3. Suspension feeders. In terms of total polychaete abundance, suspension feeders were dominant at Station HB2 and were also abundant at Station HB6. This was primarily due to the sabellid *Euchone* sp. B, which accounted for 59% of the polychaete abundance at Station HB2. This species was also the dominant suspension feeder at Station HB1. The sabellid *Fabricia* sp. A was the dominant suspension feeder at Station HZ. Suspension feeders made up the smallest proportion of the community at Stations HB3, 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 HB1, HB3, HB4, HZ, HB6, and HB7. The lumbrinerid *Lumbrineris latreilli* was the dominant carnivore at Station HB2. In terms of total abundance, carnivores made up the smallest proportion at Stations HB1, HB2, HZ, and HB6.

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

Motile polychaetes were the most abundant worms at Stations HB1, HB3, HB4, HZ, and HB7. In addition, they were the most abundant species at each of the seven stations. Tubicolous worms (*Myriochele oculata* and the sabellid *Euchone* sp. B) dominated the polychaete fauna at Stations HB2 and HB6. The syllid *Pionosyllis heterocirrata* was a dominant motile worm at Stations HB1, HB3, HB4, HZ, HB6, and HB7 and the pilargid

Synelmis acuminata at Stations HB1, HB2, and HB7. Discretely motile polychaetes were the least abundant at every station except Station HB7, but they comprised the fewest number of species at only Stations HZ and HB6. The spionids *Prionospio cirrobranchiata* (at Stations HB1, HB2, HB3, HB4, HB6, and HB7) and *Polydora normalis* (at Station HZ) dominated the stations in the discretely motile category.

Syllids were reproductively active at both ZID and non-ZID stations; egg-carrying and epitoke-bearing *Sphaerosyllis taylori* were found at Stations HB2 and HB4. A specimen of *Sphaerosyllis capensis* was found with epitokes at Station HB7. *Pionosyllis heterocirrata* with swimming setae were found at Stations HB1, HB2, HB4, and HZ. One individual of the syllid *Exogone* sp. C was found with epitokes at Station HB2. At Station HZ one individual of *Brania mediodentata* was found with eggs.

Crustaceans

A total of 651 crustaceans were collected. Mean crustacean abundances (no./sample) ranged from 13.8 (3,041/m^2) at Station HZ to 25.0 (5,510/m^2) at Station HB1 (Figure 14). Variances were homogeneous and data were normally distributed. There were no significant differences in mean abundance of crustaceans among stations (ANOVA, Appendix Table B.5).

A total of 34 taxa (copepods were not identified to the species level) of crustaceans and pycnogonids were collected; of these, 10 species (29%) were amphipods. Mean number of crustacean species ranged from 4.2 at Station HZ to 9.0 at Station HB1 (Figure 15). Variances were homogeneous and data were normally distributed. There were no significant differences in mean number of crustacean taxa among stations (ANOVA, Appendix Table B.6).

Tanaidaceans, amphipods, and copepods were the numerically dominant taxa, making up 39.0%, 25.8%, and 19.4%, 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 34 taxa collected in the entire Barbers Point study area was the lowest since repeated annual collections began in 1990. Generally, between 36 and 49 taxa are collected each year. The largest drops in diversity (four fewer taxa per site) occurred both at reference stations (HB1 and HB7) and at an outfall station (HB3). The Barbers Point outfall study area does not appear to be subject to extremely large swings in benthic community composition or consistency; generally, it represents a rather stable environment. This should aid in identifying any impacts associated with the outfall itself. Crustacean and pycnogonid species abundance for all replicates and stations is provided in Appendix Tables D.8 through D.14.

Three species (the podocopid ostracods *Cytherelloidea monodenticulata* and *Mutilis oahuensis* and the shrimp *Leptochela hawaiiensis*) were newly collected in the study area. Only four decapod species were collected in 1996, whereas between two and seven decapod species were collected in previous years. Since 1990, a total of 88 taxa have been collected at least once in the Barbers Point study area. Reexamination and reevaluation of earlier collections resulted in the consolidation of two previously separately listed decapods, bringing the number of separately identified taxa collected from 1990 through 1995 to 85, not 86 as reported in Nelson et al. (1995). Between three and eight taxa have been newly collected each year since the first two years of sampling when a total of 62 taxa were collected. Consistently low additions to the total crustacean community after the initial collection phase is reflective of an efficient collection, processing, and sorting program. Over the last seven years the sampling program has effectively collected even the rarer species, including those which occur intermittently in the study area.

Mollusks

A total of 7,826 mollusks representing 113 species were collected. Mean abundance of mollusks per sample (no./10 cm^3) ranged from 173.6 at Station HB2 to 279.6 at Station HB4 (Figure 16). Data at all stations except Station HB7 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 23.0 at Station HB2 to 34.8 at Station HB4 (Figure 17). Data at all stations except Station HB1 were normally distributed (Appendix Table C.2). However, the composite mollusk species data set passed the test for normality prior to ANOVA. 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 HB4 than at Station HB2. 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 HB2 had significantly fewer mollusk species than Stations HB1, HB4, and HB6. No other differences were significant.

Diversity (H') ranged from 2.16 at Station HB2 to 2.95 at Station HB6 (Figure 18). Evenness (J) ranged from 0.54 at Station HZ to 0.70 at Station HB6. 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, HB4, and HB6. These mollusk abundance patterns are consistent with those of all previous samplings (Nelson et al. reports). 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 ZID station HZ as compared to reference station HB7, a pattern generally similar to that of 1995. Most nonmollusk species had relatively lower abundances at Station HB7 as compared to the other stations. For the crustacean component of the nonmollusks, no significant pattern among stations was observed.

ZID-boundary station HB4 had significantly greater mollusk abundance than ZID-boundary station HB2, a pattern also seen in 1995. 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, which had been the case from 1992 to 1995 (Nelson et al. 1992b, 1994a, 1994b, 1995), was not observed in 1996.

There were no significant differences among stations in number of nonmollusk taxa or in the crustacean component of the nonmollusks. With regard to mollusk species richness, ZID-boundary station HB2 had significantly fewer species than reference stations HB1 and HB6 and ZID-boundary station HB4. Station HB1, which had the highest number of mollusk species from 1992 through 1995 (Nelson et al. 1992b, 1994a, 1994b, 1995), was the third most diverse station in 1996.

Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. Lower nonmollusk diversity and evenness values were seen at Station HB2 in 1993 but not in either 1994 or 1995 (Nelson et al. 1994a, 1994b, 1995). A slight depression in diversity and evenness values was again observed at Station HB2 in 1996, but the magnitude of the depression was so small that there remains 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 similarity index indicated that nonmollusk abundance and species composition were broadly similar at most stations. In the period from 1986 to 1993, cluster analysis consistently intermixed ZID, near-ZID, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b). In 1994 and 1995, some separation between stations in or near the ZID and far-field reference stations was observed (Nelson et al. 1994b, 1995). In 1996 stations were again generally interspersed in the cluster analysis. In comparing the 1996 cluster results with those of earlier years some caution is necessary, since the clustering algorithm was changed from flexible to group-average sorting in order to conform to current recommendations for optimum methodologies (Carr 1993).

Sediment grain sizes in the 1996 samples were broadly similar among stations, except for Station HB7, which had a higher percentage of coarse sand, and Station HB2, which had relatively more silt and clay. The percentage of fine sediments at ZID station HZ showed no increase over that measured in samples taken in 1986 through 1995 (Nelson et al. reports). The increase in the silt and clay fraction of the sediments, which was first observed in 1993 for all stations, persisted in 1996 (for comparison see figure 3 in Nelson et al. 1992b, 1994a, 1994b, 1995). However, the mean percentage of the silt and clay fraction decreased slightly at most stations in 1996 as compared to 1995. The increase in fine sediments in 1993 occurred at all seven stations, thus it is unlikely to have been an effect of the outfall discharge.

ORP analysis showed no evidence of reducing conditions at the surface of sediments at any station; this has been the consistent pattern for this parameter. The significantly lower mean ORP value at Station HB2 appears to have been caused by a single, unusually low reading which depressed the mean, although a somewhat lower mean ORP value would be consistent with the higher percentage of silt and clay at this station.

In 1994 and 1995, various ZID or ZID-boundary stations had significant elevations in sediment O&G values as compared to other stations (Nelson et al. 1994b, 1995); however, in 1996 no significant differences were seen. The 1996 results confirm the tendency for high year-to-year variation in sediment O&G values to occur. The variability in sediment O&G values suggests that there may be little direct influence of the diffuser effluent on this parameter.

Sediment TOC in 1996 was below detection limits, and thus was lower at all stations than in all other sampling years. The most likely explanation for this change is that the analytical laboratory used for the 1996 samples removed all traces of the organic carbon from the sediment during the acid digestion to remove inorganic carbon. While low, TOC values in previous years have been above the detection limits of current instrumentation.

The total number of nonmollusk taxa recorded in the 1996 study (147) was within the range recorded in previous studies (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, 144 in 1993, 159 in 1994, 151 in 1995). The total number of crustacean taxa collected in 1996 (34) was lower than that collected in recent years. 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 1996.

Mean nonmollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1996 (Figure 19). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Numerous pairwise comparisons among dates showed significant differences, generally with values for more recent dates being higher than values for earlier dates. This pattern was confirmed by a linear regression analysis of data from 1990 to 1996, which found a trend of significantly increasing mean abundance over this period ($p = 0.0045$, $y = 24.2x - 48{,}133$). Mean nonmollusk abundance was greater at Station HB4 than at Stations HB1, HB3, and HB7 and higher at Station HZ than at Stations HB3 and HB7. The significant increase in abundance over time appears to be a regional effect in the study area. However, mean abundance over the entire study period at two stations near the diffuser (HB4 and HZ) was elevated compared to two of the reference stations; this is a pattern consistent with some impact resulting from the effluent discharged from the diffuser. This interpretation is complicated by the fact that ZID-boundary station HB3 was also significantly lower in mean abundance than Stations HB4 and HZ.

Mean nonmollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1996 (Figure 20). Two-way ANOVA results showed significant differences among sampling dates ($p < 0.0001$) but not among sampling stations ($p = 0.2294$). Mean nonmollusk taxa richness was significantly greater in 1994 than in 1986 and 1991 and less in 1990 than in all other years (Figure 20). No apparent trend comparable to that for abundance was seen for nonmollusk taxa richness, nor was any apparent spatial trend seen for this parameter.

Mean crustacean abundance was also compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1996 (Figure 21). Two-way ANOVA results showed significant differences both among sampling dates ($p = 0.0004$) and among sampling stations ($p = 0.0288$). Mean crustacean abundance was significantly less in 1990 than in 1993 and 1994 and significantly greater at reference Station HB6 than at ZID-boundary station HB3 or ZID station HZ. The decreased abundance in 1990 is consistent with the overall pattern of nonmollusk abundance for that year. Interannual variations in abundance are not related solely to differences in the time of year that samples were taken. The 1990, 1992, 1994, 1995, and 1996 samples, all of which were taken in January or

February, show considerable variation in mean crustacean abundance. The depression of crustacean abundance at two stations near the diffuser relative to one of the reference stations indicates a potential effect of the outfall.

Mean crustacean taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1996 (Figure 22). Two-way ANOVA results showed significant differences both among sampling dates ($p = 0.0001$) and among sampling stations ($p < 0.0049$). Mean crustacean taxa richness was significantly less in 1990 than in 1991 through 1996 and significantly greater in 1994 than in 1986, 1991, 1992, and 1996. Mean crustacean taxa richness was significantly greater at reference station HB6 than at ZID-boundary station HB4 and ZID station HZ. The low number of taxa counted in 1990 reflects the low total abundance of crustaceans collected that year. No general temporal trend was apparent. The depression of mean crustacean abundance at two stations near the diffuser relative to one of the reference stations indicates a potential effect of the outfall.

Dominant taxa of the nonmollusk fauna were similar to those of previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that of previous sampling years. The dominant polychaete species since 1994 showed some variation from earlier sampling years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). Dominant species in 1996 were similar to those found in 1994 and 1995 (Nelson et al. 1994b, 1995) and included the polychaetes *Euchone* sp. B., *Myriochele oculata, Pionosyllis heterocirrata, Prionospio cirrobranchiata, Synelmis acuminata, Ophyrotrocha* sp. A, and *Podarke angustifrons*.

As in previous years (1986, 1990 through 1995), the crustacean fauna in the vicinity of the Barbers Point outfall was dominated by amphipods, isopods, and tanaidaceans. Compared with the Waianae, Sand Island, and Mokapu outfall study areas, the entire Barbers Point study area (both reference and outfall stations) continues to be somewhat depressed in decapods.

Some reduction in crustacean taxa richness was seen at some stations closest to the outfall as compared with reference stations. Stations HB4 and HZ yielded only 10 and 11 noncopepod crustacean taxa, respectively. However, the two other ZID-boundary stations, HB2 and HB3, had reasonable diversity with 14 and 16 noncopepod crustacean taxa, respectively. Only three stations recorded lower total taxa per station in 1996 than in 1995. Mean crustacean taxa richness (taxa per replicate) does not seem to be as useful as total taxa per station as an indicator of outfall effects, given the high intrastation variability encountered. Some replicates had four to seven times more taxa than other replicates.

High within-station variance in both numerical abundance and species abundance argues that although the entire area is generally homogeneous, very small-scale patchiness of the bottom (on a scale of 1 m to less than 10 m) can greatly affect the composition and abundance of the crustacean community in the individual replicate samples.

Overall, crustacean abundance at all stations was generally lower in 1996 (except for Stations HB7 and HZ) than in 1995. Crustacean abundance did not correlate particularly well with taxa richness. ZID-boundary station HB4 had the second highest abundance but the lowest taxa richness.

Crustacean taxa richness and abundance cannot be consistently related to direct proximity to the Barbers Point Ocean Outfall. Although in some previous years (e.g., 1991, Nelson et al. 1992a) taxa richness appeared to be reduced adjacent to and immediately to the south of the outfall (Stations HB3, HB4, and HZ), this pattern has not been seen for several years. In 1996, Stations HB4 and HZ were low in taxa richness, while Stations HB2 and HB3 had taxa richness comparable with that of reference stations. The shifting patterns of number of taxa and abundance from year to year appear to be more strongly influenced by other factors, such as small-scale differences in bottom topography or a subtle variation in sediment composition.

Mean mollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1995 (Figure 23). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk abundance was significantly greater in 1996 than in all other years except 1994. Mean mollusk abundance was greater at Station HB1 than all other stations. Neither the temporal nor spatial pattern of differences indicates a negative effect of the diffuser effluent on mollusk abundance.

Because the mollusk specimens were 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 was generally much less for the mollusk fraction than for the nonmollusk fraction prior to 1996. The pattern of abundance in the sampling area on all dates shows that Station HB6 has consistently had the fewest and Station HB1 the greatest number of mollusk individuals (Figure 23).

Mean mollusk species richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1996 (Figure 24). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p = 0.0002$). Mean mollusk species richness was significantly greater in 1996 than in all other sampling years. Mean mollusk species richness was significantly greater at Stations HB1, HB4, and HB6 than at Station HB2. Neither the temporal nor spatial pattern of differences indicates a negative effect of the diffuser effluent on mollusk species richness.

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 was not detected in any sample in 1996. In previous years, mean sediment TOC was in the narrow range of 0.04% to 0.47%, except in 1993 when methodological problems were experienced with the analyses and values ranged from 0.56% to 1.4%. The ocean outfall in Orange County, California, discharges onto the continental shelf in an erosional benthic environment (Maurer et al. 1993) which may be somewhat similar to that found in Mamala Bay, Oʻahu. In the vicinity of the Orange County outfall, sediment TOC ranged from approximately 0.3% to 0.9% (Maurer et al. 1993). In areas which possess more depositional benthic environments, the percentage of organic content in the sediments is typically much higher. For example, this percentage 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 near the Barbers Point Ocean Outfall suggests 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 1996. Cluster analysis of nonmollusk data indicated that all stations were similar to one another in terms of species composition and relative abundance (similarity >70%).

There has been a significant trend of increased abundance of nonmollusks within the study area since 1990, although no trend has been seen either for the crustacean component of the nonmollusks or for the mollusks. Significantly elevated abundances of nonmollusks over the entire study period have occurred at two stations near the diffuser relative not only to two of the reference stations but also to a third near-diffuser station. Despite this elevated abundance, which may be related to the effluent discharged from the diffuser, there is no indication of any marked alteration of the benthic community at these stations in terms of species composition.

Species diversity (H') and evenness (J) were very similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment by Pearson and Rosenberg (1978) proposes 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 indication of the types of changes in bottom communities predicted by the organic enrichment hypothesis. Maurer et al. (1993) proposed that the Pearson–Rosenberg model may be inappropriate for erosional continental shelf environments. Their study of an outfall on the continental shelf off California found that even with some organic enrichment near the diffuser, there was no evidence of elimination of rare species, even though three species did achieve numerical dominance. The response of the benthic community near the Barbers Point Ocean Outfall does not show the alternate response pattern described by Maurer et al. (1993), presumably because sediment organics there do not show even the moderate enrichment found near the Orange County outfall.

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AUTHORS:
Dr. Walter G. Nelson
Professor
Division of Marine and Environmental Systems
Florida Institute of Technology
150 West University Blvd., Bldg. 22
Melbourne, Florida 32901
Tel.: 407/768-8000, x7454
Fax: 407/984-8461
Dr. Julie H. Bailey–Brock
Professor (Invertebrate Zoology)
Department of Zoology
University of Hawai'i at Mo(a,¯)noa
2538 The Mall, Edmondson Hall 357
Honolulu, Hawai'i 96822
Tel.: 808/956-6149
Fax: 808/956-9812
Dr. William J. Cooke
Ecological Consultant
Marine Environmental Research
705 Nunu Street
Kailua, Hawai'i 96734
Tel.: 808/254-0203
Dr. E. Alison Kay
Professor (Malacology)
Department of Zoology
University of Hawai'i at Mo(a,¯)noa
2538 The Mall, Edmondson Hall 351
Honolulu, Hawai'i 96822
Tel.: 808/956-8620
Fax: 808/956-9812

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BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O'AHU, HAWAI'I, JANUARY–FEBRUARY 1997

Walter G. Nelson
Julie H. Bailey-Brock
William J. Cooke
E. Alison Kay

Project Report PR-97-08

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Project Report
for
"A Five-Year Biological and Sediment Monitoring Program
on the Marine Communities Near the City's Ocean Sewer Outfalls"
Project No.: C54997
Project Period: 1 January 1997–30 September 2002
Principal Investigator: James E.T. Moncur

WATER RESOURCES RESEARCH CENTER
University of Hawai'i at Mo(a,¯)noa
Honolulu, Hawai'i 96822

The taxa abundance and richness counts for ben[illegible] organisms and the data calculations in this publication are the responsibility of the authors. The Water Resources Research Center staff is responsible for pu[illegible]ion production activities.

to 33.8 species at Station HB3 (Figure 5). Variances were heterogeneous (Appendix Table B.4), and this problem was not corrected by standard data transformation. Data were therefore analyzed by the nonparametric Kruskal–Wallis method, which found significant differences in mean number of species per sample among stations (Appendix Table B.4). However, the power of the a posteriori multiple-comparisons test was insufficient to detect the differences among the means for this data set.

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 2.17 (Station HB4) to 2.95 (Station HB7). The range of values was within that of samples taken in previous years (Nelson et al. reports). Evenness ranged from 0.58 (Station HB4) to 0.74 (Station HB1), which was also comparable to the range of values observed in previous years (Nelson et al. reports). 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 79 most abundant nonmollusk species are shown in Figure 7. All stations were grouped at similarity values of greater than 60%, indicating similar species composition and abundance among all stations. There was very little sorting among stations with regard to proximity to the diffuser. For example, reference stations HB1 and HB6, ZID-boundary station HB3, and ZID station HZ were grouped as most similar.

Polychaetes

A total of 2,811 polychaetes, from 93 species, representing 41.0% of total nonmollusk abundance, were collected. These numbers were similar to those of previous years: 2,685 polychaetes from 90 species in 1994 (Nelson et al. 1994b), 2,527 polychaetes from 87 species in 1995 (Nelson et al. 1995), and 3,836 polychaetes from 95 species in 1996 (Nelson et al. 1996). The greatest number of polychaetes was found at Station HB6 (633), followed in decreasing order by Stations HB3, HB4, HB1, HZ, HB7, and HB2 (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 HB3 (63), followed by Station HB6 (45), Stations HZ and HB7 (44 each), Station HB1 (40), Station HB4 (31), and Station HB2 (27) (Figure 9).

Different polychaetes were dominant at several of the stations. The sabellid *Euchone* sp. B was a dominant species at Stations HB1 (36%), HB2 (40%), and HB6 (38%), as was the case in 1996. The sabellid *Augeneriella dubia* was dominant at Station HB4 (19%), replacing the dorvilleid *Ophryotrocha* sp. A. The syllid *Pionosyllis heterocirrata* was dominant at Stations HB3 (15%), HZ (19%), and HB7 (27%), which were dominated in 1996 by *Ophryotrocha* sp. A, the spionid *Polydora normalis*, and the pilargid *Synelmis acuminata*, respectively. The spionid *Polydora normalis* was the dominant species at Station HZ from 1993 to 1996.

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 Stations HB3 (35%) and HZ (36%) and were the most speciose of the four trophic categories. The maximum number of deposit-feeding polychaete species was 27 at Station HB3.

The dominant polychaetes in the deposit-feeding category were *Prionospio cirrobranchiata* (at Stations HB2 [13%], HZ [7%], and HB7 [9%]) and the oweniid *Myriochele oculata* (at Stations HB1 [10%], HB3 [8%], HB4 [7%] and HB6 [14%]).

2. Omnivores. In terms of percentage of total polychaetes, omnivorous worms were best represented at Station HB4 (57%); this is consistent with the results of all Barbers Point surveys since 1986 (Nelson et al. reports). At Station HB7, the syllid *Pionosyllis heterocirrata* (27%) and the pilargid *Synelmis acuminata* (21%) dominated the omnivorous component in the total collection, as in 1993 through 1996. *P. heterocirrata* was also the most abundant omnivore at Stations HB1 (7%), HB3 (15%), HB4 (16%), HZ (19%), and HB6 (10%), whereas *S. acuminata* was the most abundant omnivore at Station HB2 (12%).

3. Suspension feeders. In terms of total polychaete abundance, suspension feeders were dominant at Stations HB1 (39%), HB2 (44%), HB4 (29%), and HB6 (43%). This was primarily due to large numbers of the sabellids *Euchone* sp. B (Stations HB1 [36%], HB2 [40%], and HB6 [38%]) and *Augeneriella dubia* (HB4 [19%]). *A. dubia* was also the dominant suspension feeder at Stations HB3 (3%) and HZ (8%), and *Euchone* sp. B was the dominant suspension feeder at Station HB7 (2%). Suspension feeders made up the smallest proportion of the community at Stations HZ (12.5%), HB3 (10%), and HB7 (5%).

4. Carnivores. Carnivorous polychaetes were present at all stations, with maximum abundance occurring at Station HB3 (21%). The hesionid *Podarke angustifrons* was the dominant carnivore at Stations HB1 (5%), HB3 (9%), HB4 (18%), HZ (14%), HB6 (6%), and HB7 (7%). The lumbrinerid *Lumbrineris latreilli* was the dominant carnivore at Station HB2 (1%). In terms of total abundance, carnivores made up the smallest proportion at Stations HB1 (10%), HB2 (6%), HB4 (20%), and HB6 (9%).

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

Motile polychaetes were the most abundant worms at Stations HB3 (51%), HB4 (52%), HZ (56%), and HB7 (77%). In addition, they had the greatest number of species at each of the seven stations. Tubicolous polychaetes were dominant at Stations HB1 (50%), HB2 (54%), and HB6 (59%). The oweniid *Myriochele oculata* and the sabellid *Euchone* sp. B were dominant tubicolous polychaetes at Stations HB1 (36% and 10%, respectively), HB2 (40% and 8%, respectively), and HB6 (36% and 10%, respectively). The syllid *Pionosyllis heterocirrata* was a dominant motile worm at Stations HB1 (7%), HB3 (15%), HB4 (16%), HZ (19%), HB6 (11%), and HB7 (27%) and the pilargid *Synelmis acuminata* at Stations HB2 (12%) and HB7 (12%). The hesionid *Podarke angustifrons* was a dominant motile polychaete at Stations HB3 (9%), HB4 (18%), HZ (14%), HB6 (6%), and HB7 (7%). Discretely motile polychaetes were the least abundant at Stations HB1 (20%), HB2 (22%), HB4 (13%), and HB6 (11%). The spionids *Prionospio cirrobranchiata* (at Stations HB1 [8%], HB2 [13%], HZ [7%], HB6 [4%], and HB7 [9%]) and *P. cirrifera* (at Stations HB3 [7%] and HB4 [6%]) were the dominant worms in the discretely motile category.

Syllids were reproductively active at both ZID and non-ZID stations; egg-carrying and epitoke-bearing *Sphaerosyllis taylori* were found at Stations HB2 and HB7. At Station HZ one individual of *Brania mediodentata* was found with eggs. A specimen of *Langerhansia* sp. A was found with eggs at Station HB2.

Crustaceans

The total number of crustaceans collected was 289, which is less than half the number collected in 1996. Mean crustacean abundances (no./sample) ranged from 4.2 (926/m^2) at Station HB2 to 12.4 (2,733/m^2) at Station HB4 (Figure 14). Variances were homogeneous and data were normally distributed. There were no significant differences in mean abundance of crustaceans among stations (ANOVA, Appendix Table B.5).

A total of 27 taxa (copepods were not identified to the species level) of crustaceans were collected; of these, 9 species (33%) were amphipods. Mean number of taxa ranged from 2.0 at Station HB4 to 5.0 at Station HB1 (Figure 15). Variances were homogeneous and data were normally distributed. There were no significant differences in mean number of crustacean taxa among stations (ANOVA, Appendix Table B.6).

Copepods, tanaidaceans, and amphipods were the numerically dominant taxa, making up 53.6%, 21.1%, and 12.5%, respectively, of total crustacean abundance. No species was uniformly most abundant at all stations. Copepods and the tanaid *Leptochelia dubia* were present at most stations and were generally among the most abundant taxa.

Only 27 taxa were collected from the entire study area compared to earlier collections which included from 34 to 49 taxa. Even more striking, only 289 crustacean specimens were collected compared to 651 specimens collected in 1996. The entire Barbers Point study area (both reference and outfall stations) continues to be somewhat depressed in terms of decapods, although two new decapod species (*Penaeopsis* sp. A and an unidentified crab megalops, the last larval stage) were newly collected in 1997. Only three decapod species were collected in the entire study area compared with up to seven decapod species usually collected. Crustacean abundance for each taxa from each replicate is provided for each station in Appendix Tables D.8 through D.14.

Four taxa—including two gammarid amphipods (*Ampithoe akuolaka* and *Colomastix kapiolani*) and the two decapods (mentioned above)—were newly collected in 1997. Since 1990, a total of 92 taxa have been collected at least once in the Barbers Point study area. Between three and eight taxa have been newly collected each year since the first two years of sampling when a total of 62 taxa were collected. The Barbers Point outfall study area does not appear to be subject to extremely large swings in benthic community composition or consistency. It seems to be generally a rather stable environment. This should aid in identifying any impacts associated with the outfall itself.

Mollusks

A total of 8,043 mollusks representing 107 species were collected. Mean abundance of mollusks per sample (no./10 cm^3) ranged from 152.0 at Station HB2 to 308.0 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 19.6 at Station HB2 to 37.8 at Station HB7 (Figure 17). Data at all stations except Station HB7 were normally distributed (Appendix Table C.2). However, the composite mollusk species data set passed the test for normality prior to ANOVA. 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 Stations HB1 and HB4 than at Stations HB2, HZ, HB3 and HB6. 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 HB2 had significantly fewer mollusk species than Stations HB6, HB1, HB4, and HB7; and Station HZ had significantly fewer species that Stations HB4 and HB1. No other differences were significant.

Diversity (H') ranged from 2.04 at Station HB2 to 2.90 at Station HB7 (Figure 18). Evenness (J) ranged from 0.55 at Station HB2 to 0.67 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, HB4, and HB6. These mollusk abundance patterns are consistent with those of all previous samplings (Nelson et al. reports). Mollusk abundance for each species from each replicate is provided for each station in Appendix E.

DISCUSSION

The only significant difference in total nonmollusk abundance among stations was that ZID-boundary station HB4 had significantly higher abundance than ZID-boundary station HB2. For the crustacean component of the nonmollusks, no significant difference among stations was observed.

Reference station HB1 and ZID-boundary station HB4 had significantly greater mollusk abundance than ZID-boundary stations HB2 and HB3, ZID station HZ, and reference station HB6. Also, Station HB2 had significantly fewer mollusks than reference station HB7. 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, which had been the case from 1992 to 1995 (Nelson et al. 1992b, 1994a, 1994b, 1995), was not observed in 1996 (Nelson et al. 1996) but was again seen in 1997.

Although there were significant differences in number of nonmollusk taxa among stations, no specific pairwise comparison could be statistically identified. However, the maximum difference in mean taxa richness was between ZID-boundary stations HB3 and HB2. There were no significant differences among stations in the crustacean component of the nonmollusks.

For the crustacean fauna, there was no consistent reduction in diversity at outfall stations compared to reference stations. ZID-boundary stations HB2 and HB4 yielded only five and four non-copepod crustacean taxa, respectively, whereas ZID-boundary station HB3 and ZID station HZ had reasonable (for 1997) diversity with eleven and ten non-copepod crustacean taxa, respectively. Mean crustacean taxa richness per replicate does not seem to be as useful as total taxa richness per station as an indicator of outfall effects, given the high intrastation variability encountered. Some replicates had four to seven times more taxa than other replicates.

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

With regard to mean mollusk species richness, ZID-boundary station HB2 had significantly fewer species than reference stations HB1, HB6, and HB7 and ZID-boundary station HB4. ZID station HZ also had significantly fewer mollusk species than reference station HB7 and ZID-boundary station HB4. There is no clear pattern of mollusk species richness in relation to proximity to the outfall diffuser. Station HB1, which had the highest number of mollusk species from 1992 through 1995 (Nelson et al. 1992b, 1994a, 1994b, 1995), was the third most diverse station in 1996 (Nelson et al. 1996) and 1997.

Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. Lower nonmollusk diversity and evenness values were reported for Station HB2 in 1993, but this pattern has not been repeated since (Nelson et al. 1994a, 1994b, 1995, 1996). There is little evidence that the outfall is having an effect on species richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis similarity index indicated that nonmollusk abundance and species composition were broadly similar at most stations. In the period from 1986 to 1993, cluster analysis consistently intermixed ZID, near-ZID, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b). In 1994 and 1995, some separation between stations in or near the ZID and far-field reference stations was observed (Nelson et al. 1994b, 1995). In 1996 (Nelson et al. 1996) and 1997, stations were again generally interspersed in the cluster analysis. In comparing the 1996 and 1997 cluster results with those of earlier years some caution is necessary, since the clustering algorithm was changed in 1996 from flexible to group-average sorting in order to conform to current recommendations for optimum methodologies (Carr 1993).

Sediment grain sizes in the 1997 samples were broadly similar among stations, except for Stations HB1 and HB7, which had a higher percentage of medium and coarse sand, and Station HB2, which had relatively more silt and clay. The percentage of fine sediments at ZID station HZ showed no increase over that measured in samples taken in 1986 through 1996 (Nelson et al. reports). The increase in the silt and clay fraction of the sediments observed in 1993 for all stations began to moderate in 1996, and this trend continued in 1997 (for comparison see figure 3 in Nelson et al. 1992b, 1994a, 1994b, 1995, 1996). The mean percentage of the silt and clay fraction in 1997 resembles that seen in 1992 (Nelson et al. 1992b). The increase in fine sediments in 1993 occurred at all seven stations, thus it is unlikely to have been an effect of the outfall discharge.

ORP analysis showed no evidence of reducing conditions at the surface of sediments at any station; this has been the consistent pattern for this parameter. At Station HB2 the significantly lower mean ORP value is consistent with the higher percentage of silt and clay, which tend to reduce the ability of oxygen to diffuse into the bottom sediments.

In 1994 and 1995, various ZID or ZID-boundary stations had significant elevations in sediment O&G values as compared to other stations (Nelson et al. 1994b, 1995); however, no significant differences were seen in either 1996 or 1997. Over the course of the monitoring studies, high year-to-year variation in sediment O&G values has occurred (Nelson et al. reports). The variability in sediment O&G values suggests that there may be little direct influence of the diffuser effluent on this parameter.

Sediment TOC was below detection limits in 1997 and thus was lower at all stations than in all other sampling years except 1996, which showed the same pattern. The most likely explanation for this change is that the analytical laboratory used for the 1996 and 1997 samples removed all traces of the organic carbon from the sediment during the acid digestion to remove inorganic carbon. Although low, TOC values in previous years have been above the detection limits of current instrumentation. Similar below-detection-limit values of TOC have been reported by the same analytical laboratory for sediment samples at the Sand Island Ocean Outfall monitoring stations (Nelson et al. 1997). Analyses of sediment nitrogen levels for samples taken concurrently with the sediment TOC samples at the Sand Island monitoring stations suggest that the contract laboratory is consistently underestimating sediment TOC (Nelson et al. 1997). Unfortunately, similar measurements of sediment nitrogen were not taken for the Barbers Point Ocean Outfall monitoring stations, thus the conclusion of measurement bias for TOC cannot be conclusively confirmed, although it is strongly suspected.

The total number of nonmollusk taxa recorded in 1997 (138) was the lowest recorded in the nine years of monitoring at the Barbers Point Ocean Outfall (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, 144 in 1993, 159 in 1994, 151 in 1995, and 147 in 1996). The number of crustacean taxa collected in 1997 (27) was also lower than that of earlier years, when counts ranged from 34 to 49 taxa. Unlike in previous years (1990 through 1996), the current year's crustacean collection from the vicinity of the Barbers Point Ocean Outfall cannot be directly compared to earlier collections because procedural differences in the handling of the collections in the field resulted in much less sediment water being retained and preserved. This evidently occurred before preservation and preliminary sorting at the University of Hawai'i. As a result, far fewer ostracod, amphipod, isopod, and tanaidacean specimens were collected. However, post-collection processing was consistent for all samples, allowing station-to-station comparison for 1997.

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 1997. If the typical number of crustacean species collected (34 to 49) were added to the 111 other nonmollusk species collected in 1997, the total would be within that observed over the 1986 to 1996 period.

Mean nonmollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figure 19). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Numerous pairwise comparisons among dates showed significant differences, generally with values for more recent dates being higher than values for earlier dates. This pattern was confirmed by a linear regression analysis of data from 1990 to 1997, which found a trend of significantly increasing mean abundance over this period ($p = 0.0070$, $y = 19.1x - 79.4$). The slight decrease in 1997 versus 1996 is partly explained by the processing differences for the crustaceans described above.

Mean nonmollusk abundance was greater at Station HB4 than at Stations HB1, HB3, and HB7, higher at Station HZ than at Station HB7, and higher at Station HB6 than at HB7. The significant increase in abundance over time appears to be a regional effect in the study area. However, mean abundance over the entire study period at two stations near the diffuser (HB4 and HZ) was elevated compared to two of the reference stations; this is a pattern consistent with some impact resulting from the effluent discharged from the diffuser. This interpretation is complicated by the fact that ZID-boundary station HB3 was also significantly lower in mean abundance than Station HB4.

Mean nonmollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figure 20). Two-way ANOVA results showed significant differences among sampling dates ($p < 0.0001$) but not among sampling stations ($p = 0.1395$). Mean nonmollusk taxa richness was significantly greater in 1994 than in 1986 and 1991 and significantly lower in 1990 than in all other years except 1997 (Figure 20). Taxa richness was significantly lower in 1997 than in 1992, 1994, and 1996. The low counts for 1997 are due to methodological problems that impacted the number of crustacean taxa collected. No temporal trend comparable to that for abundance was seen for nonmollusk taxa richness, nor was any apparent spatial trend seen for this parameter.

Mean crustacean abundance was also compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figure 21). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p = 0.0309$). Mean crustacean abundance was significantly lower in 1990 and 1997 than in 1993 and 1994 and significantly lower in 1992 than in 1994. Mean crustacean abundance was significantly greater at reference station HB6 than at ZID-boundary station HB3. The decreased abundance in 1990 is consistent with the overall pattern of nonmollusk abundance for that year. Interannual variations in abundance are not related solely to differences in the time of year that samples were taken. The 1990, 1992, and 1994 through 1997 samples, all of which were taken in January or February, show considerable variation in mean crustacean abundance. The depression of crustacean abundance at one station near the diffuser relative to one (not all three) of the reference stations does not indicate a clear effect of the outfall.

Mean crustacean taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figure 22). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p = 0.0021$). Mean crustacean taxa richness was significantly lower in 1990 than in 1991 through 1996; significantly lower in 1997 than in 1991, 1993, 1994, and 1995; and significantly greater in 1994 than in 1986, 1990, 1991, 1992, 1996, and 1997. Mean crustacean taxa richness was significantly greater at reference station HB6 than at ZID-boundary station HB4 and ZID station HZ. The low mean number of taxa counted in 1990 reflects the low total abundance of crustaceans collected that year. While problems with collections methods in 1997 complicate interpretation, there appears to have been a steady decline in crustacean taxa richness since 1994. The significant depression of mean crustacean abundance at two stations near the diffuser relative to one of the reference stations indicates a potential effect of the outfall. In fact, all stations near the diffuser have fewer crustacean taxa than all reference stations. Although not all of the pairwise station comparisons are statistically significant, the overall pattern is consistent with an effect of the diffuser effluent on crustacean taxa.

Dominant taxa of the nonmollusk fauna were similar to those of previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that of previous sampling years. The sipunculan *Aspidosiphon muelleri* was the third most abundant taxon in 1997. The dominant polychaete species since 1994 showed some variation from earlier sampling years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). Dominant species in 1997 were similar to those found in 1994 through 1996 (Nelson et al. 1994b, 1995, 1996) and included the polychaetes *Euchone* sp. B, *Myriochele oculata*, *Pionosyllis heterocirrata*, *Podarke angustifrons*, *Prionospio cirrobranchiata*, and *Synelmis acuminata*.

Mean mollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figure 23). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk abundance was significantly greater in 1996 and 1997 than in all other years except 1994. Mean mollusk abundance was significantly greater at reference Station HB1 than at all other stations and significantly greater at ZID boundary station HB4 than at reference station HB6. Neither the temporal nor spatial pattern of differences indicates a negative effect of the diffuser effluent on mollusk abundance.

Because the mollusk specimens were 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 was generally much less for the mollusk fraction than for the nonmollusk fraction prior to 1996. The pattern of abundance in the sampling area on all dates shows that Station HB6 has consistently had the fewest and Station HB1 the greatest number of mollusk individuals (Figure 23).

Mean mollusk species richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figure 24). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk species richness was significantly greater in 1996 and 1997 than in all other sampling years except 1991. Mean mollusk species richness was significantly greater at Stations HB1, HB4, and HB7 than at Station HB2 and significantly greater at Station HB1 than at Station HZ. Neither the temporal nor spatial pattern of differences indicates a consistent negative effect of the diffuser effluent on mollusk species richness.

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 was not detected in any sample in 1996 or 1997. In previous years, mean sediment TOC was in the narrow range of 0.04% to 0.47%, except in 1993 when methodological problems were experienced with the analyses and values ranged from 0.56% to 1.40%. The ocean outfall in Orange County, California, discharges onto the continental shelf in an erosional benthic environment (Maurer et al. 1993) which may be somewhat similar to that found in Mamala Bay, O‘ahu. In the vicinity of the Orange County outfall, sediment TOC ranged from approximately 0.3% to 0.9% (Maurer et al. 1993). In areas which possess more depositional benthic environments, the percentage of organic content in the sediments is typically much higher. For example, this percentage 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 near the Barbers Point Ocean Outfall suggests that little particulate matter from the diffuser ever reaches the sediment surface in the study area.

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 1997. Cluster analysis of nonmollusk data indicated that all stations were similar to one another in terms of species composition and relative abundance (similarity >60%).

There has been a significant trend of increased abundance of nonmollusks within the study area since 1990, whereas the trend for the crustacean component of the nonmollusks appears to be negative since 1994. However, the significantly lower crustacean taxa counts in 1997 may have been due to methodological problems with the collections instead of environmental impacts. The trend for the mollusks has been toward increased abundance since 1994. Significantly elevated abundances of nonmollusks over the entire study period have occurred at two stations near the diffuser relative not only to two of the reference stations but also to a third near-diffuser station. Despite this elevated abundance, which may be related to the effluent discharged from the diffuser, there is no indication of any marked alteration of the benthic community at these stations in terms of species composition.

Species diversity (H') and evenness (J) were very similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment by Pearson and Rosenberg (1978) proposes 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 indication of the types of changes in bottom communities predicted by the organic enrichment hypothesis. Maurer et al. (1993) proposed that the Pearson–Rosenberg model may be inappropriate for erosional continental shelf environments. Their study of an outfall on the continental shelf off California found that even with some organic enrichment near the diffuser, there was no evidence of elimination of rare species, even though three species did achieve numerical dominance. The response of the benthic community near the Barbers Point Ocean Outfall does not show the alternate response pattern described by Maurer et al. (1993), presumably because sediment organics there do not show even the moderate enrichment found near the Orange County outfall.

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Tables

TABLE A.1. Range and Depth for Replicate Grab Samples, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997

Station	Sampling Date	Replicate	Range (yd) 1[a]	Range (yd) 2[b]	Depth (m)
HB1	30 January	1	12,484	7,948	61.3
		2	12,482	7,946	61.0
		3	12,486	7,949	61.6
		4	12,489	7,947	62.2
		5	12,486	7,956	61.6
HB2	30 January	1	15,746	5,751	61.3
		2	15,746	5,752	61.3
		3	15,740	5,749	61.3
		4	15,739	5,752	61.6
		5	15,742	5,748	61.0
HB3	4 February	1	16,467	5,992	67.1
		2	16,465	5,989	67.4
		3	16,465	5,988	67.4
		4	16,466	5,990	67.1
		5	16,465	5,993	67.1
HB4	31 January	1	16,827	6,123	59.4
		2	16,823	6,124	59.4
		3	16,821	6,127	59.1
		4	16,822	6,128	59.4
		5	16,823	6,130	59.7
HZ	4 February	1	16,505	5,980	63.7
		2	16,505	5,980	63.7
		3	16,508	5,979	63.7
		4	16,505	5,981	63.7
		5	16,508	5,981	63.7

HB6	31 January	1	17,098	6,536	61.3
		2	17,098	6,531	61.0
		3	17,099	6,534	61.0
		4	17,095	6,536	61.0
		5	17,103	6,536	61.0
HB7	31 January	1	20,256	8,702	61.0
		2	20,260	8,700	61.3
		3	20,256	8,700	61.0
		4	20,258	8,698	61.0
		5	20,255	8,699	61.0

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[a] Distance from Sand Island Wastewater Treatment Plant.

[b] Distance from Honouliuli Wastewater Treatment Plant.

TABLE A.2. Sediment Chemical Characterization of Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January–February 1997

Station-Replicate	PD (cm)	ORP (+mV)	O&G (mg/wet kg)	TOC (% dry weight)
HB1-1	8.0	220	266	[100]
HB1-2	8.0	185	260	[100]
HB1-3	10.0	195		
HB1-4	11.0	190	143	[100]
HB1-5	8.0	200		
HB2-1	12.0	35	184	[100]
HB2-2	14.5	45	180	[100]
HB2-3	7.0	25		
HB2-4	8.5	30	181	[100]
HB2-5	7.5	35		
HB3-1	8.0	175	192	[100]
HB3-2	11.0	220	447	[100]
HB3-3	7.0	245	136	[100]
HB3-4	7.5	245		
HB3-5	6.0	240		
HB4-1	10.0	145	200	[100]
HB4-2	12.0	190	222	[100]
HB4-3	12.0	205	225	[100]
HB4-4	7.5	205		
HB4-5	7.0	190		
HZ-1	12.0	215	130	[100]
HZ-2	9.0	210	116	[100]
HZ-3	9.0	230	104	[100]
HZ-4	13.0	215		
HZ-5	10.0	230		

HB6-1	8.0	210	158	[100]
HB6-2	6.5	220		
HB6-3	8.0	215	282	[100]
HB6-4	8.0	225	268	[100]
HB6-5	9.0	215		
HB7-1	9.0	215	237	[100]
HB7-2	6.5	215	179	[100]
HB7-3	7.0	210	59	[100]
HB7-4	8.0	200		
HB7-5	8.0	200		

SOURCE: PD (penetration depth), ORP (oxidation-reduction potential), and O&G (oil and grease) data from Water Quality Laboratory, Department of Wastewater Management, City and County of Honolulu; TOC (total organic carbon) data from Intertek Testing Services, Environmental Laboratories (Colchester, Vermont).

NOTE: [Value] = analyte not detected at stated detection limit of 100 mg/kg.

TABLE A.3. Sediment Grain-Size Analysis of Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997

Station-Replicate	Sample Weight Distribution (%)							
	Phi Size							
	-2	-1	0	1	2	3	4	>4–12
HB1-1	5.24	3.32	10.56	17.25	19.96	24.67	13.40	5.26
HB1-2	0.74	3.95	12.87	20.29	20.57	23.03	11.51	5.24
HB1-4	1.26	4.06	13.42	20.36	21.03	22.62	11.28	4.88
HB2-1	0.08	0.81	3.24	9.99	23.51	28.01	25.16	9.09
HB2-2	0.00	0.29	2.49	9.05	23.07	30.49	25.64	8.11
HB2-4	0.06	0.81	4.64	12.36	29.67	27.21	18.18	7.71
HB2-4 (rep)	0.00	1.57	5.08	13.52	30.83	26.64	17.05	7.03
HB3-1	0.09	0.52	1.87	7.12	23.81	45.70	15.54	4.34
HB3-2	2.50	3.01	5.86	13.98	27.58	34.19	9.87	3.59
HB3-3	0.55	1.29	3.35	10.51	29.83	42.01	8.96	3.72
HB4-1	0.13	1.10	4.74	15.23	24.98	28.42	18.02	6.41
HB4-2	0.47	1.30	4.63	13.99	23.77	31.90	18.09	5.28
HB4-3	0.55	1.50	6.02	16.89	27.00	29.14	13.42	4.78
HZ-1	0.64	0.85	3.59	13.87	31.15	38.93	8.35	2.72
HZ-1 (rep)	0.15	0.74	2.88	12.69	31.04	40.20	8.80	2.94
HZ-2	0.54	0.72	2.60	12.03	31.14	40.94	8.44	3.20
HZ-3	0.57	0.92	3.23	12.30	29.21	39.36	9.56	3.66
HB6-1	0.06	0.87	4.16	12.21	25.48	39.06	13.69	4.20
HB6-3	0.27	1.04	5.12	15.34	27.35	35.37	11.67	4.27
HB6-3 (rep)	0.18	1.51	5.39	14.67	26.68	35.48	12.31	4.50
HB6-4	0.24	1.28	6.77	16.99	26.25	33.36	8.72	3.36

HB7-1	0.44	1.21	7.11	16.36	29.66	34.68	7.07	3.33
HB7-2	2.12	4.96	10.09	16.04	25.37	30.50	7.20	3.40
HB7-3	1.91	5.55	12.11	18.46	25.37	27.24	6.42	3.43

SOURCE: Water Quality Laboratory, Department of Wastewater Management, City and County of Honolulu.

NOTE: The values listed indicate the fraction percentage of the estimated dry weight of the sediment samples. The coarse fraction (-2 to +4) was analyzed by the sieve method. The fine fraction (greater than +4 to +12) was analyzed by the pipette method.

TABLE B.1. Basic Statistics for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997 (Sample Size n = 5)

	Station						
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	147.00	122.80	252.20	259.40	215.80	236.40	136.80
Standard Deviation	25.66	55.50	116.70	83.33	55.22	75.53	40.64
Standard Error of Mean	11.48	24.82	52.19	37.26	24.69	33.78	18.17
95% of CI Mean	31.86	68.91	144.90	103.46	68.56	93.78	50.46
Skewness	-1.27	-0.49	-0.56	0.05	-0.34	-0.68	0.91
Kurtosis	2.75	-0.23	0.94	-0.10	-0.72	-2.84	0.70
Median	153.00	139.00	255.00	278.00	209.00	288.00	127.00
Normality Test (*p*)	0.107	0.527	0.592	0.646	0.685	0.041	0.618

NOTE: CI = confidence interval, *p* = probability. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution.

TABLE B.2. Basic Statistics for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997 (Sample Size n = 5)

	Station						
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	30.00	19.20	33.80	22.80	29.20	30.40	29.20
Standard Deviation	3.39	4.38	14.34	4.55	4.76	2.79	7.46
Standard Error of Mean	1.52	1.96	6.41	2.03	2.13	1.25	3.34
95% of CI Mean	4.21	5.44	17.81	5.65	5.92	3.47	9.27
Skewness	0.19	0.34	0.68	0.59	-0.95	1.50	0.20
Kurtosis	-2.23	-1.84	0.10	-1.63	0.04	2.04	-1.06
Median	29.00	19.00	33.00	21.00	31.00	29.00	28.00

Normality Test (*p*)	0.521	0.445	0.732	0.332	0.364	0.175	0.721

Note: CI = confidence interval, *p* = probability. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution.

TABLE B.3. Analysis of Variance and A Posteriori Comparison of Means for Log_{10} Tansformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Between Stations	0.571	6	0.095	3.08	0.0191
Experimental Error	0.864	28	0.031		
Total	1.435	34			

Untransformed Data

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	147.00	122.80	252.20	259.40	215.80	236.40	136.80
Standard Deviation	25.66	55.50	116.70	83.33	55.22	75.53	40.64

Levene Median test for equal variance: $p = 0.32$ not significant.

Transformed Data

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	2.16	2.04	2.35	2.40	2.32	2.35	2.12
Standard Deviation	0.08	0.25	0.27	0.15	0.12	0.15	0.13

Levene Median test for equal variance: $p = 0.710$ not significant.

Bonferroni t-tests:

	HB2	HB7	HB1	HZ	HB6	HB3	HB4
HB2		–	–	–	–	–	*
HB7			–	–	–	–	–
HB1				–	–	–	–
HZ					–	–	–
HB6						–	–
HB3							–

*$p < 0.05$.

TABLE B.4. Kruskal–Wallis Analysis of Variance and A Posteriori Comparison of Means for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997

H = 13.195 with 6 df ($p = 0.04$)

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Taxa Richness	30.00	19.20	33.80	22.80	29.20	30.40	29.20
Standard Deviation	3.39	4.38	14.34	4.55	4.76	2.79	7.46

Levene Median test for equal variance: $p = 0.015$.

Student–Newman–Keuls method:

	HB1	HB6	HB3	HB4	HB2	HZ	HB7
HB1		–	–	–	–	–	–
HB6			–	–	–	–	–
HB3				–	–	–	–
HB4					–	–	–
HB2						–	–
HZ							–

*$p < 0.05$.

TABLE B.5. Analysis of Variance for Untransformed Crustacean Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Between Stations	180.69	6	30.11	0.87	0.527
Experimental Error	966.00	28	34.50		
Total	1,146.69	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7

No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	7.60	4.20	8.20	12.40	9.60	7.80	8.00
Standard Deviation	2.51	3.70	5.76	6.77	9.96	3.70	5.43

Levene Median test for equal variance: *p* = 0.65 not significant.

Bonferroni t-tests:

	HZ	HB3	HB7	HB6	HB2	HB4	HB1
HZ		–	–	–	–	–	–
HB3			–	–	–	–	–
HB7				–	–	–	–
HB6					–	–	–
HB2						–	–
HB4							–

*$p < 0.05$.

TABLE B.6. Analysis of Variance for Untransformed Crustacean Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Between Stations	27.49	6	4.58	1.23	0.326
Experimental Error	105.20	28	3.75		
Total	132.69	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	5.00	2.60	3.00	2.00	3.00	3.40	3.80
Standard Deviation	1.87	1.82	2.12	1.73	2.24	0.89	2.49

Levene Median test for equal variance: $p = 0.65$ not significant.

Bonferroni t-tests:

	HZ	HB4	HB6	HB3	HB7	HB2	HB1
HZ		–	–	–	–	–	–
HB4			–	–	–	–	–
HB6				–	–	–	–
HB3					–	–	–
HB7						–	–
HB2							–

$^*p < 0.05$.

TABLE C.1. Basic Statistics for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997
(Sample Size n = 5)

Statistic	Station HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	308.00	152.00	206.80	286.00	200.80	208.20	246.80
Standard Deviation	30.99	24.22	17.94	39.48	52.06	24.87	43.45
Standard Error of Mean	13.86	10.83	8.02	17.66	23.28	11.12	19.43
95% of CI Mean	38.48	30.07	22.27	49.03	64.65	30.88	53.95
Skewness	-0.51	-1.42	-0.99	0.34	1.47	0.55	0.48
Kurtosis	-1.59	2.59	-0.55	-0.18	1.74	0.81	-2.83
Median	316.00	157.00	216.00	279.00	179.00	209.00	231.00
Normality Test (*p*)	0.589	0.205	0.162	0.706	0.292	0.561	0.390

NOTE: CI = confidence interval, *p* = probability. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution.

TABLE C.2. Basic Statistics for Untransformed Mollusk Species Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997
(Sample Size n = 5)

Statistic	Station HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	33.00	19.60	28.40	36.40	25.20	30.40	37.80
Standard Deviation	6.00	1.14	4.16	1.52	8.17	2.51	7.05
Standard Error of Mean	2.68	0.51	1.86	0.68	3.65	1.12	3.15
95% of CI Mean	7.45	1.42	5.16	1.88	10.14	3.12	8.75
Skewness	-0.71	-0.40	-0.92	0.32	1.14	0.20	0.60
Kurtosis	0.74	-0.18	0.95	-3.08	0.74	-3.03	-3.24
Median	34.00	20.00	30.00	36.00	23.00	30.00	33.00
Normality Test (*p*)	0.708	0.414	0.351	0.329	0.569	0.351	0.042

NOTE: CI = confidence interval, p = probability. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution.

TABLE C.3. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Between Stations	87,260.4	6	14,543.4	11.78	<0.0001
Experimental Error	34,579.2	28	1,234.9		
Total	121,839.6	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	308.00	152.00	206.80	286.00	200.80	208.20	246.80
Standard Deviation	30.99	24.22	17.94	39.48	52.06	24.87	43.45

Levene Median test for equal variance: $p = 0.50$ not significant.

Bonferroni t-tests:

	HB2	HZ	HB3	HB6	HB7	HB4	HB1
HB2		–	–	–	*	*	*
HZ			–	–	–	*	*
HB3				–	–	*	*
HB6					–	*	*
HB7						–	–
HB4							–

$*p < 0.05$.

TABLE C.4. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Species Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January–February 1997

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Between Stations	1,233.1	6	203.86	7.95	<0.0001
Experimental Error	718.4	28	25.66		
Total	1,951.5	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Species Richness	33.00	19.60	28.40	36.40	25.20	30.40	37.80
Standard Deviation	6.00	1.14	4.16	1.52	8.17	2.51	7.05

Levene Median test for equal variance: $p = 0.09$ not significant.

Bonferroni t-tests:

	HB2	HZ	HB3	HB6	HB1	HB4	HB7
HB2		–	–	*	*	*	*
HZ			–	–	–	*	*
HB3				–	–	–	–
HB6					–	–	–
HB1						–	–
HB4							–

$*p < 0.05$.

BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O‘AHU, HAWAI‘I, JANUARY 1998

Richard C. Swartz
Julie H. Bailey–Brock
William J. Cooke
E. Alison Kay

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Principal Investigator: James E.T. Moncur

WATER RESOURCES RESEARCH CENTER
University of Hawai'i at Mānoa
Honolulu, Hawai'i 96822

The taxa abundance and richness counts for benthic organisms and the data calculations in this publication are the responsibility of the authors. The Water Resources Research Center staff is responsible for publication production activities.

INTRODUCTION

The Honouliuli Wastewater Treatment Plant is a primary treatment system. Wastewaters of mainly domestic origin are treated at the plant prior to discharge in Māmala Bay through an 84-in. (2.13-m) diameter outfall located off the southern coast of O‘ahu, Hawai‘i.

A waiver of secondary treatment for sewage discharge through the Barbers Point Ocean Outfall has been granted to the City and County of Honolulu (CCH) by the Region 9 office of the U.S. Environmental Protection Agency (EPA). This report provides the results of the tenth survey in an ongoing series of studies of the macrobenthic, soft-bottom community in the vicinity of the discharge; it also provides an overview of trends in biological communities adjacent to the outfall over the thirteen-year period from 1986 to 1998. The first benthic survey took place in 1986. The samples on which this report is based were collected on 10 and 12 January 1998. The Division of Water Quality, Department of Wastewater Management, City and County of Honolulu, did not provide the sediment data until late April; hence this report is being submitted late.

PROJECT ORGANIZATION

General coordination for this project is provided by James E.T. Moncur, assistant director of the Water Resources Research Center of the University of Hawai‘i at Mānoa and project principal investigator. The principal members of the project team (listed in alphabetical order) and their contributions to this study are as follows:

Julie H. Bailey–Brock	Polychaete, oligochaete, and sipunculan analysis and report
William J. Cooke	Crustacean analysis and report
E. Alison Kay	Mollusk analysis and report
Richard C. Swartz	Statistical analysis and final report preparation
Ross S. Tanimoto	City and County of Honolulu project representative and coordinator for sediment grain-size, total volatile solids, and oxidation-reduction potential analyses

MATERIALS AND METHODS

Specific locations of the sampling stations are provided in Figure 1, and a general vicinity map for the area serviced by the Honouliuli Wastewater Treatment Plant is provided in Figure 2. Seven stations previously established along the approximate diffuser isobath (61 m) were surveyed. In 1990 survey station names were changed from those used in the 1986 survey (Nelson et al. 1987). Survey stations (1986 station names are in parenthesis) and their locations are as follows:

Station HB1 (A)	Approximately 3.5 km east of the zone of initial dilution (ZID) boundary to evaluate effects far-field and beyond the ZID
Station HB2 (B)	On the northeast ZID boundary
Station HB3 (C)	On the southeast ZID boundary
Station HB4 (D)	On the southwest ZID boundary
Station HZ (Z)	Within the ZID to evaluate diffuser effects
Station HB6 (E)	Approximately 0.5 km southwest of the ZID boundary as a near-field reference station
Station HB7 (F)	Approximately 3.5 km southwest of the ZID boundary as a far-field reference station

Station Positioning

The exact positioning of each station was determined using the Motorola Mini-ranger navigation system. Station locations in relation to latitude, longitude, and bathymetric contours are shown in Figure 1. Ranges for each replicate grab sample at each station are given in Appendix Table A.1. Depths for all stations fell within the range of 59.4 to 67.1 m. Station positions within and at the boundaries of the ZID were located precisely during the original sampling using the submersible *Makali'i* in coordination with its mother ship (Nelson et al. 1987).

Sampling Methods

The sampling methodology used in this study generally follows the recommendations of Swartz (1978) and guidelines of the U.S. Environmental Protection Agency (1987a, 1987b), hereafter referred to as EPA procedures. The previous reports on the benthic monitoring adjacent to the Barbers Point Ocean Outfall (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b, 1995, 1996, 1997a) will be hereafter referred to as "Nelson et al. reports."

In 1994, the modified 0.1-m^2 van Veen grab sampler previously used was replaced by a 0.16-m^2 van Veen grab sampler. The new grab, which was deployed from a stern-mounted

A-frame on the City's research vessel *Noi I Kai*, was used to obtain bottom samples at all seven stations. Sampling dates were 10 and 12 January 1998. Penetration of the sampler was adequate for all replicates. The minimum penetration depth was 8.0 cm, and the maximum was 12.0 cm (Appendix Table A.2).

Five replicate grab samples were taken at each station. From each replicate sample, a subsample 7.6 cm in diameter by 5 cm deep was taken for infaunal analysis and a subsample 4.8 cm in diameter by 5 cm deep for mollusk analysis. Subsampling was necessary because the epifauna and infauna in the area are known to be both small and abundant (Nelson 1986; Russo et al. 1988). Replicated grab samples at each station, rather than replicated subsamples from one grab sample, were taken to provide information on intrastation variability. All five biological subcores for nonmollusk analysis were processed on a 0.5-mm screen and the organisms retained and preserved as appropriate for subsequent identification.

Samples for geochemical analyses (total organic carbon [TOC], oxidation-reduction potential [ORP], oil and grease [O&G], and grain size) were obtained from the grabs from which the biological subcores were taken because each replicate grab contained more than enough sediment for both purposes (methods established by National Pollutant Discharge Elimination System permit no. HI0020877). Three subsamples (one from each of three different grab samples) were taken for all stations. The top 2 cm of sediment of each subsample were used for geochemical analysis. Samples for TOC and sediment O&G analyses were put in screw-cap jars, which were placed on ice, and taken to the laboratory for analysis. Sediment ORP was measured on board the research vessel immediately after each sample was obtained. Laboratory analyses of sediment grain size and sediment ORP followed EPA procedures. Analysis of TOC was carried out using EPA procedures by Intertek Testing Services, Environmental Laboratories (Colchester, Vermont). It performed the analysis using a modification of the Lloyd Kahn method which utilizes an infrared detector to detect carbon dioxide. Inorganic carbon was removed from the samples by treating them with a 1:1 solution of hydrochloric acid prior to TOC analysis.

Sample Processing

Handling, processing, and preservation of the biological samples followed EPA procedures. Nonmollusk samples were fixed with buffered 10% formalin for a minimum of 24 hours. Following fixation, all samples were placed in 70% ethanol. Mollusk samples were placed in labeled jars in the field, then placed on ice and transported to the laboratory where they were refrigerated. Samples were washed in freshwater (to minimize loss of fine sediments), fixed in 75% isopropyl alcohol for 24 hours, and then air dried. A subsample in a 10-cm^3 aliquot was removed from each mollusk sample for sorting.

The fixed nonmollusk samples were elutriated using the technique of Sanders et al. (1965). This method removes from the sediment all organisms that are not heavily calcified (Nelson et al. 1987). Samples were washed several times, and the water from each was poured through 0.5-mm-mesh sieves. Polychaetes and other invertebrates retained on the sieve were transferred to alcohol, stained with rose bengal solution, and stored in 70% ethanol. Samples from some replicates (Station HB1 [replicates 1 and 5], Station HB3 [replicates 3 and 5], Station HB4 [replicates 3 and 4], Station HZ [replicates 1 and 4], Station HB6 [replicates 1, 3, and 4] and Station HB7 [replicates 1, 3, 4, and 5]) contained rubble pieces, which were acid-dissolved to remove endolithic and cryptic species. From zero to seventy additional organisms were collected from the rubble fragments, depending on the replicate.

Because the biological subcores had to be processed using two different procedures—one for mollusks and the other for all other organisms—the two components of the fauna were not directly comparable and thus were analyzed separately. Because the mollusk specimens were not separated into living and dead shell fractions, they represent time-averaged samples. Mollusks have been extensively analyzed by Kay (1975, 1978, 1979, 1982), Kay and Kawamoto (1980, 1983), Nelson (1986), and Russo et al. (1988).

All specimens were identified to the lowest taxonomic level possible. A selected bibliography for the identification of marine benthic species in Hawai‘i is provided in Nelson et al. (1987, appendix D). An additional source used for the identification of polychaetes in Hawai‘i is Blake et al. (1995). Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained for six years at the University of Hawai‘i.

In previous benthic sampling reports for Barbers Point, name changes for several polychaete species were indicated. This report includes additional name changes made after re-examining specimens. *Aricidea* sp. A is now listed as *Paraonella* sp. A, *Hesionura* sp. B as *Hesionura australiensis*, *Pygospio* sp. A and *Laonice* sp. A as *Laonice cirrata*, *Protodorvillea* sp. B as *Dorvillea* sp. B, *Questa* sp. A as *Novaquesta* sp. A, *Sphaerosyllis capensis* and *Sphaerosyllis taylori* as *Sphaerosyllis* sp. G, and *Typosyllis aciculata* as *Typosyllis aciculata orientalis*. In addition, the taxon Tunicate was redesignated as Urochordata. These taxonomic changes have been made to the nonmollusk species list used by the biomonitoring team. Another change to the list is the addition of Sipuncula sp. G, a new organism collected during the 1998 sampling period.

Data Analysis

All data for both nonmollusks and mollusks were tested for assumptions of normality (Kolmogorov–Smirnov test; Sokal and Rohlf 1995) and heterogeneity of variances (F_{max} test) prior to statistical analysis. Where data sets failed tests of assumptions, square root transformation was applied. Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following a significant result using ANOVA, a posteriori Student–Newman–Keuls tests were used to determine which differences in means among stations were significant. All statistical analyses were performed using Prophet and Microsoft Excel software. Detailed statistical results are provided in Appendixes B and C.

An overall comparison of taxa composition among stations was carried out using cluster analysis (Pielou 1984). The Bray–Curtis similarity index (Bloom 1981) on double square root transformed data was performed using the group-average sorting strategy. To make analysis more manageable, only those nonmollusk taxa that contributed at least 0.05% to the total abundance were included. Using this criterion, only taxa represented by a total of more than four individuals were included in the data set, which was reduced from 140 to 71 taxa. The similarity matrix was computed with Microsoft Excel software.

The Shannon–Wiener diversity index (H') (ln) 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 using Microsoft Excel software.

To examine trends over the entire study period, comparisons were made among mean values for all sampling dates and sampling stations using two-way ANOVA without replication and a posteriori Student–Newman–Keuls tests.

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) are 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.

Sediment grain-size patterns were similar to those found in 1996 and 1997. Stations HB1 and HB7, with a greater percentage of medium and coarse sand, differed most from the other stations (Figure 3). Stations HB2, HB3, HZ, and HB6 had higher percentages of fine sand than medium and coarse sand, while Station HB4 had approximately equal percentages of the two sand-size components. Station HB2 had the highest percentage of fine sand and the highest percentage of silt and clay. Sediments at all stations were >90% sand (Appendix Table A.3). Results of replicate sediment sample analysis for all seven stations indicated substantial homogeneity in grain size within stations (Appendix Table A.3). Analysis of duplicate samples at Stations HB1, HB3, and HB7 indicated consistency of analytical techniques.

Direct electrode measurements of ORP ranged from +60 to +235 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, Student–Newman–Keuls tests) showed that Station HB2 had a significantly lower value than Stations HB4, HZ, HB6, and HB7. These results are similar to those obtained in the 1997 survey (Nelson et al. 1997a) except the ORP values were much higher, i.e. showing less evidence of reducing conditions, at Station HB2 in 1998 (range: 80 to 170 mV) than in 1997 (range: 25 to 45 mV).

Sediment O&G values ranged from less than 5 to 173 mg/wet kg (Appendix Table A.2). Mean O&G values ranged from 48.3 mg/wet kg (at Station HZ) to 148.0 mg/wet kg (at Station HB4). Comparison of mean O&G per station (one-way ANOVA) showed that there were no significant differences among stations ($F = 1.99$, $df = 6, 14$; $p = 0.14$).

Total organic carbon in the sediments was below the detection limit (0.01% TOC, dry weight) of the analytical method used for all samples—except for one replicate at Station HB1 (0.28% TOC), one replicate at Station HB2 (0.02% TOC), and one replicate at Station HB3 (0.21% TOC) (Appendix Table A.2).

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, sipunculans, echinoderms, nematodes, nemerteans, priapulids, phoronids, anthozoans, hydrozoans, platyhelminths, bryozoans, a chordate species, copepods, ostracods, cumaceans, tanaids, amphipods, isopods, and decapods.

The 8,373 nonmollusk specimens counted and identified for all stations and replicates represent 140 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (3,521 individuals, 42.1%) and taxa richness (85 taxa, 60.7%). Nematodes were the second most dominant nonmollusk taxon in terms of abundance (2,059 individuals, 24.6%). Oligochaetes constituted 11.5% (961 individuals) of numerical abundance, sipunculans contributed 9.8% (820 individuals), and crustaceans contributed 8.3% (697 individuals). The 36 crustacean taxa, 11 of which were amphipods, represented 25.7% of the total number of nonmollusk taxa. Abundance estimates for each species from each replicate are given for each of the seven stations 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 taxa). Data were normal for all stations except that for nonmollusk individuals at Station HZ (Appendix Table B.1).

Mean total nonmollusk abundance ranged from 140.4 individuals per sample (30,949/m^2, at Station HB2) to 392.2 individuals per sample (86,455/m^2, at Station HB6) (Figure 4). Variances were homogeneous (Appendix Table B.3). According to the ANOVA on untransformed data, there were significant differences in mean abundance among stations (Appendix Table B.3). Mean abundance was significantly higher at Station HB6 than at Stations HB2, HB3, HB1, and HB7. No other pairwise comparisons of means were significantly different.

The mean number of nonmollusk taxa per sample ranged from 23.4 taxa at Station HB3 to 40.8 taxa at Station HZ (Figure 5). Variances were homogeneous (Appendix Table B.4). According to the ANOVA on untransformed data, there were significant differences in mean number of nonmollusk taxa among stations (Appendix Table B.4). Mean number of nonmollusk taxa was significantly higher at Station HZ than at Stations HB3 and HB2; it was also significantly higher at Station HB6 than at Station HB3. No other pairwise comparisons of means were significantly different.

Composite station diversity (H') and evenness (J) for the nonmollusks are shown in Figure 6. Values for both parameters were similar for all stations. Values for diversity ranged from 2.37 (at Station HB4) to 2.97 (at Station HB1). The range of values was within that of samples taken in previous years (Nelson et al. reports). Evenness ranged from 0.58 (at Station HB4) to 0.69 (at Station HB1), which was also comparable to the range of values observed in previous years (Nelson et al. reports). Relative to other stations, there was no consistent pattern of lower diversity or evenness at ZID or ZID-boundary stations.

Results of cluster analysis indicating the relative similarity of stations based on the 71 most abundant nonmollusk taxa are shown in Figure 7. All stations were grouped at similarity values of greater than 67%, indicating similar taxa composition and abundance among all stations. There was very little sorting among stations with regard to proximity to the diffuser. For example, reference stations HB1 and HB6, ZID-boundary station HB4, and ZID station HZ were grouped as most similar.

Polychaetes

A total of 3,521 polychaetes representing 85 taxa were collected; they comprised 42.1% of total nonmollusk abundance. These numbers are similar to those of previous years: 2,685 polychaetes representing 90 taxa in 1994 (Nelson et al. 1994b), 2,527 polychaetes representing 87 taxa in 1995 (Nelson et al. 1995), 3,836 polychaetes representing 95 taxa in 1996 (Nelson et al. 1996), and 2,811 polychaetes representing 93 taxa in 1997 (Nelson et al. 1997a). The greatest number of polychaetes was found at Station HB6 (1,113 individuals), followed in decreasing order of abundance by Stations HZ (537 individuals), HB4 (458 individuals), HB1 (406 individuals), HB2 (381 individuals), HB7 (352 individuals), and HB3 (274 individuals) (Figure 8). Polychaetes were the most taxa-rich group at all stations (Appendix Tables D.1 through D.7). Maximum polychaete taxa richness occurred at Station HZ (51 taxa), followed in decreasing order by Stations HB1 (46 taxa), HB7 (43 taxa), HB6 (42 taxa), HB4 (40 taxa), HB2 (39 taxa), and HB3 (32 taxa) (Figure 9).

Dominant polychaete taxa differed at several stations (Table 1). The sabellid *Euchone* sp. B was dominant at Stations HB1 (42% of polychaetes), HB2 (45%), and HB6 (47%), continuing its dominance at these stations since 1996. The syllid *Pionosyllis heterocirrata* was dominant at Stations HB3 (18%), HB4 (22%), and HB7 (29%). It was also dominant at Stations HB3 and HB7 in 1997. This year it replaced *Augeneriella dubia* as the dominant species at Station HB4. This year *Polydora normalis* returned to dominance at Station HZ, where it was dominant from 1993 through 1996. In 1997 it was replaced as the dominant species at this station by *Pionosyllis heterocirrata*.

Syllids were reproductively active at ZID and non-ZID stations. *Sphaerosyllis* sp. G was found at three stations: HB1 (one individual with one egg), HZ (one individual with four epitokes), and HB7 (one individual with three eggs). *Brania mediodentata* was found at Stations HB1 (one individual with one egg) and HZ (one individual with six epitokes). *Exogone* sp. C and *Exogone* sp. E were found at Stations HB4 (one individual with two epitokes) and HB7 (one individual with twelve eggs), respectively.

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 Stations HZ (266 individuals) and HB6 (265 individuals) and most speciose at all stations. The number of deposit-feeding taxa ranged from 13 (at Station HB3) to 21 (at Station HZ). The dominant polychaetes in the deposit-feeding category were the spionids *Polydora normalis* (20% at Station HZ), *Prionospio cirrifera* (6% at both Stations HB1 and HB2 and 11% at Station HB7), *Prionospio cirrobranchiata* (8% at Station HB2 and 14% at Station HB3), and the oweniid *Myriochele oculata* (21% at Station HB4 and 17% at Station HB6).

2. Omnivores. In terms of percentage of total polychaete individuals per station, omnivorous worms were best represented at Station HB7 (58%); this is consistent with the results of all Barbers Point surveys since 1986 (Nelson et al. reports). At Station HB7 the syllid *Pionosyllis heterocirrata* (29%) and the pilargid *Synelmis acuminata* (15%) dominated the omnivorous component, as in 1993 through 1997; and *Sphaerosyllis* sp. G (7%) was the third dominant omnivore. *Pionosyllis heterocirrata* was the dominant omnivore at Stations HB1 (7%), HB3 (18%), HB4 (22%), and HB6 (7%), whereas *Synelmis acuminata* was the dominant omnivore at Stations HB2 (9%) and HZ (10%).

3. Suspension feeders. In terms of percentage of total polychaete individuals per station, suspension feeders were dominant at Stations HB1 (47%), HB2 (52%), and HB6 (53%). This was primarily due to the large numbers of the sabellid *Euchone* sp. B (42% at Station HB1, 45% at Station HB2, and 47% at Station HB6). *Aonides* sp. A was the most dominant suspension feeder at Station HB3 (9%), *Augeneriella dubia* at Stations HB4 (11%) and HB7 (1%), and *Euchone* sp. B at Station HZ (8%). Suspension feeders were least abundant at Station HB7 (3%).

4. Carnivores. Carnivorous polychaetes were present at all stations, with their greatest abundance occurring at Station HB4 (15%). The hesionid *Podarke angustifrons* was the dominant carnivore at all stations: HB1 (4%), HB2 (3%), HB3 (9%), HB4 (11%), HZ (7%), HB6 (3%), and HB7 (5%). In terms of total abundance, carnivores made up the smallest numbers at Stations HB1 (9%), HB2 (7%), HB3 (11%), HB4 (15%), HZ (9%), and HB6 (5%).

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

1. Tubicolous polychaetes. Tubicolous polychaetes were most abundant at Stations HB1 (52%), HB2 (53%), and HB6 (71%). The sabellid *Euchone* sp. B was the dominant tubicolous polychaete at Stations HB1 (42%), HB2 (45%), HZ (8%), and HB6 (47%); whereas the oweniid *Myriochele oculata* was the dominant species at Stations HB4 (21%) and HB7 (1%). In terms of taxa richness, however, tubicolous polychaetes had the smallest number at each station.

2. Motile polychaetes. Motile polychaetes were the most abundant worms at Stations HB3 (47%), HB4 (51%), and HB7 (74%). In addition, they had the greatest number of taxa at each of the seven stations. The syllid *Pionosyllis heterocirrata* was the dominant motile polychaete at Stations HB1 (7%), HB3 (18%), HB4 (22%), HB6 (7%), and HB7 (29%). The pilargid *Synelmis acuminata* was the dominant motile polychaete at Stations HB2 (9%) and HZ (10%), and it showed high levels of abundance at Stations HB1 (5%), HB3 (10%), and HB7 (15%).

3. Discretely motile polychaetes. Discretely motile polychaetes were most abundant at Station HZ (43%). *Prionospio cirrobranchiata* was the most abundant discretely motile species at Stations HB2 (8%), HB3 (14%), and HB4 (4%); *Prionospio cirrifera* at Stations HB1 (6%) and HB7 (11%); *Polydora normalis* at Station HZ (20%); and *Nereis* sp. B at Station HB6 (6%).

Crustaceans

A total of 697 crustaceans and pycnogonids, representing 8.3% of the nonmollusk abundance, were collected. Abundance for each taxon from each replicate is provided for each station in Appendix Tables D.8 through D.14. Mean abundance (no./sample) ranged from 4.0 (882/m^2, at Station HB3) to 32.2 (7,098/m^2, at Station HB6) (Figure 14). Variances were heterogeneous for untransformed data but became homogeneous after square root transformation (Appendix Table B.5). There were significant differences in mean abundance among stations (ANOVA, Appendix Table B.5). Stations HB3 and HB2 had significantly lower mean abundance than Stations HZ, HB4, HB1, HB7, and HB6.

A total of 36 crustacean and pycnogonid taxa (copepods were not identified to the species level) were collected; of these, 11 taxa (30.6%) were amphipods. Mean number of taxa ranged from 2.8 (at Station HB3) to 8.0 (at Stations HB1 and HB7) (Figure 15). Variances were homogeneous and data were normally distributed. Station HB3 had a significantly lower mean number of taxa than Stations HZ, HB6, HB1, and HB7 (ANOVA, Appendix Table B.6).

Tanaids, amphipods, and copepods were the numerically dominant taxa, making up 44.8%, 20.7%, and 18.2%, respectively, of total crustacean and pycnogonid abundance. No taxon was uniformly most abundant at all stations. Copepods and the tanaid *Leptochelia dubia* were present at all stations and were generally among the most abundant crustaceans. *L. dubia* ranked among the five most abundant nonmollusk taxa at Stations HB1, HB6, and HB7
(Table 1).

Crustacean and pycnogonid abundance (697 individuals) and taxa number (36) in 1998 were substantially greater than in 1997 (289 individuals, 27 taxa) when collections were reduced because of procedural differences in sample handling (Nelson et al. 1997a). Excluding the low values obtained in 1997, abundance and taxa richness in 1998 were within the range observed in earlier collection years (range for 1986 and for 1990 through 1996 collections: 164 to 1,121 individuals, 34 to 49 taxa).

Comparing the crustacean community composition across stations demonstrates clearly that any impact the outfall may be having is not consistent across the ZID area. At ZID-boundary station HB2, samples included two decapods (a callianassid and an unidentified megalops) and four gammaridean amphipod taxa. At ZID station Z one decapod (the pagurid hermit crab) and five gammaridean amphipod taxa were present. However, at ZID-boundary station HB3 no decapods were collected and only two gammaridean amphipod taxa were present. Conversely, at reference station HB6, no decapods were collected and only three gammaridean amphipod taxa were present; and at reference station HB1, two decapods were collected and six gammaridean amphipod taxa were present.

Only two taxa—the myodocopid ostracod enumerated as "Myodocope sp. D." and an excellent specimen of the burrowing anomuran *Callianassa* sp. A—were newly collected in 1998. This brings the total number of discretely identified/reported taxa from the study area in nine years to 94. Copepods are enumerated as a single taxon, although several different taxa are certainly present. Cumaceans and mysids are similary enumerated. Between two and eight taxa have been newly collected each year since the first two years of sampling when a total of 62 taxa were collected. The Barbers Point outfall study area does not appear to be subject to extremely large swings in benthic community composition or consistency. It seems to be generally a rather stable environment. This should aid in identifying any impacts associated with the outfall itself.

Mollusks

A total of 10,395 mollusks representing 131 taxa were collected. Mean abundance of mollusks per sample (no./10 cm^3) ranged from 229.0 (at Station HB7) to 414.0 (at Station HB1) (Figure 16). Data were normally distributed at all stations except Station HB4 (Appendix Table C.1). Complete basic statistics for total mollusk data are shown in Appendix Table C.1.

Mean number of mollusk taxa per sample ranged from a low of 26.4 (at Station HB2) to 40.2 (at Station HB1) (Figure 17). Data at all stations except Stations HB3 and HZ were normally distributed (Appendix Table C.2). However, the composite mollusk taxa data set passed the test for normality prior to ANOVA. Complete basic statistics for number of mollusk taxa 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 Stations HB7, HB2, HZ, and HB6. No other differences in means were significant.

Variances for number of mollusk taxa data were homogeneous (Appendix Table C.4). There were significant differences in mean mollusk taxa number among stations (ANOVA, Appendix Table C.4). Station HB2 had significantly fewer mollusk taxa than all other stations; and Station HZ had significantly fewer taxa that Station HB1. No other differences were significant.

Diversity (H') ranged from 2.18 (at Station HB2) to 3.01 (at Station HB7) (Figure 18). Evenness (J) ranged from 0.57 (at Station HB2) to 0.71 (at Station HB7). Diversity and evenness values for mollusks were generally similar for all stations (Figure 18).

The mollusk abundance patterns are consistent with those of all previous samplings (Nelson et al. reports). Mollusk abundance for each taxa from each replicate is provided for each station in Appendix E. The molluscan fauna was very similar at all stations, especially among the dominant taxa (Table 2). The gastropod taxa *Diala scopulorum*, *Cerithidium perparvulum*, *Scaliola* spp., and *Balcis* spp. were abundant at all stations. *Diala semistriata* was abundant at all stations except Station HB2. *Finella pupoides* was abundant at all stations except Stations HB1 and HB7. These six dominant mollusk taxa accounted for 74.5% of all individuals collected.

DISCUSSION

The only significant difference in total nonmollusk abundance among stations was that one of the reference stations (HB6) had significantly higher abundance than the other two reference stations (HB1 and HB7) and the two ZID-boundary stations (HB2 and HB3). For the crustacean component of the nonmollusks, Stations HB2 and HB3 had significantly fewer individuals than Stations HB1, HB4, HZ, HB6, and HB7. Although the statistical comparisons among stations were usually not significant, more crustacean individuals were collected at each of the reference stations than at any of the ZID or ZID-boundary stations.

Reference station HB1 had significantly greater mollusk abundance than ZID-boundary station HB2, ZID station HZ, and reference stations HB6 and HB7. 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, which had been the case from 1992 to 1995 (Nelson et al. 1992b, 1994a, 1994b, 1995), was not observed in 1996 (Nelson et al. 1996) but was again seen in 1997 (Nelson et al. 1997a) and 1998.

ZID station HZ had significantly more nonmollusk taxa than ZID-boundary stations HB2 and HB3. Reference station HB6 had significantly more nonmollusk taxa than ZID-boundary station HB3. Station HB3 had significantly lower mean number of crustacean taxa than ZID station HZ and reference stations HB1, HB6, and HB7. Although the statistical comparisons were usually not significant, mean crustacean taxa richness per replicate was greater at each of the reference stations than at any of the ZID or ZID-boundary stations.

Mean crustacean taxa richness per replicate may not be as useful as total taxa richness per station as an indicator of outfall effects, given the high intrastation variability encountered. The total number of crustacean taxa collected at ZID station HZ was 16, slightly more than at reference stations HB6 (15 taxa) and HB7 (14 taxa). Total crustacean richness at ZID-boundary station HB2 was 14, which is comparable to that for reference stations HB6 and HB7.

Reductions in crustacean abundance and taxa richness near the Barbers Point Ocean Outfall relative to reference stations have not been observed in every previous monitoring survey. Although in some years (e.g., 1991, Nelson et al. 1992a) taxa richness appeared to be reduced adjacent to the outfall, this pattern had not been seen for several years until 1998. The shifting patterns of number of taxa and abundance from year to year appear to be more strongly influenced by other factors, such as small-scale differences in bottom topography or a subtle variation in sediment composition. The presence of nine species of stress-sensitive gammaridean amphipods also indicates that changes in the crustacean assemblage near the outfall in 1998 are associated with factors other than chemical contamination by the effluent discharge.

Taxonomic diversity (expressed here simply as the number of discretely recorded taxa) is considered to be a better measure of the state of the crustacean communities at these sampling stations than the abundance data. Crustacean and pycnogonid abundance counts can be strongly influenced by a large number of juveniles released from brooding adults (for tanaids, isopods, and amphipods). Abundance data generated from other taxa (such as mollusks, most polychaetes, and many decapods) represent a settlement from the plankton of a larval form which has found the site suitable for settlement. While high crustacean abundance data (particularly if juveniles are being produced) clearly indicate that the site is suitable, low abundance data is not necessarily indicative of unsuitability.

A rather comprehensive picture of the crustacean communities in the study area has been developed (at least for crustaceans smaller than 1 cm) over the last nine years despite the rather small areal coverage (7.6 cm diameter) of the sampling replicates. This is demonstrated by the fact that only two new records were recorded for 1998. Certainly this steadily declining collection of new records does not indicate any significant change in the crustacean community. If the community was undergoing significant changes in composition, the collection curve over time would not be expected to be leveling out as it is. It should be noted that larger (2 cm and up) shrimp and crabs, while certainly present in the study area, have almost no chance of being collected. In general, the Honouliuli study area is less diverse than comparable study areas near the Waianae WWTP outfall and more diverse than the deeper Sand Island outfall study area.

With regard to mean mollusk taxa richness, ZID-boundary station HB2 had significantly fewer taxa than all other stations. ZID station HZ had significantly fewer mollusk taxa than reference station HB1. There was no consistent pattern of mollusk taxa richness in relation to proximity to the outfall diffuser. There were no statistically significant differences between the two reference stations (B6 and B7) and any of the four ZID-boundary and ZID stations except HB2.

Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. Lower nonmollusk diversity and evenness values were reported for Station HB2 in 1993, but this pattern has not been repeated since (Nelson et al. 1994a, 1994b, 1995, 1996, 1997a). There is little evidence that the outfall is having an effect on taxa richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis similarity index indicated that nonmollusk abundance and taxa composition were broadly similar at most stations (>67% similarity index value). In the period from 1986 to 1993, cluster analysis consistently intermixed ZID, ZID-boundary, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). In 1994 and 1995, some separation between stations in or near the ZID and far-field reference stations was observed (Nelson et al. 1994b, 1995). In 1996 (Nelson et al. 1996), 1997 (Nelson et al. 1997a), and 1998, stations were again generally interspersed in the cluster analysis. In comparing the 1996 through 1998 cluster results with those of earlier years some caution is necessary, since the clustering algorithm was changed in 1996 from flexible to group-average sorting in order to conform to current recommendations for optimum methodologies (Carr 1993).

Sediment grain sizes in the 1998 samples were broadly similar among stations, except for Stations HB1 and HB7, which had a higher percentage of medium and coarse sand. Station HB2 had the highest percentage of very fine sand and the highest percentage of silt and clay. The percentage of fine sediments at ZID station HZ showed no increase over that measured in samples taken in 1986 through 1997 (Nelson et al. reports). The increase in the silt and clay fraction of the sediments observed in 1993 for all stations began to moderate in 1996, and this trend continued in 1997 and 1998 (for comparison see figure 3 in Nelson et al. 1992b, 1994a, 1994b, 1995, 1996, 1997). The mean percentage of the silt and clay fraction in 1998 (4.86%) closely resembles that seen in 1997 (4.77%) (Nelson et al. 1997a). The increase in fine sediments in 1993 occurred at all seven stations, thus it is unlikely to have been an effect of the outfall discharge.

ORP analysis showed no evidence of reducing conditions at the surface of sediments at any station; this has been the consistent pattern for this parameter. At Station HB2 the significantly lower mean ORP value is consistent with the higher percentage of both the fine sand and the silt and clay components which tend to reduce the ability of oxygen to diffuse into the bottom sediments.

In 1994 and 1995, various ZID or ZID-boundary stations had significant elevations in sediment O&G values as compared to other stations (Nelson et al. 1994b, 1995); however, no significant differences were seen in 1996, 1997, or 1998. Over the course of the monitoring studies, high year-to-year variation in sediment O&G values has occurred (Nelson et al. reports). The variability in sediment O&G values suggests that there may be little direct influence of the diffuser effluent on this parameter.

Sediment TOC was below detection limits in 18 of 21 replicate samples and thus was lower at all stations than in all other sampling years except 1996 and 1997, which showed no replicates above the detection limit. The most likely explanation for this change is that the analytical laboratory used for TOC analyses after 1995 removed all traces of the organic carbon from the sediment during the acid digestion to remove inorganic carbon. Although low, TOC values in previous years have been above the detection limits of current instrumentation. Similar below-detection-limit values of TOC have been reported by the same analytical laboratory for sediment samples at the Sand Island Ocean Outfall monitoring stations (Nelson et al. 1997b). Analyses of sediment nitrogen levels for samples taken concurrently with the sediment TOC samples at the Sand Island monitoring stations suggest that the contract laboratory is consistently underestimating sediment TOC (Nelson et al. 1997b). Unfortunately, similar measurements of sediment nitrogen were not taken for the Barbers Point Ocean Outfall monitoring stations, thus the conclusion of measurement bias for TOC cannot be conclusively confirmed, although it is strongly suspected.

The total number of nonmollusk taxa recorded in 1998 (140) was the second lowest recorded in the ten years of monitoring at the Barbers Point Ocean Outfall (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, 144 in 1993, 159 in 1994, 151 in 1995, 147 in 1996, and 138 in 1997). The 36 crustacean and pycnogonid taxa collected in 1998 was within the range observed in earlier years, when counts ranged from 34 to 49 taxa. That range does not include the low value of 27 taxa collected in 1997 when counts were reduced because of differences in sample handling. 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 1998.

Mean nonmollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1998 (Figures 19 and 20).

Two-way ANOVA results showed significant differences both among sampling dates ($p <$ 0.0001) and among sampling stations ($p < 0.0001$). Numerous pairwise comparisons among dates showed significant differences, generally with values for more recent dates being higher than values for earlier dates. This pattern was confirmed by a linear regression analysis of data from 1990 to 1998, which found a trend of significantly increasing mean abundance over this period
($p = 0.0017$, $y = 18.3x - 82.6$, where y = mean nonmollusk abundance and x = year code: 1990 = 10 through 1998 = 18). The slightly lower mean nonmollusk abundance in 1997 versus 1996 and 1998 is partly explained by the processing differences for the crustaceans during the 1997 survey.

The Student–Newman–Keuls test showed no significant pairwise multiple contrasts among stations for mean nonmollusk abundance based on data collected in 1986 and from 1990 through 1998. Previous analysis of this data set had shown significant differences among stations (Nelson et al. 1997a). However, the temporal increase in nonmollusk abundance described above is evident at all stations and thus greatly increases the variance associated with each station mean. The historic range in mean nonmollusk abundance within individual stations now greatly exceeds the range among stations. The substantial within-station variance accounts for the absence of significant differences among stations in 1998.

Mean nonmollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1998 (Figures 21 and 22). Two-way ANOVA results showed significant differences among sampling dates ($p < 0.0001$) but not among sampling stations ($p = 0.0527$). Mean nonmollusk taxa richness was significantly lower in 1990 than in all other years and significantly lower in 1997 than in 1992, 1993, 1994, and 1996 (Figure 21). The low counts for 1997 are due to methodological problems that impacted the number of crustacean taxa collected. Mean nonmollusk taxa richness was also significantly lower in 1986 than in 1992, 1994, and 1996 and significantly lower in 1991 than in 1994. No temporal trend comparable to that for abundance was seen for nonmollusk taxa richness, nor was any apparent spatial trend seen for this parameter.

Mean crustacean abundance was also compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1998 (Figures 23 and 24). Two-way ANOVA results showed significant differences both among sampling dates ($p <$ 0.0001) and among sampling stations ($p = 0.0061$). Mean crustacean abundance was significantly lower in 1990 and 1997 than in 1993 and 1994 and significantly lower in 1992 than in 1994. The decreased abundance in 1990 is consistent with the overall pattern of nonmollusk abundance for that year. Interannual variations in abundance are not related solely to differences in the time of year that samples were taken. The 1990, 1992, and 1994 through 1998 samples, all of which were taken in January or February, show considerable variation in mean crustacean abundance. Student–Newman–Keuls tests showed no significant differences in historic mean crustacean abundance among stations. Nelson et al. (1997a) reported that mean crustacean abundance was significantly greater at reference station HB6 than at ZID-boundary station HB3, but this difference was not significant when the 1998 results were added to the historic data set.

Mean number of crustacean taxa was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figures 25 and 26). Two-way ANOVA results showed significant differences both among sampling dates ($p <$ 0.0001) and among sampling stations ($p = 0.0007$). Mean crustacean taxa richness was significantly lower in 1990 than in all years except 1997; significantly lower in 1997 than in 1991, 1993, 1994, 1995, and 1996; and significantly greater in 1994 than in all years except 1993. The low mean number of taxa counted in 1990 reflects the low total abundance of crustaceans collected that year. The reduction in crustacean taxa richness in 1997 was due to procedural differences in sample handling. The increase in the number of crustacean taxa collected in 1998 reverses a temporal decline that was evident from 1994 through 1997 (Figure 25). Student–Newman–Keuls tests showed no significant pairwise comparisons of mean number of crustacean taxa among stations. Despite the lack of statistical significance, there is a pattern of reduced crustacean taxa richness at all ZID and ZID-boundary stations (Figure 26). In fact, all stations near the diffuser have fewer crustacean taxa than all reference stations. The overall pattern is consistent with an effect of the diffuser effluent on crustacean taxa.

Dominant taxa of the nonmollusk fauna were similar to those of previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that of previous sampling years. The sipunculan *Aspidosiphon muelleri* was the second most abundant taxon in 1998 (Table 1). The dominant polychaete taxa since 1994 showed some variation from earlier sampling years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). Dominant taxa in 1998 were similar to those found in 1994 through 1997 (Nelson et al. 1994b, 1995, 1996, 1997a) and included the polychaetes *Euchone* sp. B, *Pionosyllis heterocirrata*, *Myriochele oculata*, *Synelmis acuminata*, *Podarke angustifrons*, and *Prionospio cirrobranchiata*, and the tanaid *Leptochelia dubia* (Table 1).

Mean mollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figures 27 and 28). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk abundance was significantly greater in 1998 than in all other years, and significantly greater in 1996 and 1997 than in all earlier years except 1994. Mean mollusk abundance was significantly greater at reference station HB1 than at all other stations except HB4. Neither the temporal nor spatial pattern of differences indicates a negative effect of the diffuser effluent on mollusk abundance.

Because the mollusk specimens were 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 was generally much less for the mollusk fraction than for the nonmollusk fraction prior to 1996. There has been a temporal trend of increasing mollusk abundance since 1993 (Figure 27). The pattern of abundance in the sampling area on all dates shows that Station HB1 has consistently had the greatest number of mollusk individuals (Figure 28).

Mean mollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1997 (Figures 29 and 30). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk taxa richness was significantly greater in 1996, 1997, and 1998 than in all other sampling years. Mean mollusk taxa richness was significantly greater at Stations HB1, HB4, and HB7 than at Station HB2. There has been a temporal pattern of increasing number of mollusk taxa since 1992 (Figure 29). Neither the temporal nor spatial pattern of differences indicates a consistent negative effect of the diffuser effluent on mollusk taxa richness.

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 was not detected in any sample in 1996 or 1997 and in only 3 of 21 replicates in 1998. In previous years, mean sediment TOC was in the narrow range of 0.04% to 0.47%, except in 1993 when methodological problems were experienced with the analyses and values ranged from 0.56% to 1.40%. The ocean outfall in Orange County, California, discharges onto the continental shelf in an erosional benthic environment (Maurer et al. 1993) which may be somewhat similar to that found in Māmala Bay, O‘ahu. In the vicinity of the Orange County outfall, sediment TOC ranged from approximately 0.3% to 0.9% (Maurer et al. 1993). In areas which possess more depositional benthic environments, the percentage of organic content in the sediments is typically much higher. For example, this percentage 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 near the Barbers Point Ocean Outfall suggests that little particulate matter from the diffuser ever reaches the sediment surface in the study area.

The spatial patterns of organism abundance and taxa richness in relation to the outfall varied depending on the taxonomic grouping. There were no consistent, statistically significant patterns of reductions of either organism abundance or taxa richness of nonmollusks and mollusks near the diffuser in 1998. The macrobenthos was much more similar than dissimilar among the seven sampling stations. Cluster analysis of nonmollusk data indicated that all stations were similar to one another in terms of species composition and relative abundance (similarity >67%). The dominant mollusk species were almost identical at all stations. Only six taxa are on the list of mollusks that rank among the five most abundant taxa at any one of the seven stations.

The abundance of nonmollusks and mollusks in the study area has increased in recent years. However, there is no consistent spatial pattern in the historic abundance or taxa richness of either nonmollusks or mollusks. More mollusk taxa were collected in 1998 than in any previous survey year. The number of nonmollusk taxa collected in 1998 was near the middle of the historic range.

The abundance and taxa richness of crustaceans increased in 1998, reversing a temporal decline that began in 1994. There is a pattern of reductions in crustacean abundance and taxa richness at the four ZID and ZID-boundary stations relative to each of the three reference stations. This pattern is evident in the historic (1986, 1990 through 1997) and 1998 data sets. This pattern may indicate a trend related to proximity to the diffuser. However, it is important to realize that despite the quantitative reductions in crustacean abundance and taxa richness, 42 of the possible 48 pairwise station comparisons between the reference station and both the ZID and ZID-boundary stations in the historic and 1998 data sets were not statistically significant. Also, the pattern is not consistent for total crustacean taxa collected at each station. For example, more crustacean taxa were collected at ZID station HZ than at two of the reference stations in 1998. Also, more amphipod species were collected at the ZID and ZID-boundary stations than at the reference stations in 1998. The presence of pollution-sensitive taxa like amphipods (especially the phoxocephalid *Paraphoxus* sp. A) indicates that the diminished crustacean fauna at the ZID and ZID-boundary stations may be related to a noncontaminant factor.

Taxa diversity (H') and evenness (J) were very similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment by Pearson and Rosenberg (1978) proposes that in the transition zone on an enrichment gradient, a few taxa 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 indication of the types of changes in bottom communities predicted by the organic enrichment hypothesis. Maurer et al. (1993) proposed that the Pearson–Rosenberg model may be inappropriate for erosional continental shelf environments. Their study of an outfall on the continental shelf off California found that even with some organic enrichment near the diffuser, there was no evidence of elimination of rare species, even though three species did achieve numerical dominance. The response of the benthic community near the Barbers Point Ocean Outfall does not show the alternate response pattern described by Maurer et al. (1993), presumably because sediment organics there do not show even the moderate enrichment found near the Orange County outfall.

In conclusion, there is little evidence of adverse effects of the Barber Point Ocean Outfall on the macrobenthic community in 1998. The only significant indication of an effect lies in the crustacean component where there were significantly fewer individuals at ZID-boundary stations HB2 and HB3 than at any of the three reference stations, and significantly fewer taxa at ZID-boundary station HB3 than at any of the reference stations. However, other analyses do not suggest an adverse effect of the outfall on crustaceans. There were no significant differences in abundance or taxa richness between ZID station HZ or ZID-boundary station HB4 and all reference stations. In fact, the total number of crustacean taxa was greater at ZID station HZ than at two of the reference stations. The presence of nine amphipod species at the ZID and ZID-boundary stations indicates that alterations in the crustacean component may be related to a noncontaminant factor. The analyses of the noncrustacean fauna clearly demonstrate the presence of a diverse and abundant macrobenthos within and near the ZID of the Barber Point Ocean Outfall.

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BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O'AHU, HAWAI'I, APRIL 1999

Richard C. Swartz
Julie H. Bailey–Brock
William J. Cooke
E. Alison Kay

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WATER RESOURCES RESEARCH CENTER
University of Hawai‘i at Mo(a,¯)noa
Honolulu, Hawai‘i 96822

ABSTRACT

Benthic infauna in the vicinity of the Barbers Point Ocean Outfall was sampled at seven stations on 13 and 14 April 1999 with a modified van Veen grab sampler. The stations were located along the diffuser isobath (61 m) as follows: Station HZ within the zone of initial dilution (ZID); Stations HB2, HB3, and HB4 on the ZID boundary; Station HB6 at 0.5 km from the ZID; and Stations HB1 and HB7 at 3.5 km from the ZID.

Sediments were predominantly (>90%) fine to coarse sands at all stations, although the proportion of medium and coarse sand was greater at Stations HB1, HB2, HB4, HZ, and HB7 than at Stations HB3 and HB6. Total organic carbon in the sediments at all stations was less than 0.02%. Values for oxidation-reduction potential and sediment oil and grease (O&G) showed no indication of significant organic buildup in sediments at any station except Station HB2. The high O&G values at Station HB2 were not associated with any biological alterations.

A total of 9,679 nonmollusk individuals from 183 taxa were collected. Polychaetes represented 44.0%, nematodes 17.2%, crustaceans 14.2%, oligochaetes 9.9%, and sipunculans 9.5% of total nonmollusk abundance. Mean total nonmollusk abundance ranged from 152.6 individuals per sample (33,639/m^2, at Station HB1) to 355.8 individuals per sample (78,431/m^2, at Station HB6). Mean crustacean abundance ranged from 16.2 (3,571/m^2, at Station HB3) to 65.6 (14,461/m^2, at Station HB7). Mollusks were analyzed separately because they represent time-averaged collections of live and dead shells. Mean mollusk abundance ranged from 139.0/10 cm^3 (at Station HB6) to 317.6/10 cm^3 (at Station HZ). There were no significant differences among the seven stations in mean nonmollusk abundance, number of nonmollusk taxa, crustacean abundance, and number of crustacean taxa. There were significant differences in mollusk abundance and richness, but they do not indicate a spatial pattern related to the outfall. For example, reference station HB7 and ZID station HZ had more molluscan individuals and taxa than the other reference stations and the ZID-boundary stations. There has been a significant trend of increased abundance for nonmollusks within the entire study area since 1990. Since 1994, there has been a trend of increased abundance for mollusks. A temporal trend of decreased abundance for crustaceans that began in 1994, reversed itself in 1998 and 1999, when the density of crustaceans increased substantially over the 1997 level. Mean crustacean abundance averaged over the entire study period (1986 to 1999) was significantly lower at ZID-boundary station HB3 than at reference station HB6. However, for the 1999 collection the difference between these two stations was not significant. Both diversity and evenness values for both nonmollusks and mollusks were generally similar among all stations in 1999. Cluster analysis of nonmollusk data confirmed that all stations

were relatively similar to one another in terms of species composition and relative abundance. There is no indication of any marked alteration of the benthic community composition related to station proximity to the diffuser.

INTRODUCTION

The Honouliuli Wastewater Treatment Plant is a primary treatment system. Wastewaters of mainly domestic origin are treated at the plant prior to discharge in Mo(¯,a)mala Bay through an 84-in. (2.13-m) diameter outfall located off the southern coast of O'ahu, Hawai'i.

A waiver of secondary treatment for sewage discharge through the Barbers Point Ocean Outfall has been granted to the City and County of Honolulu (CCH) by the Region 9 office of the U.S. Environmental Protection Agency (EPA). However, since September 1996 approximately one-fourth to one-half of the discharge has been secondary-treated effluent from the 'Ewa Water Reclamation Facility. The EWRF discharge will eventually be reused offsite. This report provides the results of the eleventh survey in an ongoing series of studies of the macrobenthic, soft-bottom community in the vicinity of the discharge; it also provides an overview of trends in biological communities adjacent to the outfall over the fourteen-year period from 1986 to 1999. The first benthic survey took place in 1986. The samples on which this report is based were collected on 13 and 14 April 1999.

PROJECT ORGANIZATION

General coordination for this project is provided by James E.T. Moncur, assistant director of the Water Resources Research Center of the University of Hawai'i at Mo(¯,a)noa and project principal investigator. The principal members of the project team (listed in alphabetical order) and their contributions to this study are as follows:

Julie H. Bailey–Brock	Polychaete, oligochaete, and sipunculan analysis and report
William J. Cooke	Crustacean analysis and report
E. Alison Kay	Mollusk analysis and report
Richard C. Swartz	Statistical analysis and final report preparation
Ross S. Tanimoto	City and County of Honolulu project representative and coordinator for sediment grain-size, total volatile solids, and oxidation-reduction potential analyses

MATERIALS AND METHODS

Specific locations of the sampling stations are provided in Figure 1, and a general vicinity map for the area serviced by the Honouliuli Wastewater Treatment Plant is provided in Figure 2. Seven stations previously established along the approximate diffuser isobath (61 m) were surveyed. In 1990 survey station names were changed from those used in the 1986 survey (Nelson et al. 1987). Survey stations (1986 station names are in parenthesis) and their locations are as follows:

Station HB1 (A) Approximately 3.5 km east of the zone of initial dilution (ZID) boundary to evaluate effects far-field and beyond the ZID

Station HB2 (B)	On the northeast ZID boundary
Station HB3 (C)	On the southeast ZID boundary
Station HB4 (D)	On the southwest ZID boundary
Station HZ (Z)	Within the ZID to evaluate diffuser effects
Station HB6 (E)	Approximately 0.5 km southwest of the ZID boundary as a near-field reference station
Station HB7 (F)	Approximately 3.5 km southwest of the ZID boundary as a far-field reference station

Station Positioning

The exact positioning of each station was determined using the Garmin differential global positioning system. Station locations in relation to latitude, longitude, and bathymetric contours are shown in Figure 1. Locations for each replicate grab sample at each station are given in Appendix Table A.1. Depths for all stations fell within the range of 60.7 to 67.1 m. Station positions within and on the boundaries of the ZID were located precisely during the original sampling using the submersible *Makali'i* in coordination with its mother ship (Nelson et al. 1987).

Sampling Methods

The sampling methodology used in this study generally follows the recommendations of Swartz (1978) and guidelines of the U.S. Environmental Protection Agency (1987a, 1987b), hereafter referred to as EPA procedures. The 1986 through 1997 reports on the benthic monitoring adjacent to the Barbers Point Ocean Outfall (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b, 1995, 1996, 1997a) will be hereafter referred to as "Nelson et al. reports." The 1998 report is by Swartz et al. (1998).

In 1994, the modified 0.1-m^2 van Veen grab sampler previously used was replaced by a 0.16-m^2 van Veen grab sampler. The new grab, which was deployed from a stern-mounted A-frame on the City's research vessel *Noi I Kai*, was used to obtain bottom samples at all seven stations. Sampling dates were 13 and 14 April 1999. Penetration of the sampler was adequate for all replicates. The minimum penetration depth was 6.0 cm, and the maximum was 12.0 cm (Appendix Table A.2).

Five replicate grab samples were taken at each station. From each replicate sample, a subsample 7.6 cm in diameter by 5 cm deep was taken for infaunal analysis and a subsample 4.8 cm in diameter by 5 cm deep for mollusk analysis. Subsampling was necessary because the epifauna and infauna in the area are known to be both small and abundant (Nelson 1986; Russo et al. 1988). Replicated grab samples at each station, rather than replicated subsamples from one grab sample, were taken to provide information on intrastation variability. All five biological subcores for nonmollusk analysis were processed on a 0.5-mm screen and the organisms retained and preserved as appropriate for subsequent identification.

Samples for geochemical analyses (total organic carbon [TOC], oxidation-reduction potential [ORP], oil and grease [O&G], and grain size) were obtained from the grabs from which the biological subcores were taken because each replicate grab contained more than enough sediment for both purposes (methods established by National Pollutant Discharge Elimination System permit no. HI0020877). Three subsamples (one from each of three different grab samples) were taken for all stations. The top 2 cm of sediment of each subsample were used for geochemical analysis. Samples for TOC and sediment O&G analyses were put in screw-cap jars, which were placed on ice, and taken to the laboratory. Sediment ORP was measured on board the research vessel immediately after each sample was obtained. Laboratory analyses of sediment grain size and sediment O&G followed EPA procedures. Analysis of TOC was carried out using EPA procedures by Severn Trent Laboratories (Colchester, Vermont). It performed the analysis using a modification of the Lloyd Kahn method, which utilizes an infrared detector to measure carbon dioxide. Inorganic carbon was removed from the samples by treating them with a 1:1 solution of hydrochloric acid prior to TOC analysis.

Sample Processing

Handling, processing, and preservation of the biological samples followed EPA procedures. Nonmollusk samples were fixed with buffered 10% formalin for a minimum of 24 hours. Following fixation, all samples were placed in 70% ethanol. Mollusk samples were placed in labeled jars in the field, then placed on ice and transported to the laboratory where they were refrigerated. Samples were washed in freshwater (to minimize loss of fine sediments), fixed in 75% isopropyl alcohol for 24 hours, and then air dried. A subsample in a 10-cm^3 aliquot was removed from each mollusk sample for sorting.

The fixed nonmollusk samples were elutriated using the technique of Sanders et al. (1965). This method removes from the sediment all organisms that are not heavily calcified (Nelson et al. 1987). Samples were washed several times, and the water from each was poured through 0.5-mm-mesh sieves. Polychaetes and other invertebrates retained on the sieve were transferred to alcohol, stained with rose bengal solution, and stored in 70% ethanol. Samples from two stations (Station HB1 [replicate 1] and Station HB4 [replicates 1 and 2]) contained rubble pieces, which were acid-dissolved to remove endolithic and cryptic species. Organisms collected from the rubble fragments included 13 individuals (2 taxa) from Station HB1 and 79 individuals (12 taxa) from Station HB4.

Because the biological subcores had to be processed using two different procedures—one for mollusks and the other for all other organisms—the two components of the fauna were not directly comparable and thus were analyzed separately. Because the mollusk specimens were not separated into living and dead shell fractions, they represent time-averaged samples. Mollusks have been extensively analyzed by Kay (1975, 1978, 1979, 1982), Kay and Kawamoto (1980, 1983), Nelson (1986), and Russo et al. (1988).

All specimens were identified to the lowest taxonomic level possible. A selected bibliography for the identification of marine benthic species in Hawai'i is provided in Nelson et al. (1987, appendix D). An additional source used for the identification of polychaetes in Hawai'i is Blake et al. (1995). Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained for six years at the University of Hawai'i.

In previous benthic sampling reports for Barbers Point, name changes for several polychaete species were indicated. This report includes additional name changes made after re-examining specimens. Most of the species of *Zeppelina*, formerly in the family Ctenodrilidae, have been synonymized with the genus *Dodecaceria*, in the family Cirratulidae (George and Petersen 1991). Therefore, *Zeppelina* sp. A is now synonymous with *Dodecaceria* sp. C. The onuphids *Onuphis* sp. A and *Onuphis geofiliformis* were identified as the same species, belonging to the genus *Mooreonuphis* (Fauchald 1982). A species name could not yet be determined, so the species is temporarily identified as *Mooreonuphis* sp. A. *Sigambra parva* has been revised to *S. tentaculata*, and the genus has been moved from the family Pilargidae to the family Hesionidae (Licher and Westheide 1997). The following taxa have been found at other outfalls but are new to Barbers Point: *Ceratonereis tentaculata*, *Lumbrineriopsis* sp. A, *Marphysa* cf. *conferta*, *Minuspio* sp. A, *Odontosyllis* sp. A, and *Pisione remota.*

There were no name changes for the crustaceans, but new taxa were found. The eight additions to the list for this outfall are *Bairdia hanaumaensis*, *Caprella* cf. *gigantochir*, *Anamixis stebbingi*, *Leucothoides ? pottsi*, *Paradexamine maunaloa*, *Podocerus talegus*, *Nikoides danae*, and *Ogyrides* sp. A.

Name changes among the mollusks include *Ervilia sandwichensis* to *Rochefortina sandwichensis* and *Limopsis waikikia* to *Cosa waikikia* (Hayami and Kase 1993). Newly found mollusk taxa at Barbers Point include *Chlamydella* sp. A, *Alvania isolata*, *Bittium* sp., *Cancilla* sp., Eulimidae sp., *Evalea peasei*, *Gemmula monilifera*, *Haminoea curta*, *Phillippia* sp., *Planaxis suturalis*, Pyramidellidae sp. C, *Pyramidelloides miranda*, *Rastodens* sp., *Scissurella pseudoequatoria*, *Turbonilla* sp. C, *Turbonilla* sp. D, *Turbonilla* sp. E, and *Vexillum suavis.*

Data Analysis

All data for both nonmollusks and mollusks were tested for assumptions of normality

(Kolmogorov–Smirnov test; Sokal and Rohlf 1995) and heterogeneity of variances (F_{max} test) prior to statistical analysis. Where data sets failed tests of assumptions, square root or $\log_{10}$ transformation was applied. Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following a significant result using ANOVA, a posteriori Student–Newman–Keuls tests were used to determine which differences in means among stations were significant. All statistical analyses were performed using Prophet and Microsoft Excel software. Detailed statistical results are provided in Appendixes B and C.

An overall comparison of taxa composition among stations was carried out using cluster analysis (Pielou 1984). The Bray–Curtis similarity index (Bloom 1981) on double square root transformed data was performed using the group-average sorting strategy. To make analysis more manageable, only those nonmollusk taxa that contributed at least 0.05% to the total abundance were included. Using this criterion, only taxa represented by a total of more than four individuals were included in the data set, which was reduced from 183 to 109 taxa. The similarity matrix was computed with Microsoft Excel software.

The Shannon–Wiener diversity index (H') (ln) 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 using Microsoft Excel software.

To examine trends over the entire study period, comparisons were made among mean values for all sampling dates and sampling stations using two-way ANOVA without replication and a posteriori Student–Newman–Keuls tests.

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) are 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.

Sediment grain-size patterns were different at some stations from those found in 1997 and 1998. Stations HB1 and HB7 continued to have a substantially greater percentage of medium and coarse sand than the combined percentages of fine sand and silt (Figure 3). The dominance of medium and coarse sand was also seen at Stations HB2, HB4, and HZ, although in 1997 and 1998 the combined fine sand and silt fractions at each of these stations represented a greater percentage of sediment weight than the medium and coarse sand fraction (Nelson et al. 1997a; Swartz et al. 1998). Sediments at Stations HB3 and HB6 had a higher percentage of the combined fine sand and silt fractions than the medium and coarse sand fraction in 1997, 1998, and 1999. Sediments at all stations were greater than 90% sand (Appendix Table A.3). With one exception, results of replicate sediment sample analysis for all seven stations indicated substantial homogeneity in grain size within stations (Appendix Table A.3). The exception was the second sample at Station HB4; it had a much greater percentage of coarse sediment than the other two samples at that station. Analysis of duplicate samples at Stations HZ, HB6, and HB7 indicated consistency of analytical techniques.

Direct electrode measurements of ORP ranged from +30 to +195 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 there were no significant differences among the seven stations (F = 1.56, $p = 0.19$). ORP measurements are similar to those obtained in the 1997 survey (Nelson et al. 1997a) and 1998 survey (Swartz et al. 1998), except the ORP values were much higher (i.e., showing less evidence of reducing conditions) at Station HB2 in 1999 (range: 85 to 170 mV) and in 1998 (range: 80 to 170 mV) than in 1997 (range: 25 to 45 mV).

Sediment O&G values ranged from less than 5 to 792 mg/wet kg (Appendix Table A.2). Mean O&G values ranged from 19.3 mg/wet kg (at Station HB1) to 758.3 mg/wet kg (at Station HB2). Comparison of mean O&G per station (one-way ANOVA) showed that there were highly significant differences among stations (F = 52.2, $p < 0.0001$). Mean O&G was significantly higher at Station HB2 than at all other stations. The spatial pattern of O&G values is highly variable among years, but the O&G measurement of greater than 700 mg/wet kg in all three replicate samples from Station HB2 in 1999 is extraordinary.

Total organic carbon in the sediments at all stations was less than 0.02% (Appendix Table A.2). Total organic carbon was below detection limits in all samples in 1997 (Nelson et al. 1997a) and in all but three samples (n = 21) in 1998 (Swartz et al. 1998).

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, nematodes, platyhelminths, echinoderms, anthozoans, chaetognaths, hemichordates, hydrozoans, nemerteans, sipunculans, poriferans, insects, priapulids, phoronids, bryozoans, chordates, pycnogonids, copepods, ostracods, cumaceans, tanaids, mysids, amphipods, isopods, and decapods.

The 9,679 nonmollusk specimens counted and identified for all stations and replicates represent 183 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (4,261 individuals, 44.0%) and taxa richness (113 taxa, 61.7%). Nematodes were the second most

dominant nonmollusk taxon in terms of abundance (1,666 individuals, 17.2%). Crustaceans constituted 14.2% (1,377 individuals) of numerical abundance, oligochaetes contributed 9.9% (954 individuals), and sipunculans contributed 9.5%
(923 individuals). The 49 crustacean taxa, 20 of which were amphipods, represented 26.8% of the total number of nonmollusk taxa. Abundance estimates for each species from each replicate are given for each of the seven stations 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 taxa). Data were normal for all stations (Appendix Table B.1).

Mean total nonmollusk abundance ranged from 152.6 individuals per sample (33,639/m^2, at Station HB1) to 355.8 individuals per sample (78,431/m^2, at Station HB6) (Figure 4). Variances were homogeneous (Appendix Table B.3). According to the ANOVA on untransformed data, there were no significant differences in mean abundance among stations (Appendix Table B.3).

The mean number of nonmollusk taxa per sample ranged from 35.6 taxa (at Station HB1) to 49.2 taxa (at Station HB6) (Figure 5). Variances were homogeneous (Appendix Table B.4). According to the ANOVA on untransformed data, there were no significant differences in mean number of nonmollusk taxa among stations (Appendix Table B.4).

Composite station diversity (H') and evenness (J) for the nonmollusks are shown in Figure 6. Values for both parameters were similar for all stations. Values for diversity ranged from 2.83 (at Station HB3) to 3.39 (at Station HB4). The range of values was slightly higher than that of samples taken in previous years (Nelson et al. reports; Swartz et al. 1998). Evenness ranged from 0.66 (at Stations HB3 and HZ) to 0.75 (at Station HB4), which was also slightly higher than the range of values observed in previous years (Nelson et al. reports; Swartz et al. 1998). Relative to other stations, there was no consistent pattern of lower diversity or evenness at ZID or ZID-boundary stations.

Results of cluster analysis indicating the relative similarity of stations based on the 109 most abundant nonmollusk taxa are shown in Figure 7. All stations were grouped at similarity values of greater than 66%, indicating similar taxa composition and abundance among all stations. There was very little sorting among stations with regard to proximity to the diffuser. For example, reference station HB6, ZID-boundary stations HB2 and HB3, and ZID station HZ were grouped as the most similar four station cluster.

Polychaetes

A total of 4,261 polychaetes representing 113 taxa were collected; they comprised 44.0% of total nonmollusk abundance. These numbers are higher than those of previous years: 2,685 polychaetes representing 90 taxa in 1994 (Nelson et al. 1994b), 2,527 polychaetes representing 87 taxa in 1995 (Nelson et al. 1995), 3,836 polychaetes representing 95 taxa in 1996 (Nelson et al. 1996), 2,811 polychaetes representing 93 taxa in 1997 (Nelson et al. 1997a), and 3,521 polychaetes representing 85 taxa in 1998 (Swartz et al. 1998). The greatest number of polychaetes was found at Station HB4 (973 individuals), followed in decreasing order of abundance by Stations HB6 (873 individuals), HB2 (737 individuals), HB7 (550 individuals), HZ (466 individuals), HB3 (368 individuals), and HB1 (294 individuals) (Figure 8). Polychaetes were the most taxa-rich group at all stations (Appendix Tables D.1 through D.7). Maximum polychaete taxa richness occurred at Station HB4 (63 taxa), followed in decreasing order by Stations HB2 (60 taxa), HB6 (57 taxa), HZ (56 taxa), HB7 (54 taxa), HB1 (51 taxa), and HB3 (48 taxa) (Figure 9).

Dominant polychaete taxa differed at several stations (Table 1). The sabellid *Euchone* sp. B was dominant at Stations HB2 (46% of polychaetes), and HB6 (42%), continuing its dominance at these stations since 1993. *Euchone* sp. B was the dominant polychaete at Station HB1 from 1996 through 1998, but only three specimens were found at that station in 1999. The pilargid *Synelmis acuminata* was the dominant polychaete this year at Stations HB1 (21%) and HB7 (31%). The syllid *Pionosyllis heterocirrata* was dominant at Stations HB3 (17%) and HZ (17%) in 1999, as it was in 1997 and 1998. The spionid *Polydora normalis* was dominant this year at Station HB4 (14%).

Individuals of the families Syllidae, Phyllodocidae, and Serpulidae were represented by reproducing individuals this year. Seven species of syllids were reproductively active at ZID and non-ZID stations: *Sphaerosyllis* sp. G at all stations but Station HB2; *Sphaerosyllis riseri* at Station HZ; *Brania mediodentata* at Stations HB4 and HZ; *Exogone* sp. D at Station HB7; *Exogone longicornis* at Station HZ; *Pionosyllis heterocirrata* at Stations HB4, HZ, and HB7; and *Pionosyllis spinisetosa* at Station HB4. The phyllodocid *Phyllodoce madeirensis* was reproducing at Station HB6, and the serpulid *Salmacina dysteri* was observed reproducing by schizoparity at Stations HB2, HB4, HZ, and HB6. Stations HB2, HB4, and HZ had the most individuals reproducing, while Stations HB4 and HZ had the widest variety of species reproducing.

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 the most abundant trophic category at Station HB4 (507 individuals, 52% of all polychaetes) and most speciose at all stations. The number of deposit-feeding taxa ranged from 18 (at Station HB7) to 26 (at Station HB4). The dominant polychaetes in the deposit-feeding category were the spionids *Polydora normalis* (14% at

Station HB4) and *Prionospio cirrobranchiata* (7% at Station HB1), the oweniid *Myriochele oculata* (8% at Station HB6, 7% at Station HB4, and 5% at Station HZ), and the dorvilleid *Ophryotrocha* sp. A (9% Station at HB4).

2. Omnivores. In terms of percentage of total polychaete individuals per station, omnivorous worms were best represented at Station HB7 (341 individuals, 62% of all polychaetes); this is consistent with the results of all Barbers Point surveys since 1986 (Nelson et al. reports; Swartz et al. 1998). Omnivorous worms were also numerically dominant at Stations HB1 (145 individuals, 49%), HB3 (115 individuals, 31%), and HZ (176 individuals, 38%). The number of omnivorous taxa ranged from 8 (at Station HB3) to 17 (at Station HB4). At Station HB7 the pilargid *Synelmis acuminata* (31%) and the syllid *Pionosyllis heterocirrata* (11%) dominated the omnivorous component, as in 1993 through 1997; and the syllid *Haplosyllis spongicola* (11%) was the third dominant omnivore. *Pionosyllis heterocirrata* was also the dominant omnivore at Stations HB2 (9%), HB3 (17%), HB4 (14%), HZ (17%), and HB6 (6%), whereas *Synelmis acuminata* was the dominant omnivore at Station HB1 (21%). The pilargid *Synelmis acuminata* and the syllid *Pionosyllis heterocirrata* are the omnivorous species most responsible for the numerical dominance of this trophic category this year.

3. Suspension feeders. In terms of percentage of total polychaete individuals per station, suspension feeders were dominant at Stations HB2 (432 individuals, 47% of all polychaetes) and HB6 (456 individuals, 53%). This was primarily due to the large numbers of the sabellid *Euchone* sp. B (46% at Station HB2 and 42% at Station HB6). *Euchone* sp. B was rare at Station HB1 in 1999, after being the most dominant polychaete at that station from 1996 to 1998. Another sabellid, *Augeneriella dubia,* was the dominant suspension feeder at Station HB3 (12%). Of the four trophic categories, suspension-feeders were least speciose at two (HB1 and HB7) of the seven stations. The number of taxa ranged from 8 (at Station HB7) to 14 (at Station HB2).

4. Carnivores. Carnivorous polychaetes were present at all stations, with their greatest abundance occurring at Station HB6 (110 individuals, 13% of all polychaetes). Carnivores were the least abundant trophic category at five stations: HB6, HZ (86 individuals, 18%), HB3 (70 individuals, 19%), HB4 (78 individuals, 8%), and HB2 (62 individuals, 8%). The number of taxa ranged from 10 (at Stations HB3, HB4, and HB6) to 15 (at Station HB7). The hesionid *Podarke angustifrons* was the dominant carnivore at six stations: HB3 (12%), HZ (8%), HB1 (7%), HB6 (5%), and HB2 and HB4 (4% each). Another hesionid, *Micropodarke* sp. A, dominated at Station HB7 (6%).

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

1. Tubicolous polychaetes. Tubicolous polychaetes were the most abundant motility category at Stations HB2 (446 individuals, 61% of all polychaetes) and HB6 (525 individuals, 60%). This group had the fewest taxa at four stations (16 taxa at Station HB2, 10 taxa at Station HB3, 15 taxa at Station HB6, and 8 taxa at Station HB7) and tied for fewest taxa with discretely motile worms at Stations HB1 (10 taxa each), HB4 (12 taxa each), and HZ (12 taxa each). The dominant tubicolous polychaete taxa included the sabellid *Euchone* sp. B at Stations HB2 (46%) and HB6 (42%), the oweniid *Myriochele oculata* at Stations HB4 (7%) and HZ (5%), and the sabellid *Augeneriella dubia* at Stations HB3 (12%), HB1 (2%), and HB7 (1%).

2. Motile polychaetes. Motile polychaetes were the most abundant worms at Stations HB1 (251 individuals, 73%), HB3 (196 individuals, 53%), HB4 (550 individuals, 57%), HZ (256 individuals, 55%), and HB7 (443 individuals, 81%). In addition, they had the highest number of taxa at each of the seven stations, ranging from 24 (at Stations HB3 and HB6) to 39 (at Station HB4). The syllid *Pionosyllis heterocirrata* was the dominant motile polychaete at Stations HB2 (9%), HB3 (17%), HB4 (14%), HZ (17%), and HB6 (6%). This syllid also showed high levels of abundance at Stations HB1 (47 individuals) and HB7 (63 individuals). *Synelmis acuminata*, a pilargid, was the dominant motile polychaete at Stations HB1 (21%) and HB7 (31%); it also showed high levels of abundance at Stations HB2 (57 individuals), HZ (56 individuals), HB6 (48 individuals), HB4 (39 individuals), and HB3 (26 individuals).

3. Discretely motile polychaetes. Of the three motility categories, discretely motile polychaetes were least abundant at all stations except HB1 and HB7, where they ranked second in abundance. The number of taxa was greatest at Stations HB2 and HB6 (18 taxa each) and lowest at Station HB1 (10 taxa). The dominant discretely motile species were all spionids: *Prionospio cirrobranchiata* was the most abundant discretely motile species at Stations HB1 (7% of all polychaetes), HB2 (4%), HB6 (3%), and HB7 (4%); *Polydora normalis* at Station HB4 (14%); and *Aonides* sp. A at Station HB3 (3%).

Crustaceans

A total of 1,377 crustaceans and pycnogonids, representing 14.2% of the nonmollusk abundance, were collected. Abundance for each taxon from each replicate is provided for each station in Appendix Tables D.8 through D.14. Mean abundance (no./sample) ranged from 16.2 (3,571/m^2, at Station HB3) to 65.6 (14,461/m^2, at Station HB7) (Figure 14). Variances were heterogeneous for untransformed data but became homogeneous after square root transformation (Appendix Table B.5). There were no significant differences in mean abundance among the seven stations (ANOVA, Appendix Table B.5).

A total of 49 crustacean and pycnogonid taxa (copepods were not identified to the species level) were collected; of these, 20 taxa (40.8%) were amphipods. Mean number of taxa ranged from 5.6 (at Station HB3) to 13.4 (at Station HB7) (Figure 15). Variances were homogeneous, and data were normally distributed. There were no significant differences in mean abundance among the seven stations (ANOVA, Appendix Table B.6).

Amphipods, tanaids, and copepods were the numerically dominant taxa, making up 32.1%, 29.2%, and 18.9%, respectively, of total crustacean and pycnogonid abundance. No taxon was uniformly most abundant at all stations. Copepods and the tanaid *Leptochelia dubia* were present at all stations and were generally among the most abundant crustaceans. *L. dubia* ranked among the five most abundant nonmollusk species at Stations HB1, HB2, HB3, HZ, and HB6 (Table 1). The amphipods *Eriopisella sechellensis* and *Gammaropsis atlantica* ranked among the five most abundant nonmollusk species at Stations HB1 and HB7, respectively.

Crustacean and pycnogonid abundance (1,377 individuals) and taxa number (49) in 1999 were substantially greater than in 1998 (697 individuals, 36 taxa). Abundance and taxa richness in 1999 equaled or exceeded the highest values observed in earlier collection years (range for 1986 and for 1990 through 1998 collections: 164 to 1,121 individuals, 34 to 49 taxa). A low count of 27 is excluded from the range for taxa richness because of procedural differences in 1997 (Nelson et al. 1997a).

Comparing the crustacean community composition across stations demonstrates clearly that any impact the outfall may be having is not consistent across the ZID area. More crustacean taxa were collected at ZID-boundary station HB2 (32 taxa) than at the far-field station HB1 (20), reference station HB6 (22), or reference station HB7 (31). As many amphipod taxa (generally considered to be pollution sensitive) were collected at ZID station HZ (8 taxa) as at far-field station HB1 (7 taxa) or reference station HB6 (8 taxa). However, the lowest total number of crustacean taxa (11), amphipod species (3), and crustacean individuals (81) were collected at ZID-boundary station HB3, although there were no statistically significant differences in mean taxa richness or abundance between Station HB3 and any of the other stations (Appendix Tables B.5 and B.6).

Eight taxa—one podocopid ostracod, one caprellid amphipod, four gammarid amphipods, and two caridean shrimp—were newly collected in 1999. The podocopid ostracod, *Bairdia hanaumaensis*, has previously been collected in other O'ahu reef slope outfall samples, so its presence in this study area was not unexpected. In contrast, the large caprellid amphipod, *Caprella* cf. *gigantochir*, has never, in our experience, been collected from O'ahu waters. The newly collected gammarid amphipods are well-known species whose presence in the study area is also not unexpected. They include *Anamixis stebbingi*, *Leucothoides ? pottsi*, *Paradexamine maunaloa*, and *Podocerus talegus*. The two newly collected caridean shrimp, *Nikoides danae* and *Ogyrides* sp. A, have previously been collected on O'ahu reef slopes. The collection of these two shrimp improves knowledge of the larger crustacean fauna in this area.

This brings the total number of discretely identified/reported taxa from the study area in ten years to 102. Copepods are enumerated as a single taxon, although several different taxa are certainly present. Cumaceans and mysids are similarly enumerated. Between two and eight taxa have been newly collected each year since the first two years of sampling (1990 and 1991) when a total of 62 taxa were collected. The Barbers Point outfall study area does not appear to be subject to extremely large swings in benthic community composition or consistency. It seems to be generally a rather stable environment. This should aid in identifying any impacts associated with the outfall itself.

Mollusks

A total of 8,012 mollusks representing 132 taxa were collected. Mean abundance of mollusks per sample (no./10 cm^3) ranged from 139.0 (at Station HB6) to 317.6 (at Station HZ) (Figure 16). Data were normally distributed at all stations except Station HB6 (Appendix Table C.1). Complete basic statistics for total mollusk data are shown in Appendix Table C.1.

Mean number of mollusk taxa per sample ranged from 22.4 (at Station HB2) to 38.2 (at Station HB7) (Figure 17). Data at all stations except Station HB2 were normally distributed (Appendix Table C.2). However, the composite mollusk taxa data set passed the test for normality prior to ANOVA. Complete basic statistics for number of mollusk taxa at all stations are shown in Appendix Table C.2.

Variances for mollusk abundance data were heterogeneous for untransformed data but became homogeneous after $\log_{10}$ transformation (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 HZ than at Stations HB6, HB2, and HB4; at Stations HB7, HB1, and HB3 than at Stations HB6 and HB2; and at Station HB4 than at Station HB6.

Variances for number of mollusk taxa data were homogeneous (Appendix Table C.4). There were significant differences in mean mollusk taxa number among stations (ANOVA, Appendix Table C.4). Mean number of mollusk taxa was significantly greater at Station HB7 than at Stations HB2, HB6, HB4, HB1, and HB3; and at Station HZ than at Stations HB2 and HB6.

Diversity (H') ranged from 2.20 (at Station HB2) to 2.70 (at Station HB7) (Figure 18). Evenness (J) ranged from 0.58 (at Stations HB2 and HZ) to 0.67 (at Station HB6). Diversity and evenness values for mollusks were generally similar for all stations (Figure 18).

The mollusk abundance patterns are consistent with those of all previous samplings (Nelson et al. reports; Swartz et al. 1998). Mollusk abundance for each taxa from each replicate is provided for each station in Appendix E. The molluscan fauna was very similar at all stations, especially among the dominant taxa (Table 2). The gastropod taxa *Diala scopulorum*, *Cerithidium perparvulum*, *Diala semistriata*, *Balcis* spp., and *Scaliola* spp. were abundant at all stations. *Finella pupoides* was abundant at all stations except Stations HB1 and HB7. These six dominant mollusk taxa accounted for 75.7% of all individuals collected.

DISCUSSION

In 1999 there were no significant differences among the seven stations in mean nonmollusk abundance, number of nonmollusk taxa, crustacean abundance, and number of crustacean taxa. These results for the nonmollusks are similar to those obtained in most previous survey years for samples taken near the Barbers Point Ocean Outfall. The nonmollusks have generally been just as abundant and speciose at the stations near the outfall (HB2, HB3, HB4, and HZ) as at the reference and far-field stations (HB1, HB6, and HB7). The 1999 results for the crustaceans show less of a trend for reduced crustacean abundance and taxa richness near the outfall than was evident in some earlier survey years, including 1998. In 1999 the statistical comparisons were not significant, and some of the quantitative values at the ZID and ZID-boundary stations exceeded those at the far-field and reference stations, e.g., mean crustacean abundance and taxa richness at ZID-boundary station HB2 equaled or exceeded corresponding means at far-field station HB1 and reference station HB6.

ZID station HZ had significantly greater mollusk abundance than reference station HB6 and ZID-boundary stations HB2 and HB4. Mollusk abundance was also significantly greater at reference station HB7, far-field station HB1, and ZID-boundary station HB3 than at reference station HB6 or ZID-boundary station HB2. Thus there was no general statistically significant pattern with regard to mollusk abundance and proximity to the diffuser. The abundance of mollusks was highest at Station HB1 in 1992, 1993, 1994, 1995, 1997, and 1998 (Nelson et al. 1992b, 1994a, 1994b, 1995, 1997a; Swartz et al. 1998), but that station ranked third behind Stations HZ and HB7 in 1999.

Mean crustacean taxa richness per replicate may not be as useful as total taxa richness per station as an indicator of outfall effects, given the high intrastation variability encountered. The total number of crustacean taxa collected at ZID station HZ was 19, slightly less than at far-field station HB1 (20 taxa) and reference station HB6 (22 taxa). Total crustacean richness was highest at ZID-boundary station HB2 (32 taxa), which is comparable to that for reference station HB7 (31 taxa). Crustacean richness was lowest at ZID boundary station HB3 (11 taxa), although that was an improvement over the 8 taxa collected there in 1998.

Reductions in crustacean abundance and taxa richness near the Barbers Point Ocean Outfall relative to reference stations have not been observed in every previous monitoring survey year.

Although in some years (e.g., 1991, Nelson et al. 1992a) taxa richness appeared to be reduced adjacent to the outfall, this pattern had not been seen for several years until 1998. In 1999 the crustacean community of the study area was more abundant and diverse than in 1998 and most other years. The shifting patterns of number of taxa and abundance from year to year appear to be more strongly influenced by other factors, such as small-scale differences in bottom topography or a subtle variation in sediment composition. The presence of 12 taxa of stress-sensitive gammaridean amphipods at the ZID and ZID-boundary stations also indicates that any changes in the crustacean assemblage near the outfall in 1999 are associated with factors other than chemical contamination by the effluent discharge.

Taxonomic diversity (expressed here simply as the number of discretely recorded taxa) is considered to be a better measure of the state of the crustacean communities at these sampling stations than the abundance data. Crustacean and pycnogonid abundance counts can be strongly influenced by a large number of juveniles released from brooding adults (for tanaids, isopods, and amphipods). Abundance data generated from other taxa (such as mollusks, most polychaetes, and many decapods) represent a settlement from the plankton of a larval form which has found the site suitable for settlement. While high crustacean abundance data (particularly if juveniles are being produced) clearly indicate that the site is suitable, low abundance data are not necessarily indicative of unsuitability.

A rather comprehensive picture of the crustacean communities in the study area has been developed (at least for crustaceans smaller than 1 cm) over the last ten survey years despite the rather small areal coverage (7.6 cm diameter) of the sampling replicates. The number of new taxa recorded in 1999 (eight) is higher than that of recent years. It is not clear whether this increase in newly collected taxa represents a subtle shift in the composition of the overall crustacean community or just particularly efficient collecting this year. It should be noted that larger (2 cm and up) shrimp and crab, while certainly present in the study area, have almost no chance of being collected. In general, the Honouliuli study area is less diverse than comparable study areas near the Wai'anae WWTP outfall and more diverse than the deeper Sand Island outfall study area.

With regard to mean mollusk taxa richness, reference station HB7 had significantly more taxa than reference station HB6; ZID-boundary stations HB2, HB3, and HB4; and far-field station HB1. Mean number of mollusk taxa was also significantly greater at ZID station HZ than at reference station HB6 or ZID-boundary station HB2. Thus there was no consistent pattern of mollusk taxa richness in relation to proximity to the outfall diffuser.

Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. Lower nonmollusk diversity and evenness values were reported for

Station HB2 in 1993, but this pattern has not been repeated since (Nelson et al. 1994a, 1994b, 1995, 1996, 1997a; Swartz et al. 1998). There is little evidence that the outfall is having an effect on taxa richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis similarity index indicated that nonmollusk abundance and taxa composition were broadly similar at most stations (>66% similarity index value). The four most similar stations were from the ZID (Station HZ), ZID-boundary (Stations HB2 and HB3), and reference (Station HB6) areas. In the period from 1986 to 1993, cluster analysis consistently intermixed ZID, ZID-boundary, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). In 1994 and 1995, some separation between stations in or near the ZID and far-field reference stations was observed (Nelson et al. 1994b, 1995). In 1996 (Nelson et al. 1996), 1997 (Nelson et al. 1997a), 1998 (Swartz et al. 1998), and 1999 stations were again generally interspersed in the cluster analysis. In comparing the 1996 through 1999 cluster results with those of earlier years some caution is necessary, since the clustering algorithm was changed in 1996 from flexible to group-average sorting in order to conform to current recommendations for optimum methodologies (Carr 1993).

Sediment grain sizes in the 1999 samples were broadly similar among stations. Sand accounted for >90% of the sediment weight at all stations. The proportion of medium and coarse sand was substantially greater than that of fine sand at Stations HB1, HB2, HB4, HZ, and HB7. The two sand fractions were more evenly represented at Stations HB3 and HB6. These differences are not related to proximity to the outfall diffuser. The percentage of fine sediments at ZID station HZ showed no increase over that measured in samples taken in 1986 and from 1990 through 1998 (Nelson et al. reports; Swartz et al. 1998). The increase in the silt and clay fraction of the sediments observed in 1993 for all stations began to moderate in 1996, and this trend continued in 1997, 1998, and 1999 (for comparison see figure 3 in Nelson et al. 1992b, 1994a, 1994b, 1995, 1996, 1997a; and in Swartz et al. 1998). The mean percentage of the silt and clay fraction in 1999 (4.06%) is less than that observed in 1997 (4.77%) (Nelson et al. 1997a) and 1998 (4.86%) (Swartz et al. 1998). The increase in fine sediments in 1993 occurred at all seven stations, thus it is unlikely to have been an effect of the outfall discharge.

ORP analysis showed no evidence of reducing conditions at the surface of sediments at any station in 1999; this has been the consistent pattern for this parameter. There were no significant differences in ORP among stations in 1999. ORP values were higher in 1999 and 1998 than in 1997.

Mean O&G values were significantly greater at Station HB2 in 1999 than at all of the other stations. The elevated O&G concentrations at Station HB2 were not associated with corresponding changes in other sediment parameters, including ORP, TOC, and grain size. In 1994 and 1995, various ZID or ZID-boundary stations had significant elevations in sediment O&G values as compared to other stations (Nelson et al. 1994b, 1995); however, no significant differences were seen in 1996, 1997, or 1998. Over the course of the monitoring studies, high year-to-year variation in sediment O&G values has occurred (Nelson et al. reports; Swartz et al. 1998). The variability in sediment O&G values suggests that there may be little direct influence of the diffuser effluent on this parameter.

Sediment TOC was less than 0.02% in all replicate samples at all stations. The absence of detectable sediment TOC was reported for all samples collected in 1996 and 1997 and for all but three samples in 1998. The analytical laboratory used for TOC analyses after 1995 removes all traces of the organic carbon from the sediment during the acid digestion to remove inorganic carbon. Although low, TOC values in previous years have been above the detection limits of current instrumentation. Similar below-detection-limit values of TOC have been reported by the same analytical laboratory for sediment samples at the Sand Island Ocean Outfall monitoring stations (Nelson et al. 1997b). Analyses of sediment nitrogen levels for samples taken concurrently with the sediment TOC samples at the Sand Island monitoring stations suggest that the contract laboratory is consistently underestimating sediment TOC (Nelson et al. 1997b). Unfortunately, similar measurements of sediment nitrogen were not taken for the Barbers Point Ocean Outfall monitoring stations, thus the conclusion of measurement bias for TOC cannot be conclusively confirmed, although it is strongly suspected.

The total number of nonmollusk taxa recorded in 1999 (183) is the highest recorded in the eleven years of monitoring at the Barbers Point Ocean Outfall (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, 144 in 1993, 159 in 1994, 151 in 1995, 147 in 1996, 138 in 1997, and 140 in 1998). The 49 crustacean and pycnogonid taxa collected in 1999 equaled the highest value observed in earlier years, when counts ranged from 34 to 49 taxa. That range does not include the low value of 27 taxa collected in 1997 when counts were reduced because of differences in sample handling. 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 1999.

Mean nonmollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1999 (Figures 19 and 20). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Numerous pairwise comparisons among dates showed significant differences, generally with values for more recent dates being higher than values for earlier dates. The abundance of nonmollusks in 1999 was quantitatively greater than that of any previous year and significantly greater than that observed during the first seven survey years (1986 and 1990 through 1995). This temporal pattern of increasing nonmollusk abundance was confirmed by a linear regression analysis of data from 1990 to 1999, which found a trend of significantly increasing mean abundance over this period ($p = 0.00022$, $y = 18.9x - 90.7$, where y = mean nonmollusk abundance and x = year code: 1990 = 10 through 1999 = 19). The slightly lower mean nonmollusk abundance in 1997 versus 1996, 1998, and 1999 is partly explained by the processing differences for the crustaceans during 1997.

The Student–Newman–Keuls test showed no significant pairwise multiple contrasts among stations for mean nonmollusk abundance based on data collected in 1986 and from 1990 through 1999. Previous analysis of this data set had shown significant differences among stations (Nelson et al. 1997a). However, the temporal increase in nonmollusk abundance described above is evident at all stations and thus greatly increases the variance associated with each station mean. The historic range in mean nonmollusk abundance within individual stations now greatly exceeds the range among stations. The substantial within-station variance accounts for the absence of significant differences among stations.

Mean nonmollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1999 (Figures 21 and 22). Two-way ANOVA results showed significant differences among sampling dates ($p < 0.0001$) but not among sampling stations ($p = 0.11$). Mean nonmollusk taxa richness was significantly lower in 1990 than in all other years and significantly lower in 1997 than in 1992, 1993, 1994, 1996, and 1999 (Figure 21). The low counts for 1997 are due to methodological problems that impacted the number of crustacean taxa collected. Mean nonmollusk taxa richness was also significantly lower in 1986 than in 1992, 1994, 1996, and 1999; significantly lower in 1991 than in 1994 and 1999; and significantly lower in 1995 and 1998 than in 1999. Nonmollusk taxa richness was quantitatively higher in 1999 than in any previous year. No temporal trend comparable to that for abundance was seen for nonmollusk taxa richness, nor was any apparent spatial trend seen for this parameter in relation to proximity to the outfall.

Mean crustacean abundance was also compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1999 (Figures 23 and 24). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p = 0.003$). Mean crustacean abundance in 1999 was quantitatively higher than in all previous years and significantly higher than in all previous years except 1993 and 1994. Crustacean abundance in 1993 and 1994 was significantly higher than in

1990 and 1997. The decreased abundance in 1990 is consistent with the overall pattern of nonmollusk abundance for that year. Interannual variations in abundance are not related solely to differences in the time of year that samples were taken. The 1990, 1992, and 1994 through 1998 samples, all of which were taken in January or February, show considerable variation in mean crustacean abundance. When all data through 1999 were pooled for station comparisons, mean crustacean abundance was significantly greater at reference station HB6 than at ZID-boundary station HB3. The same result was obtained for the historic data set through 1997 (Nelson et al. 1997a) but not through 1998 (Swartz et al. 1998).

Mean number of crustacean taxa was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1999 (Figures 25 and 26). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p = 0.0003$). Mean crustacean taxa richness was significantly lower in 1990 than in all years except 1986 and 1997; significantly lower in 1997 than in 1993, 1994, 1995, and 1999; significantly greater in 1994 and 1999 than in 1990, 1997, 1986, 1992, and 1998; and significantly greater in 1994 than in 1996 and 1991. The low mean number of taxa counted in 1990 reflects the low total abundance of crustaceans collected that year. The reduction in crustacean taxa richness in 1997 was due to procedural differences in sample handling. The increase in the number of crustacean taxa collected in 1998 and 1999 reverses a temporal decline that was evident from 1994 through 1997 (Figure 25). Student–Newman–Keuls tests showed no significant pairwise comparisons of mean number of crustacean taxa among stations. Despite the lack of statistical significance, there is a historic pattern of reduced crustacean taxa richness at all ZID and ZID-boundary stations (Figure 26). In fact, all stations near the diffuser have fewer crustacean taxa than all reference stations. The overall pattern is consistent with an effect of the diffuser effluent on crustacean taxa. This historic pattern was not as obvious in 1999, especially at ZID-boundary station HB2 where more crustacean taxa were collected than at any of the other six stations.

Dominant taxa of the nonmollusk fauna were similar to those of previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that of previous sampling years. The sipunculan *Aspidosiphon muelleri* was the most abundant taxon in 1999 (Table 1). The dominant polychaete taxa since 1994 showed some variation from earlier sampling years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). Dominant taxa in 1999 were similar to those found in 1994 through 1998 (Nelson et al. 1994b, 1995, 1996, 1997a; Swartz et al. 1998) and included the polychaetes *Euchone* sp. B, *Pionosyllis heterocirrata*, *Synelmis acuminata*, *Podarke angustifrons*, and *Myriochele* *oculata*, as well as the tanaid *Leptochelia dubia* (Table 1).

Mean mollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1999 (Figures 27 and 28). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk abundance was significantly greater in 1998 than in all other years; significantly greater in 1996, 1997, and 1999 than in 1986, 1991, 1992, and 1993; and significantly greater in 1996 than in 1990. Mean mollusk abundance was significantly greater at reference station HB1 than at all other stations except HB4. Neither the temporal nor spatial pattern of differences indicates a negative effect of the diffuser effluent on mollusk abundance.

Because the mollusk specimens were 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 was generally much less for the mollusk fraction than for the nonmollusk fraction prior to 1996. There has been a temporal trend of increasing mollusk abundance since 1993 (Figure 27). The pattern of abundance in the sampling area on all dates shows that Station HB1 has consistently had the greatest number of mollusk individuals (Figure 28), but that station ranked third behind Stations HZ and HB7 in 1999.

Mean mollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 1999 (Figures 29 and 30). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk taxa richness was significantly greater in 1998 than in 1990, 1992, 1993, 1986, 1994, 1995, and 1991; significantly greater in 1996 and 1997 than in 1990, 1992, 1993, 1986, and 1994; and significantly greater in 1999 than in 1990 and 1992. Mean mollusk taxa richness was significantly greater at Stations HB1, HB4, and HB7 than at Station HB2. There has been a temporal pattern of increasing number of mollusk taxa since 1992 (Figure 29). Neither the temporal nor spatial pattern of differences indicates a consistent negative effect of the diffuser effluent on mollusk taxa richness.

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show little evidence of a buildup of organic matter in the vicinity of the Barbers Point Ocean Outfall diffuser. High ORP measurements at all stations indicated the absence of reducing conditions. Sediment O&G was low at all stations except Station HB2 where high O&G concentrations were not associated with any biological alterations. Sediment TOC was less than 0.02% in all samples in 1999 and was very low or undetectable from 1996 through 1998. In years prior to 1996, mean sediment TOC was in the narrow range of 0.04% to 0.47%, except in 1993 when methodological problems were experienced with the analyses and values ranged from 0.56% to 1.40%. The ocean outfall in Orange County, California, discharges onto the continental shelf in an erosional benthic environment (Maurer et al. 1993) which may be somewhat similar to that found in Mo(¯,a)mala Bay, O'ahu. In the vicinity of the Orange County outfall, sediment TOC ranged from approximately 0.3% to 0.9% (Maurer et al. 1993). In areas which possess more depositional benthic environments, the percentage of organic content in the sediments is typically much higher. For example, this percentage 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 Angles 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 near the Barbers Point Ocean Outfall suggests that little particulate matter from the diffuser ever reaches the sediment surface in the study area.

The spatial patterns of organism abundance and taxa richness in relation to the outfall varied depending on the taxonomic grouping. There were no consistent, statistically significant patterns of reductions of either organism abundance or taxa richness of nonmollusks and mollusks near the diffuser in 1999. The macrobenthos was much more similar than dissimilar among the seven sampling stations. Cluster analysis of nonmollusk data indicated that all stations were similar to one another in terms of taxa composition and relative abundance (similarity >66%). The dominant mollusk taxa were almost identical at all stations. Only six taxa are on the list of mollusks that rank among the five most abundant taxa at any one of the seven stations.

The abundance of nonmollusks and mollusks in the study area has increased in recent years. However, there is no consistent spatial pattern in the historic abundance or taxa richness of either nonmollusks or mollusks. More nonmollusk individuals and taxa were collected in 1999 than in any previous survey year. The number of mollusk taxa collected in 1999 was near the top of the historic range.

The abundance and taxa richness of crustaceans increased in 1998 and 1999, reversing a temporal decline that began in 1994. More crustacean individuals were collected in 1999 than in any previous survey year. There is a historic pattern of reductions in crustacean abundance and taxa richness at the four ZID-area stations relative to each of the reference and far-field stations. This pattern may indicate a trend related to proximity to the diffuser. However, this pattern was not as obvious in 1999 as in some earlier survey years. In fact, there were no significant differences among the ZID, ZID-boundary, reference, and far-field stations in either mean crustacean abundance or mean number of crustacean taxa in 1999. Also, the pattern was not consistent for total crustacean taxa collected at each station in 1999. For example, more crustacean taxa were collected at ZID-boundary station HB2 than at any of the reference and far-field stations. Also, as many or more amphipod species were collected at ZID station HZ as at reference station HB6 or far-field station HB1. The presence of pollution-sensitive taxa like amphipods (especially the phoxocephalid *Paraphoxus* sp. A) indicates that the diminished crustacean fauna at the ZID and ZID-boundary stations may be related to a noncontaminant factor.

Taxa diversity (H') and evenness (J) were very similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment by Pearson and Rosenberg (1978) proposes that in the transition zone on an enrichment gradient, a few taxa 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 indication of the types of changes in bottom communities predicted by the organic enrichment hypothesis. Maurer et al. (1993) proposed that the Pearson–Rosenberg model may be inappropriate for erosional continental shelf environments. Their study of an outfall on the continental shelf off California found that even with some organic enrichment near the diffuser, there was no evidence of elimination of rare species, even though three species did achieve numerical dominance. The response of the benthic community near the Barbers Point Ocean Outfall does not show the alternate response pattern described by Maurer et al. (1993), presumably because sediment organics there do not show even the moderate enrichment found near the Orange County outfall.

In conclusion, there is little evidence of adverse effects of the Barber Point Ocean Outfall on the macrobenthic community in 1999. The only indication of an effect lies in the crustacean component where there were fewer, but not significantly fewer, individuals and taxa at ZID-boundary stations HB3 and HB4 and ZID station HZ than at the reference stations. However, other analyses do not suggest an adverse effect of the outfall on crustaceans, especially the abundant and taxa rich crustacean assemblage at ZID-boundary station HB2. The presence of twelve amphipod species at the ZID and ZID-boundary stations indicates that alterations in the crustacean component may be related to a noncontaminant factor. The analyses of the noncrustacean fauna clearly demonstrate the presence of a diverse and abundant macrobenthos within and near the ZID of the Barber Point Ocean Outfall.

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TABLE 1. Abundance of Numerically Dominant Nonmollusk Taxa, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999

Taxon	Number of Individuals Station							Total
	HB1	HB2	HB3	HB4	HZ	HB6	HB7	
Aspidosiphon muelleri	81*	82*	142*	92*	328*	100*	70*	895
Euchone sp. B	3	339*	25	13	15	370*	5	770
Pionosyllis heterocirrata	47*	69*	61*	132*	79*	49*	63*	500
Synelmis acuminata	61*	57*	26	39	56*	48	173*	460
Leptochelia dubia	42*	71*	28*	17	29*	72*	44	303
Podarke angustifrons	20	28	43*	36	39*	46	22	234
Myriochele oculata	4	11	15	72*	23	67*		192
Augeneriella dubia	6	6	45*	62	18	21	8	166
Eriopisella sechellensis	45*	12		3	12	32	41	145
Polydora normalis				139*	1			140
Ophryotrocha sp. A				87*				87
Gammaropsis atlantica	1					3	71*	75
Haplosyllis spongicola							58*	58

*Ranked among the five most abundant nonmollusk taxa at individual stations.

TABLE 2. Abundance of Numerically Dominant Mollusk Taxa, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999

Taxon	Number of Individuals Station							Total
	HB1	HB2	HB3	HB4	HZ	HB6	HB7	
Diala scopulorum	206*	305*	316*	205*	409*	134*	81*	1,656
Cerithidium perparvulum	267*	175*	86*	170*	126*	65*	390*	1,279
Finella pupoides		33	275*	174*	447*	173*	3	1,105
Diala semistriata	195*	56*	83*	84*	91*	53*	300*	862
Balcis spp.	74*	53*	120*	131*	144*	76*	65*	663
Scaliola spp.	178*	110*	51	67	51	39	111*	607

*Ranked among the five most abundant mollusk taxa at individual stations.

TABLE A.1. Location and Depth for Replicate Grab Samples, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, April 1999

Station	Sampling Date	Replicate	Location		Depth (m)
			Latitude	Longitude	
HB1	13 April	1	21° 16' 50.4"	157° 59' 13.5"	61.6
		2	21° 16' 50.2"	157° 59' 13.4"	62.2
		3	21° 16' 50.6"	157° 59' 13.6"	61.6
		4	21° 16' 50.3"	157° 59' 13.4"	62.2
		5	21° 16' 50.5"	157° 59' 13.5"	61.6
HB2	13 April	1	21° 17' 00.5"	158° 01' 21.0"	60.7
		2	21° 17' 00.2"	158° 01' 20.8"	61.0
		3	21° 17' 00.5"	158° 01' 21.3"	61.0
		4	21° 17' 00.3"	158° 01' 20.8"	60.7
		5	21° 17' 00.1"	158° 01' 20.7"	61.3
HB3	14 April	1	21° 16' 53.4"	158° 01' 29.1"	66.8
		2	21° 16' 53.6"	158° 01' 29.2"	66.8
		3	21° 16' 53.4"	158° 01' 29.3"	67.1
		4	21° 16' 53.4"	158° 01' 29.1"	66.8
		5	21° 16' 53.4"	158° 01' 29.2"	66.8
HB4	14 April	1	21° 16' 47.8"	158° 01' 38.3"	61.3
		2	21° 16' 47.8"	158° 01' 38.4"	61.0
		3	21° 16' 47.6"	158° 01' 38.3"	61.3
		4	21° 16' 47.7"	158° 01' 38.4"	61.0
		5	21° 16' 47.8"	158° 01' 38.5"	61.0
HZ	13 April	1	21° 16' 53.5"	158° 01' 30.5"	64.0
		2	21° 16' 53.8"	158° 01' 30.7"	63.7
		3	21° 16' 53.4"	158° 01' 30.5"	64.0
		4	21° 16' 53.4"	158° 01' 30.3"	64.3
		5	21° 16' 53.3"	158° 01' 30.7"	64.0
HB6	14 April	1	21° 16' 32.3"	158° 01' 46.7"	61.0
		2	21° 16' 32.5"	158° 01' 46.7"	61.0
		3	21° 16' 32.5"	158° 01' 46.7"	61.0
		4	21° 16' 32.6"	158° 01' 46.6"	61.3
		5	21° 16' 32.7"	158° 01' 46.7"	61.3
HB7	14 April	1	21° 15' 33.0"	158° 03' 14.1"	63.4
		2	21° 15' 33.1"	158° 03' 13.9"	63.1
		3	21° 15' 33.2"	158° 03' 13.9"	63.1
		4	21° 15' 33.1"	158° 03' 13.8"	63.1
		5	21° 15' 33.2"	158° 03' 13.8"	63.1

TABLE A.2. Sediment Chemical Characterization of Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, April 1999

Station-Replicate	PD (cm)	ORP (+mV)	O&G (mg/wet kg)	TOC (% dry weight)
HB1-1	9.5	30	33	<0.02
HB1-2	9.0	80	<5	<0.02
HB1-3	10.0	110	20	<0.01
HB1-4	12.0	85		
HB1-5	11.0	155		
HB2-1	9.0	170	725	<0.01
HB2-2	9.0	165	758	<0.01
HB2-3	6.0	85		
HB2-4	9.0	165	792	<0.01
HB2-5	10.0	110		
HB3-1	9.0	115	36	<0.01
HB3-2	8.0	175	73	<0.01
HB3-3	11.0	190	126	<0.01
HB3-4	9.0	175		
HB3-5	8.0	75		
HB4-1	10.0	155	13	<0.01
HB4-2	11.0	145	60	<0.01
HB4-3	6.0	135		
HB4-4	9.0	195	213	<0.01
HB4-5	8.0	150		
HZ-1	12.0	145	133	<0.01
HZ-2	9.0	150	<5	<0.01
HZ-3	8.0	130		
HZ-4	9.0	160	<5	<0.01
HZ-5	6.0	175		
HB6-1	9.0	185	40	<0.01
HB6-2	8.0	185	60	<0.01
HB6-3	9.0	170	53	<0.01
HB6-4	8.0	60		
HB6-5	8.0	85		
HB7-1	10.0	150	7	<0.01
HB7-2	10.0	170	73	<0.01
HB7-3	10.0	125	186	<0.01
HB7-4	8.0	135		
HB7-5	8.0	160		

SOURCE: PD (penetration depth) and ORP (oxidation-reduction potential) data from Oceanographic Team, Department of Environmental Services, City and County of Honolulu; O&G (oil and grease) data from Environmental Quality Laboratory, Department of Environmental Services, City and County of Honolulu; and TOC (total organic carbon) data from Severn Trent Laboratories (Colchester, Vermont).

NOTE: <0.01% = analyte not detected at stated detection limit of 100 mg/kg.

TABLE A.3. Sediment Grain-Size Analysis of Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999

Station-	Sample Weight Distribution (%) Phi Size							
Replicate	-2	-1	0	1	2	3	4	>4–12
HB1-1	1.18	4.17	15.22	24.78	21.56	19.84	7.11	4.24
HB1-2	0.76	4.22	14.54	24.06	23.92	21.50	7.43	3.82
HB1-3	1.43	2.95	16.10	26.36	24.66	20.19	5.37	3.28
HB2-1	0.00	1.41	7.64	25.91	26.18	20.67	11.59	5.31
HB2-2	0.07	0.72	5.55	23.17	28.71	24.40	12.57	5.73
HB2-4	0.87	1.38	7.29	28.51	25.92	18.36	10.93	4.67
HB3-1	0.20	0.67	2.79	11.13	30.11	41.45	10.43	3.28
HB3-2	0.11	0.36	2.09	9.94	31.80	43.41	9.42	3.13
HB3-3	0.10	0.47	0.02	8.90	29.27	45.21	10.79	3.31
HB4-1	0.35	0.74	3.10	13.89	28.25	35.50	13.13	4.32
HB4-2	12.21	5.87	10.54	18.31	23.77	18.06	5.61	3.73
HB4-4	1.33	3.22	10.86	20.72	28.20	25.57	6.87	3.43
HZ-1	0.21	1.13	6.71	29.66	40.64	16.13	2.34	2.46
HZ-2	0.12	0.67	3.98	14.22	32.74	37.34	7.60	2.97
HZ-4	0.32	0.48	2.23	10.80	33.91	41.10	6.84	2.95
HZ-4 (rep)	0.04	0.44	2.27	10.51	33.66	41.82	6.96	2.89
HB6-1	0.53	1.81	8.61	16.16	23.94	33.78	9.43	4.08
HB6-1 (rep)	0.80	1.60	7.85	16.15	24.17	34.09	9.56	4.26
HB6-2	0.30	1.86	7.21	13.67	22.26	36.93	12.87	4.65
HB6-3	0.44	1.99	6.25	14.02	23.70	35.87	12.77	5.02
HB7-1	1.67	3.96	10.14	17.23	27.13	29.27	6.47	3.97
HB7-2	0.66	2.83	9.34	16.23	28.00	31.46	7.31	4.27
HB7-2 (rep)	1.84	3.14	9.67	15.89	27.73	31.50	7.40	4.23
HB7-3	5.57	5.20	11.07	16.25	25.36	27.53	6.14	3.48

SOURCE: Environmental Quality Laboratory, Department of Environmental Services, City and County of Honolulu.

NOTE: The values listed indicate the fraction percentage of the estimated dry weight of the sediment samples. The coarse fraction (-2 to +4) was analyzed by the sieve method. The fine fraction (greater than +4 to +12) was analyzed by the pipette method.

TABLE B.1. Basic Statistics for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999
(Sample Size n = 5)

				Station			
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	152.60	288.00	271.80	351.60	285.60	355.80	284.40
Standard Deviation	42.09	190.50	64.48	105.98	104.72	85.91	127.55
Standard Error of the Mean	18.82	85.19	28.84	47.40	46.83	38.42	57.04
95% of CI Mean	52.25	236.50	80.05	131.58	130.00	106.65	158.35
Skewness	-1.55	0.36	0.42	-0.48	-0.16	-0.77	1.12
Kurtosis	3.03	-0.01	-0.76	-1.32	-0.45	-2.07	1.90
Median	159.00	299.00	204.00	359.00	297.00	402.00	255.00
Normality Test (D)	0.332ns	0.161ns	0.185ns	0.211ns	0.143ns	0.305ns	0.236ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant.

TABLE B.2. Basic Statistics for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999
(Sample Size n = 5)

				Station			
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	35.60	46.80	37.00	48.60	41.40	49.20	44.60
Standard Deviation	9.91	21.24	8.51	10.85	8.65	4.60	13.89
Standard Error of the Mean	4.43	9.50	3.81	4.85	3.87	2.06	6.21
95% of CI Mean	12.31	26.37	10.57	13.47	10.74	5.72	17.24
Skewness	-1.03	-0.65	-0.85	0.35	-0.60	-0.14	-0.10
Kurtosis	1.39	-0.50	-1.73	-1.41	-0.52	-0.51	-2.70
Median	35.00	49.00	42.00	46.00	43.00	49.00	46.00
Normality Test (D)	0.276ns	0.177ns	0.322ns	0.195ns	0.173ns	0.128ns	0.218ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant.

TABLE B.3. Analysis of Variance for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	155,014.3	6	25,835.7	2.05	0.09
Experimental Error	352,266.4	28	12,580.9		
Total	507,280.7	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	152.60	288.00	217.80	351.60	285.60	355.80	284.40
Standard Deviation	42.09	190.50	64.48	105.98	104.72	85.91	127.55

F_{max} test for equal variance: Untransformed data, $F_{max} = 20.49$, not significant, $p > 0.05$.

Conclusion: There are no significant differences in mean nonmollusk abundance among the seven stations.

TABLE B.4. Analysis of Variance for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	897.1	6	149.5	1.02	0.43
Experimental Error	4,114.4	28	146.9		
Total	5,011.5	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	35.60	46.80	37.00	48.60	41.40	49.20	44.60
Standard Deviation	9.91	21.24	8.51	10.85	8.65	4.60	13.89

F_{max} test for equal variance: Untransformed data, $F_{max} = 21.28$, not significant, $p > 0.05$.

Conclusion: There are no significant differences in mean nonmollusk taxa number among the seven stations.

TABLE B.5. Analysis of Variance for Square Root Transformed Crustacean Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	50.28	6	8.38	1.57	0.19
Experimental Error	149.59	28	5.34		
Total	199.87	34			

Untransformed Data

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	28.00	52.40	16.20	33.00	28.20	52.00	65.60
Standard Deviation	15.23	53.88	8.93	18.77	17.14	19.04	55.03

F_{max} test for equal variance: Untransformed data, $F_{max} = 38.00$, significant, $p < 0.05$.

Transformed Data

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	5.11	6.33	3.85	5.55	5.05	7.11	7.58
Standard Deviation	1.53	3.92	1.30	1.65	1.82	1.35	3.19

F_{max} test for equal variance: Transformed data, $F_{max} = 9.03$, not significant, $p > 0.05$.

Conclusion: There are no significant differences in mean crustacean abundance among the seven stations.

TABLE B.6. Analysis of Variance for Untransformed Crustacean Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	278.74	6	46.46	2.42	0.052
Experimental Error	538.00	28	19.21		
Total	816.74	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	9.00	12.00	5.60	6.20	8.20	12.00	13.40
Standard Deviation	2.83	8.72	2.70	2.95	2.59	2.35	4.72

F_{max} test for equal variance: Untransformed data, $F_{max} = 13.82$, not significant, $p > 0.05$.

Conclusion: There are no significant differences in mean crustacean taxa number among the seven stations.

TABLE C.1. Basic Statistics for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, April 1999
(Sample Size n = 5)

	Station						
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	250.00	171.80	232.20	211.00	317.60	139.00	280.80
Standard Deviation	30.37	43.06	35.71	23.51	86.11	6.75	42.11
Standard Error of the Mean	13.58	19.26	15.97	10.51	38.51	3.02	18.83
95% of CI Mean	37.71	53.46	44.33	29.18	106.90	8.37	52.28
Skewness	0.83	0.85	-1.11	0.44	0.62	-2.17	0.14
Kurtosis	1.67	-0.17	0.26	-2.35	2.06	4.78	-1.30
Median	246.00	160.00	245.00	204.00	310.00	142.00	266.00
Normality Test (D)	0.235ns	0.208ns	0.240ns	0.217ns	0.284ns	0.417*	0.237ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant; * = $p < 0.05$.

TABLE C.2. Basic Statistics for Untransformed Mollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, April 1999
(Sample Size n = 5)

	Station						
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	28.20	22.40	30.40	27.60	33.20	23.80	38.20
Standard Deviation	4.44	3.13	5.41	4.04	4.09	2.59	7.40
Standard Error of the Mean	1.98	1.40	2.42	1.81	1.83	1.16	3.31
95% of CI Mean	5.51	3.89	6.72	5.01	5.07	3.21	9.18
Skewness	0.21	-1.84	0.12	1.24	0.35	0.36	1.16
Kurtosis	-1.46	3.75	-2.49	0.95	0.41	-2.41	1.53
Median	28.00	23.00	29.00	26.00	32.00	23.00	38.00
Normality Test (D)	0.164ns	0.379*	0.250ns	0.254ns	0.216ns	0.221ns	0.257ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant; * = $p < 0.05$.

TABLE C.3. Analysis of Variance and A Posteriori Comparison of Means for Log_{10} Transformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, April 1999

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Among Stations	0.4464	6	0.7440	13.02	<0.001
Experimental Error	0.1601	28	0.0057		
Total	0.6065	34			

Untransformed Data

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	250.00	171.80	232.20	211.00	317.60	139.00	280.80
Standard Deviation	30.37	43.06	35.71	23.51	86.11	6.75	42.11

F_{max} test for equal variance: Untransformed data, $F_{max} = 162.95$, significant, $p < 0.01$.

Transformed Data

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	2.40	2.22	2.36	2.32	2.49	2.14	2.44
Standard Deviation	0.05	0.11	0.07	0.05	0.12	0.02	0.07

F_{max} test for equal variance: Log_{10} transformed data, $F_{max} = 29.66$, not significant, $p > 0.05$.

Conclusion: There are significant differences in mean mollusk abundance between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB6	HB2	HB4	HB3	HB1	HB7	HZ
HB6		–	*	*	*	*	*
HB2			–	*	*	*	*
HB4				–	–	–	*
HB3					–	–	–
HB1						–	–
HB7							–

– = not significant; * = $p < 0.05$.

TABLE C.4. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, April 1999

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Among Stations	886.74	6	147.79	6.75	<0.001
Experimental Error	612.80	28	21.89		
Total	1,499.54	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	28.20	22.40	30.40	27.60	33.20	23.80	38.20
Standard Deviation	4.44	3.13	5.41	4.04	4.09	2.59	7.40

F_{max} test for equal variance: Untransformed data, $F_{max} = 8.16$, not significant, $p > 0.05$.

Conclusion: There are significant differences in mean mollusk taxa number between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB2	HB6	HB4	HB1	HB3	HZ	HB7
HB2		–	–	–	–	*	*
HB6			–	–	–	*	*
HB4				–	–	–	*
HB1					–	–	*
HB3						–	*
HZ							–

– = not significant; * = $p < 0.05$.

BENTHIC FAUNAL SAMPLING ADJACENT TO BARBERS POINT OCEAN OUTFALL, O‘AHU, HAWAI‘I, FEBRUARY–MARCH 2000

Richard C. Swartz
Julie H. Bailey–Brock
William J. Cooke
E. Alison Kay

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WATER RESOURCES RESEARCH CENTER
University of Hawai‘i at Mānoa
Honolulu, Hawai‘i 96822

ABSTRACT

Benthic infauna in the vicinity of the Barbers Point Ocean Outfall was sampled at seven stations on 9–10 February, 15–17 February, and 8 March 2000 with a modified van Veen grab sampler. The stations are located along the diffuser isobath (61 m) as follows: Station HZ within the zone of initial dilution (ZID); Stations HB2, HB3, and HB4 on the ZID boundary; Station HB6 at 0.5 km from the ZID; and Stations HB1 and HB7 at 3.5 km from the ZID.

Sediments were predominantly (>90%) sand at all stations. The coarse-sediment fraction was moderately higher and the fine-sand fraction moderately lower at Stations HB1, HB2, and HB7 than at the other stations. Total organic carbon in the sediments at all stations was less than 0.12%. Values for oxidation-reduction potential showed no evidence of reducing conditions at the surface of sediments at any station.

A total of 7,736 nonmollusk individuals from 164 taxa were collected. Polychaetes represented 45.1%, nematodes 19.4%, oligochaetes 11.7%, sipunculans 10.7%, and crustaceans 7.8% of total nonmollusk abundance. Mean total nonmollusk abundance ranged from 169.8 individuals per sample (37,430/m^2, at Station HB1) to 312.6 individuals per sample (68,908/m^2, at Station HB4). Mean crustacean abundance ranged from 8.4 (1,852/m^2, at Station HZ) to 25.4 (5,599/m^2, at Stations HB6 and HB7). Mollusks were analyzed separately because they represent time-averaged collections of live and dead shells. Mean mollusk abundance ranged from 123.2 individuals/10 cm^3 (at Station HB6) to 406.8 individuals/10 cm^3 (at Station HB1). There were no significant differences among the seven stations in crustacean abundance or the number of crustacean taxa. Mean crustacean abundance averaged over the entire study period (1986 to 2000) was significantly lower at ZID-boundary station HB3 than at reference station HB6. There is a historic pattern of reductions in crustacean abundance and taxa richness at the four ZID-area stations relative to each of the reference stations, although the differences are usually not statistically significant. This pattern may indicate a trend related to proximity to the diffuser. Relatively low values of crustacean abundance and taxa richness were recorded in 2000 at ZID station HZ and ZID-boundary stations HB3 and HB4, but these values were not significantly different from those of the reference stations. Crustacean abundance and taxa richness were relatively high at ZID-boundary station HB2. The collection of a variety of pollution-sensitive amphipod taxa at the ZID or ZID-boundary stations in 2000 and earlier years indicates that the diminished crustacean fauna at the ZID stations may be due to a noncontaminant factor. Crustacean abundance and taxa richness declined in 2000 from record levels observed in 1999. There were significant differences in abundance and taxa richness for both mollusks and

nonmollusks, but they do not indicate a spatial pattern related to the outfall. There has been a significant trend of increased abundance for nonmollusks within the entire study area since 1990. Since 1994, there has been a trend of increased abundance for mollusks. Both diversity and evenness values for both nonmollusks and mollusks were generally similar among all stations in 2000. Separate cluster analyses of nonmollusk and mollusk data confirmed that all stations were relatively similar to one another in terms of species composition and relative abundance. Except for statistically insignificant differences in the spatial distribution of crustaceans, there is no indication of any marked alteration of the benthic community composition related to station proximity to the diffuser.

INTRODUCTION

The Honouliuli Wastewater Treatment Plant is a primary treatment system. Wastewaters of mainly domestic origin are treated at the plant prior to discharge in Māmala Bay through an 84-in. (2.13-m) diameter outfall located off the southern coast of O'ahu, Hawai'i.

A waiver of secondary treatment for sewage discharge through the Barbers Point Ocean Outfall has been granted to the City and County of Honolulu (CCH) by the Region IX office of the U.S. Environmental Protection Agency (EPA). However, since September 1996 approximately one-fourth to one-half of the discharge has been secondary-treated effluent from the 'Ewa Water Reclamation Facility. The EWRF discharge will eventually be reused offsite. This report provides the results of the twelfth survey in an ongoing series of studies of the macrobenthic, soft-bottom community in the vicinity of the discharge; it also provides an overview of trends in biological communities adjacent to the outfall over the fifteen-year period from 1986 to 2000. The first benthic survey took place in 1986. The samples on which this report is based were collected on 9–10 February, 15–17 February, and 8 March 2000.

PROJECT ORGANIZATION

General coordination for this project is provided by James E.T. Moncur, director of the Water Resources Research Center of the University of Hawai'i at Mānoa and project principal investigator. The principal members of the project team (listed in alphabetical order) and their contributions to this study are as follows:

Julie H. Bailey–Brock	Polychaete, oligochaete, and sipunculan analysis and report
William J. Cooke	Crustacean analysis and report
E. Alison Kay	Mollusk analysis and report
Richard C. Swartz	Statistical analysis and final report preparation
Ross S. Tanimoto	City and County of Honolulu project representative and coordinator for sediment grain-size, total volatile solids, and oxidation-reduction potential analyses

MATERIALS AND METHODS

Specific locations of the sampling stations are provided in Figure 1, and a general vicinity map for the area serviced by the Honouliuli Wastewater Treatment Plant is provided in Figure 2. Seven stations previously established along the approximate diffuser isobath (61 m) were surveyed. In 1990 survey station names were changed from those used in the 1986 survey (Nelson et al. 1987). Survey stations (1986 station names are in parenthesis) and their locations are as follows:

Station HB1 (A)	Approximately 3.5 km east of the zone of initial dilution (ZID) boundary to evaluate effects far-field and beyond the ZID
Station HB2 (B)	On the northeast ZID boundary
Station HB3 (C)	On the southeast ZID boundary
Station HB4 (D)	On the southwest ZID boundary
Station HZ (Z)	Within the ZID to evaluate diffuser effects
Station HB6 (E)	Approximately 0.5 km southwest of the ZID boundary as a near-field reference station
Station HB7 (F)	Approximately 3.5 km southwest of the ZID boundary as a far-field reference station

Station Positioning

The exact position of each station was determined using the Garmin differential global positioning system. Station locations in relation to latitude, longitude, and bathymetric contours are shown in Figure 1. Positions for each replicate grab sample at each station are given in Appendix Table A.1. Depths for all stations fell within the range of 61.0 to 66.8 m. Station positions within and on the boundaries of the ZID were located precisely during the original sampling using the submersible *Makali'i* in coordination with its mother ship (Nelson et al. 1987).

Sampling Methods

The sampling methodology used in this study generally follows the recommendations of Swartz (1978) and guidelines of the U.S. Environmental Protection Agency (1987a, 1987b), hereafter referred to as EPA procedures. The 1986 through 1997 reports on the benthic monitoring adjacent to the Barbers Point Ocean Outfall (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b, 1995, 1996, 1997a) will be hereafter referred to as "Nelson et al. reports." The 1998 and 1999 reports on benthic monitoring at this outfall (Swartz et al. 1998, 1999, 2000) will be hereafter referred to as "Swartz et al. reports."

In 1994, the modified 0.1-m^2 van Veen grab sampler previously used was replaced by a 0.16-m^2 van Veen grab sampler. The new grab, which was deployed from a stern-mounted A-frame on the City's research vessel *Noi I Kai*, was used to obtain bottom samples at all seven stations. Sampling dates were 9–10 February, 15–17 February, and 8 March 2000. Penetration of the sampler was adequate for all replicates. The minimum penetration depth was 6.0 cm, and the maximum was 12.0 cm (Appendix Table A.2).

Five replicate grab samples were taken at each station. From each replicate sample, a subsample 7.6 cm in diameter by 5 cm deep was taken for infaunal analysis and a subsample 4.8 cm in diameter by 5 cm deep for mollusk analysis. Subsampling was necessary because the epifauna and infauna in the area are known to be both small and abundant (Nelson 1986; Russo et al. 1988). Replicated grab samples at each station, rather than replicated subsamples from one grab sample, were taken to provide information on intrastation variability. All five biological subcores for nonmollusk analysis were processed on a 0.5-mm screen and the organisms retained and preserved as appropriate for subsequent identification.

Samples for geochemical analyses (total organic carbon [TOC] and oxidation-reduction potential [ORP]) and for grain size analyses were obtained from the grabs from which the biological subcores were taken because each replicate grab contained more than enough sediment for both purposes (methods established by National Pollutant Discharge Elimination System permit no. HI0020877). Three subsamples (one from each of three different grab samples) were taken for all stations. The top 2 cm of sediment from each subsample were used for geochemical analysis. Samples for TOC analyses were put in screw-cap jars, which were placed on ice, and taken to the laboratory. Sediment ORP was measured on board the research vessel immediately after each sample was obtained. Laboratory analyses of sediment grain size followed EPA procedures. Analysis of TOC was carried out using EPA procedures by Severn Trent Laboratories (Colchester, Vermont). It performed the analysis using a modification of the Lloyd Kahn method, which utilizes an infrared detector to measure carbon dioxide. Inorganic carbon was removed from the samples by treating them with a 1:1 solution of hydrochloric acid prior to TOC analysis.

Sample Processing

Handling, processing, and preservation of the biological samples followed EPA procedures. Nonmollusk samples were fixed with buffered 10% formalin for a minimum of 24 hours. Following fixation, all samples were placed in 70% ethanol. Mollusk samples were placed in labeled jars in the field, then placed on ice and transported to the laboratory where they were refrigerated. Samples were washed in freshwater (to minimize loss of fine sediments), fixed in 75% isopropyl alcohol for 24 hours, and then air dried. A subsample in a 10-cm^3 aliquot was removed from each mollusk sample for sorting.

The fixed nonmollusk samples were elutriated using the technique of Sanders et al. (1965). This method removes from the sediment all organisms that are not heavily calcified (Nelson et al. 1987). Samples were washed several times, and the water from each was poured through 0.5-mm-mesh sieves. Polychaetes and other invertebrates retained on the sieve were transferred to alcohol, stained with rose bengal solution, and stored in 70% ethanol. Samples from four stations (Station HB1 [replicates 3 and 4], Station HB4 [replicates 1, 3, 4, and 5], Station HZ [replicate 3], and Station HB7 [replicate 3]) contained rubble pieces, which were acid-dissolved to remove endolithic and cryptic species. Organisms collected from the rubble fragments include 10 individuals (4 taxa) from Station HB1, 50 individuals (6 taxa) from Station HB4, 16 individuals (2 taxa) from Station HZ, and 20 individuals (3 taxa) from Station HB7.

Because the biological subcores had to be processed using two different procedures—one for mollusks and the other for all other organisms—the two components of the fauna were not directly comparable and thus were analyzed separately. Because the mollusk specimens were not separated into living and dead shell fractions, they represent time-averaged samples. Mollusks have been extensively analyzed by Kay (1975, 1978, 1979, 1982), Kay and Kawamoto (1980, 1983), Nelson (1986), and Russo et al. (1988).

All specimens were identified to the lowest taxonomic level possible. A selected bibliography for the identification of marine benthic species in Hawai‘i is provided in Nelson et al. (1987, appendix D). An additional source used for the identification of polychaetes in Hawai‘i is Blake et al. (1995). Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained for six years at the University of Hawai‘i.

In previous benthic sampling reports for Barbers Point, name changes for several polychaete taxa were indicated. A review of specimens and the literature led to several additional name changes this year. The genus *Novaquesta* has been reverted and included in *Questa* (Giere and Erseus 1998); therefore, *Novaquesta* sp. A is now *Questa* sp. A. Several changes were made to taxa in the family Syllidae: *Brania* sp. A was changed to *Odontosyllis* sp. B, *Exogone* sp. B and *Exogone* sp. D to *Exogone* sp. E, and *Parapionosyllis* sp. A to *Odontosyllis* sp. C. Other changes include the sabellid *Jasmineira* sp. A to *J. caudata*, the ampharetid *Melinna monoceroides* to *Lysippe* sp. A, and the chaetopterid Chaetopteridae sp. A to *Phyllochaetopterus* sp. B. The phoronid *Phoronis psammophila* was changed to *P. muelleri* (Bailey–Brock and Emig 2000).

The following taxa were newly found at the Barbers Point study site but have been found at other outfall sites sampled (Sand Island, Waianae, and Mokapu): *Brania rhopalophora*, *Cirratulus filiformis*, *Lacydonia* sp. A, *Myriochele* sp. C, *Polygordius* sp. A, *Psamathe* sp. A, *Rhodine* sp. A, and *Synelmis* sp. B. Taxa new to the Barbers Point study site and not previously collected at other outfall sites include *Laonome* sp. D, *Oriopsis* sp. C, and *Typosyllis* sp. D.

There were no name changes for the crustaceans, but new taxa were found. The four additions include a "praniza" larva of an unidentified gnathid isopod, *Gnathia* sp. A; a caridean shrimp, *Processa aequimana*; and two crabs, *Mursia hawaiiensis* and *Portunus macrophthalamus*.

Among the mollusks the spelling of the genus *Stosicia* has been corrected (listed incorrectly in previous reports as *Stosiscia*). Newly found mollusk taxa at Barbers Point include the bivalves *Carditella* sp., *Limopsis* spp., and *Mactra* sp., and the gastropods Coralliophilidae sp., *Merelina granulosa*, *Odostomia* sp. A, *Pyrgulina* sp., *Trochus* sp., *Turbonilla* sp. B, and *Umbraculum* sp.

Data Analysis

All data for both nonmollusks and mollusks were tested for assumptions of normality (Kolmogorov–Smirnov test; Sokal and Rohlf 1995) and heterogeneity of variances (F_{max} test) prior to statistical analysis. Where data sets failed tests of assumptions, square root or $\log_{10}$ transformation was applied. Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following a significant result using ANOVA, a posteriori Student–Newman–Keuls tests were used to determine which differences in means among stations were significant. All statistical analyses were performed using Prophet and Microsoft Excel software. Detailed statistical results are provided in Appendixes B and C.

Overall comparisons of taxa composition among stations were carried out using cluster analysis (Pielou 1984). The Bray–Curtis similarity index (Bloom 1981) on double square root transformed data was performed using the group-average sorting strategy. Separate cluster analyses were conducted for the mollusk and nonmollusk faunal fractions because of differences in sample collection and processing. To make analysis more manageable, only those taxa that contributed at least 0.05% to the total abundance were included. Using this criterion, only mollusk taxa represented by a total of more than five individuals were included in the data set, which was reduced from 128 to 55 taxa. Also, only nonmollusk taxa represented by a total of more than four individuals were included in the data set, which was reduced from 164 to 103 taxa. The similarity matrices were computed with Microsoft Excel software.

The Shannon–Wiener diversity index (H') (ln) 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 using Microsoft Excel software.

To examine trends over the entire study period, comparisons were made among mean values for all sampling dates and sampling stations using two-way ANOVA without replication and a posteriori Student–Newman–Keuls tests.

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 four grain-size categories, are compared in Figure 3. The grain-size categories (Folk 1968) are as follows: coarse sediment, retained on a +1-phi sieve; medium sand, passed through a +1-phi sieve but 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.

There were relatively small differences among stations in sediment grain-size distribution, especially in the proportion of the silt-and-clay fraction (range: 3.0% to 6.2%) and the medium- sand fraction (range: 24.4% to 30.8%) (Appendix Table A.3, Figure 3). The coarse-sediment fraction was higher at Stations HB1, HB2, and HB7 (range: 29.0% to 36.2%) than at the other stations (range: 13.2% to 25.0%). Conversely, the fine-sand fraction was lower at Stations HB1, HB2, and HB7 (range: 32.9% to 38.0%) than at the other stations (range: 42.0% to 53.0%). This spatial pattern of grain-size distribution is similar to those seen in 1997 (Nelson et al. 1997), 1998 (Swartz et al. 1998), and 1999 (Swartz et al. 1999), although sediments at Station HB2 were less coarse in 1997 and 1998 than in 1999 and 2000. Results of replicate sediment sample analysis for all seven stations indicated substantial homogeneity in grain size within stations (Appendix Table A.3). Analysis of duplicate samples at Stations HB3, HZ, and HB6 indicated consistency of analytical techniques.

Direct electrode measurements of ORP ranged from +45 to +165 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 there were significant differences among the seven stations ($F = 7.77, p < 0.001$). ORP was significantly higher at Station HZ than at Stations HB2 and HB1, and significantly higher at Stations HB6, HB3, HB7, and HB4 than at Station HB2. ORP measurements obtained for the 2000 survey are similar to those obtained for the 1997 (Nelson et al. 1997a), 1998 (Swartz et al. 1998), and 1999 (Swartz et al. 1999) surveys, except the ORP values were higher (i.e., showing less evidence of reducing conditions) at Station HB2 in 2000 (range: 45 to 105 mV), in 1999 (range: 85 to 170 mV), and in 1998 (range: 80 to 170 mV) than in 1997 (range: 25 to 45 mV).

Total organic carbon in the sediments was 0.05% or less in all except two samples (Appendix Table A.2). The two exceptions were 0.10% TOC in the replicate 2 sample at Station HB6 and 0.11% TOC in one of two split samples of replicate 2 at Station HB7. The other split sample had a TOC concentration of 0.03%. TOC was below detection limits in all samples in 1997 (Nelson et al. 1997a), below detection limits in all but three samples ($n = 21$) in 1998 (Swartz et al. 1998), and less than 0.02% in all samples in 1999 (Swartz et al. 1999).

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, nematodes, platyhelminths, echinoderms, anthozoans, chaetognaths, a hemichordate, nemerteans, sipunculans, insects, priapulids, phoronids, chordates, pycnogonids, copepods, ostracods, cumaceans, tanaids, amphipods, isopods, and decapods.

The 7,736 nonmollusk specimens counted and identified for all stations and replicates represent 164 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (3,489 individuals, 45.1%) and taxa richness (109 taxa, 66.5%). Nematodes comprised the second most dominant nonmollusk taxon in terms of abundance (1,498 individuals, 19.4%). Oligochaetes constituted 11.7% (903 individuals) of numerical abundance, sipunculans contributed 10.7% (828 individuals), and crustaceans contributed 7.8% (600 individuals). The 39 crustacean taxa, 11 of which were amphipods, represented 23.8% of the total number of nonmollusk taxa. Abundance estimates for each taxon from each replicate are given for each of the seven stations 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 taxa). Except for nonmollusk taxa number at Stations HB4 and HB6, data were normal for all stations (Appendix Table B.2).

Mean total nonmollusk abundance ranged from 169.8 individuals per sample (37,430/m^2, at Station HB1) to 312.6 individuals per sample (68,908/m^2, at Station HB4) (Figure 4). Variances were homogeneous (Appendix Table B.3). According to the ANOVA on untransformed data, there were significant differences in mean abundance among stations (Appendix Table B.3). Mean abundance was significantly higher at Station HB4 than at Stations HB1, HZ, HB3, and HB7. No other pairwise comparisons of means were significantly different.

Mean number of nonmollusk taxa per sample ranged from 31.0 taxa (at Station HB3) to 46.8 taxa (at Station HB2) (Figure 5). Variances were homogeneous (Appendix Table B.4). According to the ANOVA on untransformed data, there were significant differences in mean number of nonmollusk taxa among stations (Appendix Table B.4). Mean number of nonmollusk taxa was significantly higher at Station HB2 than at Stations HB3 and HZ. No other pairwise comparisons of means were significantly different.

Composite station diversity (H') and evenness (J) for the nonmollusks are shown in Figure 6. Values for both parameters were similar for all stations. Values for diversity ranged from 2.70 (at Station HB3) to 3.30 (at Station HB2). The range of values was similar to that of samples collected in 1999 but slightly higher than that of samples taken in years prior to 1999 (Nelson et al. reports; Swartz et al. reports). Evenness ranged from 0.64 (at Station HB3) to 0.73 (at Station HB1), which was also slightly higher than the range of values observed in years prior to 1999 (Nelson et al. reports; Swartz et al. reports). Relative to other stations, there was no consistent pattern of lower diversity or evenness at ZID or ZID-boundary stations.

The results of cluster analysis indicating the relative similarity of stations based on the 103 most abundant nonmollusk taxa are shown in Figure 7. All stations were grouped at similarity values greater than 67.0%, indicating similar taxa composition and abundance among all stations. There was some sorting among stations with regard to proximity to the diffuser. Reference stations HB1 and HB7 clustered together. However, reference station HB6 clustered closely with ZID station HZ and ZID-boundary stations HB3 and HB2.

Polychaetes

A total of 3,489 polychaetes representing 109 taxa were collected; they comprised 45.1% of total nonmollusk abundance. These numbers are lower than those recorded for 1999 (4,261 polychaetes from 113 taxa, Swartz et al. 1999) but higher than those of most recent years: 2,685 polychaetes representing 90 taxa in 1994 (Nelson et al. 1994b), 2,527 polychaetes representing 87 taxa in 1995 (Nelson et al. 1995), 3,836 polychaetes representing 95 taxa in 1996 (Nelson et al. 1996), 2,811 polychaetes representing 93 taxa in 1997 (Nelson et al. 1997a), and 3,521 polychaetes representing 85 taxa in 1998 (Swartz et al. 1998). The highest mean number of polychaetes per sample was found at Station HB4 (162.2 individuals), followed in decreasing order of abundance by Stations HB2 (132.4 individuals), HB6 (113.8 individuals), HB7 (87.8 individuals), HB1 (71.2 individuals), HZ (68.2 individuals), and HB3 (62.2 individuals) (Figure 8). Polychaetes were the most taxa-rich group at all stations (Appendix Tables D.1 through D.7). Maximum mean number of polychaete taxa per sample occurred at Station HB2 (32.0 taxa), followed in decreasing order by Stations HB4 (29.6 taxa), HB1 (26.4 taxa), HB6 (24.4 taxa), HB7 (20.8 taxa), HB3 (20.0 taxa), and HZ (19.6 taxa) (Figure 9).

Polychaetes accounted for 11 of the 13 taxa that ranked among the five most abundant taxa at individual stations (Table 1). Five taxa represented 49% of the polychaete individuals collected at the Barbers Point Ocean Outfall this year: *Synelmis acuminata* (13%), *Pionosyllis heterocirrata* (12%), *Euchone* sp. B (10%), *Prionospio cirrobranchiata* (7%), and *Myriochele oculata* (7%). Dominant polychaete taxa differed at several stations. *P. heterocirrata* was dominant at Stations HZ (16%), HB1 (15%), and HB3 (15%). This syllid species has dominated at Station HB3 since 1997. In 1999 and 2000, *Synelmis acuminata* replaced *P. heterocirrata* as the dominant polychaete at Station HB7. Although *S. acuminata* was the most dominant polychaete species only at Station HB7 (38%), this pilargid also appeared as an abundant species at all other stations.

Synelmis acuminata and *Pionosyllis heterocirrata* replaced *Euchone* sp. B as the most dominant polychaete species at Station HB1 in 1999 and 2000, respectively. At that station *Euchone* sp. B substantially decreased in abundance from 42% in 1998 to 1% in both 1999 and 2000. However, at Station HB2 this sabellid was the most abundant species this year, as has been the case since 1993. The spionid *Prionospio cirrobranchiata* was not the most dominant species at any station, but it was observed at all stations, ranging from 4% (at Station HB4) to 14% (at Station HB3). The oweniid *Myriochele oculata* was the most dominant polychaete species at Station HB6 (17%); it ranked among the dominant species at Stations HZ (12%) and HB4 (9%). The spionid *Polydora normalis*, which has been an abundant species at Stations HZ and HB4 since 1993, represented the most abundant species at Station HB4 (15%) this year. In fact, the high occurrence of this spionid shifted from being primarily at Station HZ (1993 through 1998) to Station HB4 (1999 and 2000).

Individuals of the families Syllidae, Spionidae, Serpulidae, Sabellidae, Nereididae, Hesionidae, Phyllodocidae, and Goniadidae were represented by reproducing individuals this year. Five syllid taxa were reproductively active at ZID and non-ZID stations: *Sphaerosyllis* sp. G at Stations HB1, HB2, HB4, and HB7; *Sphaerosyllis riseri* at Station HB2; *Salmacina dysteri* at Stations HB1 and HB4, *Pionosyllis heterocirrata* at Stations HB4, HB6, and HB7; and *Pionosyllis spinisetosa* at Station HB4. *Podarke angustifrons* was reproducing at Stations HB2 and HZ, and the serpulid *Salmacina dysteri* was observed reproducing by schizoparity at Stations HB1 and HB4. The nereidids *Neanthes arenaceodentata* and *Nereis* sp. B were reproducing at Stations HB4 and HB6, respectively. The phyllodocid *Hesionura australiensis* and the goniadid *Progoniada* sp. A were observed in a reproductive stage at Station HB1. Stations HB1, HB4, and HB7 had the most individuals reproducing as well as the widest variety of species reproducing.

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

1. Detritivores. Of the four trophic categories, deposit-feeding polychaetes were the most abundant group at Stations HB4 (50% of all polychaete individuals), HZ (42%), HB6 (37%), and HB3 (32%) and the most speciose group at all stations. The percentage of all polychaete taxa represented by detritivores ranged from 39% (at Station HB1) to 52% (at Station HZ). The number of detritivorous taxa ranged from 19 (at Stations HB3 and HB6) to 28 (at Station HB2). The dominant deposit-feeding polychaetes were the spionids *Polydora normalis* (15% at Station HB4) and *Prionospio cirrobranchiata* (14% at Station HB3, 12% at Station HZ, 11% at Station HB1, 5% at Station HB2, and 5% at Station HB7), and the oweniid *Myriochele oculata* (17% at Station HB6).

2. Omnivores. Omnivorous worms were best represented at Station HB7, where they accounted for 60% of all polychaetes (263 individuals); this is consistent with the results of all Barbers Point surveys since 1986 (Nelson et al. reports; Swartz et al. reports). Omnivorous worms were also numerically dominant at Station HB1 (43%, 154 individuals). They were never the least abundant of the four trophic categories at any station. The percentage of all polychaete taxa represented by omnivores ranged from 18% (at Station HZ) to 28% (at Station HB4). The number of omnivorous taxa ranged from 8 (at Station HZ) to 16 (at Stations HB2 and HB4). *Pionosyllis heterocirrata* was the dominant omnivore at four stations: HZ (16%), HB1 (15%), HB3 (15%), and HB4 (13%). *Synelmis acuminata* was the dominant omnivore at Stations HB7 (38%), HB6 (15%), and HB2 (9%).

3. Suspension feeders. Suspension feeders were dominant at Station HB2 (46% of all polychaetes, 304 individuals). This was primarily due to the large numbers of the sabellid *Euchone* sp. B (34%, 224 individuals). This polychaete taxa was also dominant at Station HB6 (17%, 95 individuals). However, it was rare at Station HB1 in 1999 and 2000, after being the most dominant polychaete at that station from 1996 to 1998. Another sabellid, *Augeneriella dubia*, was the dominant suspension feeder at Stations HB3 (9%), HB4 (4%), HB6 (4%), and HB1 (3%). Of the four trophic categories, suspension feeders were the least abundant group at Stations HB1 (11% of all polychaetes, 39 individuals), HZ (10%, 34 individuals), and HB7 (5%, 20 individuals). The percentage of all polychaete taxa represented by suspension feeders ranged from 16% (at Station HB4) to 23% (at Station HB2). Of the four trophic categories, suspension feeders were the least speciose group at Stations HB1, HB6, and HB7 (16% each). The number of suspension-feeding taxa ranged from 7 (at Stations HZ and HB6) to 16 (at Station HB2).

4. Carnivores. Carnivorous polychaetes were present at all stations, with their greatest abundance occurring at Station HB4 (10% of all polychaetes, 79 individuals). Carnivores

were least abundant at four stations: HB3 (15% of all polychaetes, 48 individuals), HB4 (10%,
79 individuals), HB6 (10%, 55 individuals) and HB2 (9%, 62 individuals). The percentage of all polychaete taxa represented by carnivores ranged from 12% (at Station HB4) to 21% (at Station HB1). The number of taxa ranged from 6 (at Station HZ) to 12 (at Station HB7). The hesionid *Podarke angustifrons* was the dominant carnivore at four stations: HB3 (11%), HB4 (6%), HZ (11%), and HB6 (6%). Another hesionid, *Micropodarke* sp. A, dominated at Stations HB7 (5%) and HB2 (3%). The goniadid *Progoniada* sp. A was the dominant carnivore at Station HB1 (5%).

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

1. Tubicolous polychaetes. Of the three motility categories, tubicolous polychaetes were the most abundant group at Stations HB2 (50% of all polychaetes, 334 individuals) and HB6 (41%, 232 individuals); they were least abundant at the other five stations. This group had the fewest taxa at six stations (Station HB4, 17% of polychaete taxa; Stations HB6 and HB7, 18% each; Station HB1, 19%; Station HZ, 20%; and Station HB3, 22%) and second fewest at the seventh station (Station HB2, 27%). The number of taxa ranged from 8 (at Station HB6) to 19 (at Station HB2). The dominant tubicolous polychaete taxa included the sabellid *Euchone* sp. B at Station HB2 (34%); the oweniid *Myriochele oculata* at Stations HB4 (9%), HZ (12%), HB6 (17%), and HB7 (1%, co-dominant); and the sabellid *Augeneriella dubia* at Stations HB1 (3%), HB3 (9%), and HB7 (1%, co-dominant with *M. oculata*).

2. Motile polychaetes. Of the three motility categories, motile polychaetes were the most abundant group at Stations HB1 (66% of all polychaetes, 234 individuals), HB3 (46%, 144 individuals), HB4 (58%, 467 individuals), HZ (51%, 175 individuals), and HB7 (81%, 357 individuals). In addition, they had the highest percentage of polychaete taxa at each of the seven stations, ranging from 41% (at Station HZ) to 60% (at Station HB1). The number of motile polychaete taxa ranged from 18 (at Station HZ) to 34 (at Stations HB1, HB2, and HB4). The syllid *Pionosyllis heterocirrata* was the dominant motile polychaete at Stations HB1 (15%), HB3 (15%), HB4 (13%), and HZ (16%). This syllid also showed high levels of abundance at Stations HB2 (7%), HB6 (7%), and HB7 (16%). *Synelmis acuminata*, a pilargid, was the dominant motile polychaete at Stations HB2 (9%), HB6 (15%), and HB7 (38%); it also showed high levels of abundance at Stations HB1 (13%), HB3 (8%), and HZ (13%). *Podarke angustifrons*, *Micropodarke* sp. A, the cirratulid *Caulleriella acicula*, and the goniadid *Progoniada* sp. A were also abundant motile taxa this year.

3. Discretely motile polychaetes. Of the three motility categories, discretely motile polychaetes were least abundant group at Stations HB2 (17% of all polychaetes, 111

individuals) and HB6 (20%, 112 individuals). They ranked second in abundance at the other five stations. The number of discretely motile individuals ranged from 57 (13% of all polychaetes, at Station HB7) to 194 (24%, at Station HB4). This group ranked second in percentage of polychaete taxa at Stations HB1 (21%), HB3 (31%), HB4 (24%), HZ (39%), HB6 (32%), and HB7 (24%) and third at Station HB2 (24%). The number of taxa ranged from 12 (at Stations HB1 and HB7) to 17 (at Stations HB2 and HZ). The dominant discretely motile species were all spionids: *Prionospio cirrobranchiata* at Stations HB1 (11% of all polychaetes), HB2 (5%), HB3 (14%), HZ (12%), HB6 (7%), and HB7 (5%); an *Polydora normalis* at Station HB4 (15%). An abundant spionid polychaete was *Prionospio cirrifera* (4% at Station HB7).

Crustaceans

A total of 600 crustaceans and pycnogonids, representing 7.8% of the nonmollusk abundance, were collected. Abundance for each taxon from each replicate is provided for each station in Appendix Tables D.8 through D.14. Mean abundance (no./sample) ranged from 8.4 (1,852/m^2, at Station HZ) to 25.4 (5,599/m^2, at Stations HB6 and HB7) (Figure 14). Variances were homogeneous for untransformed data (Appendix Table B.5). There were no significant differences in mean abundance among the seven stations (ANOVA, Appendix Table B.5).

A total of 39 crustacean and pycnogonid taxa (copepods were not identified to the species level) were collected; of these, 11 taxa (28.2%) were amphipods. Mean number of taxa ranged from 4.6 (at Stations HB3 and HZ) to 9.0 (at Station HB6) (Figure 15). Variances were homogeneous, and data were normally distributed. ANOVA indicated significant differences in mean number of taxa among the seven stations (Appendix Table B.6). However, Student–Newman–Keuls tests showed that no pairwise multiple contrasts were significantly different.

Copepods, amphipods, and tanaids were the numerically dominant taxa, making up 29.8%, 25.2%, and 19.2%, respectively, of total crustacean and pycnogonid abundance. No taxon was uniformly most abundant at all stations. Copepods, the tanaid *Leptochelia dubia,* and the amphipod *Eriopisella sechellensis* were present at all stations and were generally among the most abundant crustaceans. The amphipod *Ericthonius brasiliensis* was the only other crustacean that was collected at all stations. *Eriopisella sechellensis* was the only crustacean that ranked among the five most abundant nonmollusk species at any station; it tied for fourth most abundant nonmollusk at Station HB7 (Table 1).

Crustacean and pycnogonid abundance (600 individuals) and taxa number (39) were substantially less than the record numbers counted in 1999 (1,377 individuals, 49 taxa) but were comparable to the 1998 counts (697 individuals, 36 taxa). Abundance and taxa richness were below average values observed in collection years prior to 1999 (range for 1986 and for 1990 through 1998 collections: 164 to 1,121 individuals [mean = 653], 34 to 49 taxa [mean = 39.6]). A low count of 27 is excluded from the range for taxa richness because of procedural differences in 1997 (Nelson et al. 1997a).

Although there were no pairwise significant differences among stations in crustacean abundance and number of taxa, the range for total number of taxa collected at the ZID and ZID-boundary stations (12 to 17 taxa, Stations HB2, HB3, HB4, and HZ) was below the range observed at the reference stations (18 to 21 taxa, Stations HB1, HB6, and HB7). Also, total crustacean abundance was higher at the ZID and ZID-boundary stations than at the reference stations in only one of twelve possible pairwise comparisons. The lowest total number of crustacean taxa (12), amphipod species (3), and crustacean individuals (42) were collected at ZID station HZ. These data suggest a pattern of crustacean depression near the ZID, even though the statistical comparisons are not significant.

One isopod, one caridean shrimp, and two crabs were newly collected at the Barbers Point monitoring site in 2000. The newly collected isopod was represented by a single specimen of the "praniza" larva of an unidentified gnathid isopod (Isopoda, Gnathidae). Gnathid praniza larvae are usually found as parasites on fish, although they are sometimes found with adults commensal on sessile invertebrates, such as sponges. Since no gnathid isopod adults had been collected in the previous ten years of sampling, it is unlikely that this *Gnathia* species is a regular member of the benthic community in the study area.

The newly collected caridean shrimp, *Processa aequimana*, was represented by a single specimen each at three different stations. It had previously been collected only at other Oahu reef slope sites. Accurate identification of the crabs *Mursia hawaiiensis* and *Portunus macrophthalamus* was possible because excellent specimens were collected. It should be noted, that larger (2 cm and up) shrimps and crabs have very low probabilities of being collected, given the small areal coverage (7.6 cm diameter) of the sampling replicates. The collection of even relatively well-known decapods in this eleventh year of sampling is, therefore, not unexpected. The confirmation of *Processa aequimana, Mursia hawaiiensis*, and *Portunus macrophthalamus* from this study area helps improve the picture of the larger decapod crustacean fauna, which in previous years seemed unusually sparse.

This brings the total number of discretely identified/reported taxa from the study area in eleven years to 106. Copepods are enumerated as a single taxon, although several different taxa are certainly present. Cumaceans and mysids are similarly enumerated. Between two and eight taxa have been newly collected each year since the first two years of sampling (1990 and 1991) when a total of 62 taxa were collected. The spike of eight new taxa seen in 1999 was not repeated in 2000, suggesting that anomaly probably represented a particularly efficient year in terms of collection, sample processing, and recovery, rather than a shift in the composition of the overall crustacean community. The Barbers Point outfall study area does not appear to be subject to extremely large swings in benthic community composition or consistency. It seems to be generally a rather stable environment. This should aid in identifying any impacts associated with the outfall itself.

Mollusks

A total of 9,061 mollusks representing 128 taxa were collected. Mean abundance of mollusks per sample (no./10 cm^3) ranged from 123.2 (at Station HB6) to 406.8 (at Station HB1) (Figure 16). Data were normally distributed at all stations except Station HB1 (Appendix Table C.1). Complete basic statistics for total mollusk abundance data are shown in Appendix Table C.1.

Mean number of mollusk taxa per sample ranged from 22.2 (at Station HB6) to 35.8 (at Station HB7) (Figure 17). Data were normally distributed at all stations (Appendix Table C.2). Complete basic statistics for number of mollusk taxa at all stations are shown in Appendix Table C.2.

Variances were homogeneous for untransformed mollusk abundance data (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 and significantly lower at Station HB6 than at all other stations. Abundance was also significantly greater at Stations HB4, HB2, and HB7 than at Stations HZ and HB3.

Variances for number of mollusk taxa data were homogeneous (Appendix Table C.4). There were significant differences in mean mollusk taxa number among stations (ANOVA, Appendix Table C.4). Mean number of mollusk taxa was significantly greater at Stations HB7 and HB1 than at Stations HB6, HZ, HB2, and HB3; and at Station HB4 than at Stations HB6 and HZ.

Diversity (H') ranged from 2.02 (at Station HB2) to 2.59 (at Station HB7) (Figure 18). Evenness (J) ranged from 0.52 (at Station HB2) to 0.67 (at Station HB6). Diversity and evenness values for mollusks were generally similar for all stations (Figure 18).

The mollusk abundance patterns are consistent with those of all previous sampling years (Nelson et al. reports; Swartz et al. reports). Mollusk abundance for each taxon from each replicate is provided for each station in Appendix E. The molluscan fauna was very similar at all stations, especially among the dominant taxa (Table 2). The gastropod taxa *Diala scopulorum*, *Cerithidium perparvulum*, *Diala semistriata,* and *Balcis* spp. were abundant at all stations. *Finella pupoides* was abundant at all stations except Stations HB1, HB2, and HB7. *Scaliola* spp. was most abundant at stations where *Finella pupoides* was least abundant. These six dominant mollusk taxa accounted for 78.4% of all individuals collected.

The results of cluster analysis indicating the relative similarity of the molluscan assemblage at the seven stations are shown in Figure 19. The analysis indicated that all stations were very similar to one another (similarity index for final cluster: 70.9%). The dendrogram shows a cluster of four stations with very high similarity (>81%). The cluster includes two ZID-boundary stations (HB3 and HB4), one ZID station (HZ), and one reference station (HB6). Reference stations HB1 and HB7 linked together but were not distinctly different from the main cluster. A station cluster pattern almost identical to that shown in Figure 19 was also seen in 1998 and 1999 (Swartz et al. 2000).

The mollusk specimens collected in these surveys were not separated into living and dead shell material and therefore represent time-averaged collections that integrate conditions over a longer period. The living component of the mollusk fauna which is exposed to current discharge and effluent conditions may respond more quickly than is evident in the time-averaged collections. Thus, the evidence for high similarity of the mollusks among sampling stations may have been enhanced by the inclusion of empty shells in the cluster analysis.

DISCUSSION

In 2000 there were no significant differences among the seven stations in mean crustacean abundance and mean number of crustacean taxa. Statistically significant differences among stations in mean total nonmollusk abundance and mean number of nonmollusk taxa do not reflect an influence of the Barbers Point effluent discharge. ZID-boundary station HB4 had significantly higher nonmollusk abundance than ZID station HZ, ZID-boundary station HB3, and reference stations HB1 and HB7. ZID-boundary station HB2 had significantly more nonmollusk taxa than ZID station HZ and ZID-boundary station HB3. These results for the nonmollusks are similar to those obtained in most previous survey years for samples taken near the Barbers Point Ocean Outfall. The nonmollusks have generally been just as abundant and speciose at the stations near the outfall (HB2, HB3, HB4, and HZ) as at the reference stations (HB1, HB6, and HB7) (Nelson et al. reports; Swartz et al. reports). The 2000 results for the crustaceans show more of a trend (albeit not statistically significant) for reduced crustacean abundance and taxa richness near the outfall than was evident in 1999, but these results are similar to those obtained in some earlier survey years, including 1998. Also, in 2000 a specimen of the stress-sensitive indicator species *Paraphoxus* sp. A was collected at ZID station HZ and ZID-boundary station HB3.

Statistical comparisons of mollusk abundance and taxa richness in 2000 also do not indicate spatial patterns that are consistently related to the outfall discharge. For example, reference station HB6 had significantly lower mollusk abundance than all other stations, while reference station HB1 had significantly higher mollusk abundance than all other stations. Mean mollusk taxa richness was significantly greater at reference stations HB1 and HB7 than at reference station HB6, ZID station HZ, and ZID-boundary stations HB2 and HB3. Mollusk taxa richness was significantly greater at ZID-boundary station HB4 than at reference station HB6. Thus there was no general statistically significant pattern with regard to mollusk abundance or taxa richness and proximity to the diffuser. There are annual fluctuations in the abundance of mollusks among stations. Mollusks were most abundant at Station HB1 in 1992, 1993, 1994, 1995, 1997, 1998, and 2000, but they were third in abundance in 1996 (behind Stations HB4 and HZ) and in 1999 (behind Stations HZ and HB7) (Nelson et al. reports; Swartz et al. reports).

Mean crustacean taxa richness per replicate may not be as useful as total taxa richness per station as an indicator of outfall effects, given the high intrastation variability encountered. The total number of crustacean taxa collected at ZID station HZ was 12, less than at any other station. More taxa were collected at reference stations HB7 (21 taxa), HB1 (20 taxa), and HB6 (18 taxa) than at any of the ZID and ZID-boundary stations.

The major reduction in crustacean abundance and taxa richness between 1999 and 2000 had an equal effect on stations close to and farther away from the ZID. The average percent reduction in crustacean abundance and number of taxa at ZID and ZID-boundary stations (HB2, HB3, HB4, and HZ) was 57.8% and 14.6%, respectively. The corresponding percent reductions for reference stations (HB1, HB6, and HB7) were 50.3% and 16.8%. Whatever caused the reduction in the crustacean assemblage was not related to proximity to the outfall.

Reductions in crustacean abundance and taxa richness near the Barbers Point Ocean Outfall relative to reference stations have not been observed in every previous sampling year. Although in some years (e.g., 1991, Nelson et al. 1992a) taxa richness appeared to be reduced adjacent to the outfall, this pattern had not been seen for several years until 1998 and again in 2000. In 1999 the crustacean community of the study area was more abundant and diverse than in 1998, 2000, and most other years. The shifting patterns of number of taxa and abundance from year to year appear to be more strongly influenced by other factors, such as small-scale differences in bottom topography or a subtle variation in sediment composition. The presence of eight species of stress-sensitive gammaridean amphipods at the ZID and ZID-boundary stations also indicates that any changes in the crustacean assemblage near the outfall in 2000 are associated with factors other than chemical contamination by the effluent discharge.

Taxonomic diversity (expressed here simply as the number of discretely recorded taxa) is considered to be a better measure of the state of the crustacean communities at these sampling stations than the number of recorded individuals. For the smaller crustaceans (tanaids, isopods, and amphipods) and pycnogonids, abundance can be strongly influenced by a large number of juveniles released from brooding adults. Abundance data generated from other taxa (such as mollusks, most polychaetes, and many decapods) represent a settlement from the plankton of a larval form which has found the site suitable for habitation. While high crustacean abundance data (particularly if juveniles are being produced) clearly indicate that the site is suitable, low abundance data are not necessarily indicative of unsuitability.

A rather comprehensive picture of the crustacean communities in the study area has been developed (at least for crustaceans smaller than 1 cm) over the last eleven survey years despite the rather small areal coverage (7.6 cm diameter) of the sampling replicates. The number of new taxa recorded in 2000 (four) is about average for each annual survey since 1991 but less than the eight new taxa found in 1999. It should be noted that larger (2 cm and up) shrimp and crab, while certainly present in the study area, have almost no chance of being collected. In general, the crustacean community in the Barbers Point outfall study area is less diverse than that near the Wai‘anae outfall and more diverse than that near the Sand Island outfall.

Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. Lower nonmollusk diversity and evenness values were reported for Station HB2 in 1993, but this pattern has not been repeated since (Nelson et al. 1994a, 1994b, 1995, 1996, 1997a; Swartz et al. reports). There is little evidence that the outfall is having an effect on taxa richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis similarity index indicated that nonmollusk abundance and taxa composition were broadly similar at most stations (>67% similarity index value). The four most similar stations were from the ZID (Station HZ), ZID-boundary (Stations HB2 and HB3), and reference (Station HB6) areas. These same four stations were clustered together in 1999 (Swartz et al. 1999). In the period from 1986 to 1993, cluster analysis consistently intermixed ZID, ZID-boundary, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). In 1994 and 1995, some separation between stations in or near the ZID and far-field reference stations was observed (Nelson et al. 1994b, 1995). In 1996 (Nelson et al. 1996), 1997 (Nelson et al. 1997a), 1998 (Swartz et al. 1998), and 1999 (Swartz et al. 1999) stations were again generally interspersed in the cluster analysis. The clustering of far-field reference stations HB1 and HB7 in 2000 indicates some separation between near-ZID and far-field stations, but the clustering of near-field reference station HB6 with the ZID and ZID-boundary stations suggests the nonmollusk fauna near the

ZID is not greatly different from the reference assemblage. In comparing the 1996 through 2000 cluster results with those of earlier years, some caution is necessary since the clustering algorithm was changed in 1996 from flexible to group-average sorting in order to conform to current recommendations for optimum methodologies (Carr 1993).

Sediment grain sizes in the 2000 samples were broadly similar among stations. Sand accounted for >90% of the sediment weight at all stations. The coarse-sediment fraction was moderately higher at Stations HB1, HB2 and HB7 (range: 29.04% to 36.21%) than at the other stations (range: 13.16% to 24.96%). Conversely, the fine-sand fraction was moderately lower at Stations HB1, HB2, and HB7 (range: 32.90% to 37.99%) than at the other stations (range: 42.03% to 52.99%). The percentage of fine sediments at ZID station HZ was slightly greater in 2000 (3.96%) than in 1997 (3.23%), 1998 (2.98%), and 1999 (2.78%) (Nelson et al., 1997a; Swartz et al. reports), although these differences are probably of no ecological significance. The increase in the silt-and-clay fraction of the sediments observed in 1993 for all stations began to moderate in 1996, and this trend continued in 1997, 1998, and 1999 (for comparison see figure 3 in Nelson et al. 1992b, 1994a, 1994b, 1995, 1996, 1997a; and in Swartz et al. reports). The mean percentage of the silt-and-clay fraction in 2000 (4.18%) is less than that observed in 1997 (4.77%, Nelson et al. 1997a) and 1998 (4.86%, Swartz et al. 1998), but slightly more than that observed in 1999 (4.06%, Swartz et al. 1999). The increase in fine sediments in 1993 occurred at all seven stations, thus it is unlikely to have been an effect of the outfall discharge.

ORP analysis showed no evidence of reducing conditions at the surface of sediments at any station in 2000; this has been the consistent pattern for this parameter. ORP values were highest at ZID station HZ. They were significantly lower at ZID-boundary station HB2 than at Stations HZ, HB6, HB3, HB7, and HB4. Station ORP values were similar in 1999 and 2000 at all stations except Station HB2, where they were lower in 2000.

Sediment TOC was 0.05% or less in all replicate samples except two in 2000. The exceptions were 0.10% TOC in one replicate at reference Station HB6 and 0.11% TOC in one replicate at reference station HB7. Thus there continues to be no evidence of sediment organic enrichment near the outfall. The absence of detectable sediment TOC was reported for all samples collected in 1996 and 1997 and for all but three samples in 1998. The analytical laboratory used for TOC analyses after 1995 removes all traces of the organic carbon from the sediment during acid digestion to remove inorganic carbon. Although low, TOC values in previous years have been above the detection limits of current instrumentation. Similar below-detection-limit values of TOC have been reported by the same analytical laboratory for sediment samples taken from the Sand Island Ocean Outfall monitoring stations (Nelson et al. 1997b). Analyses of sediment nitrogen levels for samples taken concurrently with the sediment TOC samples at the Sand Island monitoring stations suggest that the contract laboratory is consistently underestimating sediment TOC (Nelson et al. 1997b). Unfortunately, similar measurements of sediment nitrogen were not taken for the Barbers Point Ocean Outfall monitoring stations, thus the conclusion of measurement bias for TOC cannot be confirmed, although it is strongly suspected.

The total number of nonmollusk taxa recorded in 2000 (164) is tied for the third highest value recorded in the twelve years of monitoring at the Barbers Point Ocean Outfall (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, 144 in 1993, 159 in 1994, 151 in 1995, 147 in 1996, 138 in 1997, 140 in 1998, and 183 in 1999). The 39 crustacean and pycnogonid taxa collected in 2000 was less than the average value observed in earlier years, when counts ranged from 34 to 49 taxa. That range does not include the low value of 27 taxa collected in 1997, when counts were reduced because of differences in sample handling. 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 2000.

Mean nonmollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2000 (Figures 20 and 21). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Numerous pairwise comparisons among dates showed significant differences, generally with values for recent dates being higher than values for earlier dates. The abundance of nonmollusks in 2000 was quantitatively, but not significantly, less than that in 1999 and significantly greater than that observed in 1986, 1990, and 1991. This temporal pattern of increasing nonmollusk abundance was confirmed by a linear regression analysis of data from 1990 to 2000, which found a trend of significantly increasing mean abundance over this period ($p = 0.0005$, $y = 15.9x - 51.2$, where y = mean nonmollusk abundance and x = year code: 1990 = 10 through 2000 = 20). The slightly lower mean nonmollusk abundance in 1997 versus 1996, 1998, and 1999 is partly explained by the processing differences for the crustaceans during 1997.

The Student–Newman–Keuls test showed two significant pairwise multiple contrasts among stations for mean nonmollusk abundance based on data collected in 1986 and from 1990 through 2000. Nonmollusk abundance for the twelve combined surveys was greater at ZID-boundary station HB4 than at reference stations HB1 and HB7.

Mean nonmollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2000 (Figures 22 and 23). Two-way ANOVA results showed significant differences among sampling dates ($p < 0.0001$) but not among sampling stations ($p = 0.17$). Mean nonmollusk taxa richness was significantly lower in 1990 than in all other years and significantly lower in 1997 than in 1992, 1993, 1994, 1996, 1999, and 2000 (Figure 22). The low counts for 1997 are due to methodological problems that impacted the number of crustacean taxa collected. Mean nonmollusk taxa richness was also significantly lower in 1986 than in 1992, 1994, 1996, 1999, and 2000; significantly lower in 1991 than in 1994 and 1999; and significantly lower in 1998 than in 1999. Nonmollusk taxa richness was less in 2000 than in 1999, when it was quantitatively greater than in any previous year. No temporal trend comparable to that for abundance was seen for nonmollusk taxa richness, nor was any apparent spatial trend seen for this parameter in relation to proximity to the outfall.

Mean crustacean abundance was also compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2000 (Figures 24 and 25). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p = 0.0006$). Mean crustacean abundance in 1999 was quantitatively higher than in all other years and significantly higher than in all years except 1993 and 1994. Crustacean abundance in 1993 and 1994 was significantly higher than in 1990 and 1997. The decreased abundance in 1990 is consistent with the overall pattern of nonmollusk abundance for that year. Interannual variations in abundance are not related solely to differences in the time of year that samples were taken. The 1990, 1992, and 1994 through 1998 samples—all of which were taken in January or February—show considerable variation in mean crustacean abundance. When all data through 2000 were pooled for station comparisons, mean crustacean abundance was significantly greater at reference station HB6 than at ZID-boundary station HB3. The same result was obtained for the historic data set through 1997 (Nelson et al. 1997a), as well as through 1999 (Swartz et al. 1999), but not through 1998 (Swartz et al. 1998).

Mean number of crustacean taxa was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2000 (Figures 26 and 27). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean crustacean taxa richness was significantly lower in 1990 than in all years except 1986 and 1997; significantly lower in 1997 than in 1991, 1993, 1994, 1995, 1999, and 2000; significantly lower in 1986 than in 1994 and 1999; and significantly greater in 1994 than in 1992, 1996, and 1998. The low mean number of taxa counted in 1990 reflects the low total abundance of crustaceans collected that year. The reduction in crustacean taxa richness in 1997 was due to procedural differences in sample handling. The increase in the number of crustacean taxa collected in 1998 and 1999 reversed a temporal decline that was evident from 1994 through 1997 (Figure 26). The number of crustacean taxa collected in 2000 was intermediate between collections in

1998 and 1999. Student–Newman–Keuls tests showed no significant pairwise comparisons of mean number of crustacean taxa among stations. Despite the lack of statistical significance, there is a historic pattern of reduced crustacean taxa richness at all ZID and ZID-boundary stations (Figure 27). In fact, all stations near the diffuser have fewer crustacean taxa than all reference stations. The overall pattern is consistent with an effect of the diffuser effluent on crustacean taxa. This historic pattern was present in 2000, when the number of crustacean taxa at all reference stations was quantitatively greater than at any ZID or ZID-boundary station, even though there were no significant differences among any station pairs in mean crustacean taxa richness.

Dominant taxa of the nonmollusk fauna were similar to those of previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that of previous sampling years. The sipunculan *Aspidosiphon muelleri* was the most abundant taxon in 2000 (Table 1). The dominant polychaete taxa since 1994 showed some variation from earlier sampling years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). Dominant taxa in 2000 were similar to those found in 1994 through 1999 (Nelson et al. 1994b, 1995, 1996, 1997a; Swartz et al. reports) and included the polychaetes *Synelmis acuminata*, *Pionosyllis heterocirrata*, *Euchone* sp. B, *Prionospio cirrobranchiata*, and *Myriochele oculata*, as well as the amphipod *Eriopisella sechellensis* (Table 1).

Mean mollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2000 (Figures 28 and 29). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk abundance was significantly greater in 1998 and 2000 than in 1986, 1990, 1991, 1992, 1993, 1994, and 1995; and significantly greater in 1996, 1997, and 1999 than in 1993. Mean mollusk abundance was significantly greater at reference station HB1 than at all other stations. Neither the temporal nor spatial pattern of differences indicates a negative effect of the diffuser effluent on mollusk abundance.

Because the mollusk specimens were 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 was generally much less for the mollusk fraction than for the nonmollusk fraction prior to 1996. There has been a temporal trend of increasing mollusk abundance since 1993 (Figure 28). The pattern of abundance in the sampling area on all dates shows that Station HB1 has historically had the greatest number of mollusk individuals (Figure 29). Consistent with the historic pattern, Station HB1 had significantly higher mean mollusk abundance than all other stations in 2000 (Table C.3).

Mean mollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2000 (Figures 30 and 31). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk taxa richness was significantly greater in 1998 than in 1986, 1990, 1991, 1992, 1993, 1994, and 1995; significantly greater in 1996 and 1997 than in 1990, 1992, and 1993; and significantly greater in 1999 and 2000 than in 1990 and 1992. Mean mollusk taxa richness was significantly greater at Stations HB1, HB4, and HB7 than at Station HB2. Ten of the twelve possible pairwise comparisons of mollusk taxa richness between reference stations (HB1, HB6, and HB7) and ZID or ZID-boundary stations (HB2, HB3, HB4, and HZ) were not statistically significant. There has been a temporal pattern of increasing number of mollusk taxa since 1992 (Figure 30). Neither the temporal nor spatial pattern of differences indicates a consistent negative effect of the diffuser effluent on mollusk taxa richness.

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show little evidence of a buildup of organic matter in the vicinity of the Barbers Point Ocean Outfall diffuser. High ORP measurements at all stations indicated the absence of reducing conditions. Sediment TOC was less than 0.12% in all samples in 2000 and was very low or undetectable from 1996 through 1999. In years prior to 1996, mean sediment TOC was in the narrow range of 0.04% to 0.47%, except in 1993 when methodological problems were experienced with the analyses and values ranged from 0.56% to 1.40%. The ocean outfall in Orange County, California, discharges onto the continental shelf in an erosional benthic environment (Maurer et al. 1993) which may be somewhat similar to that found in Mā mala Bay, O'ahu. In the vicinity of the Orange County outfall, sediment TOC ranged from approximately 0.3% to 0.9% (Maurer et al. 1993). In areas which possess more depositional benthic environments, the percentage of organic content in the sediments is typically much higher. For example, this percentage 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 Angles 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 near the Barbers Point Ocean Outfall suggests that little particulate matter from the diffuser ever reaches the sediment surface in the study area.

The spatial patterns of organism abundance and taxa richness in relation to the outfall varied depending on the taxonomic grouping. There were no consistent, statistically significant patterns of reductions of either organism abundance or taxa richness of nonmollusks and mollusks near the diffuser in 2000. The macrobenthos was much more similar than dissimilar among the seven sampling stations. Separate cluster analyses of nonmollusk and mollusk data indicated that all stations were similar to one another in terms of taxa composition and relative abundance (similarity >67% for nonmollusks, >70% for mollusks). The dominant mollusk taxa were almost identical at all stations. Only six taxa are on the list of mollusks that rank among the five most abundant taxa at any one of the seven stations.

The abundance of nonmollusks and mollusks in the study area has increased in recent years. However, there is no consistent spatial pattern in the historic abundance or taxa richness of either nonmollusks or mollusks that indicates an effect of the outfall effluent. The respective numbers of nonmollusk and mollusk individuals and taxa collected in 2000 were all near the top of their historic range.

The abundance and taxa richness of crustaceans decreased in 2000 from the historic high levels recorded in 1999. However, mean crustacean abundance in 2000 was more than twice the historic low levels recorded in 1990 and 1997. The mean number of crustacean taxa collected in 2000 was the fifth highest among the twelve survey years. There is a historic pattern of reductions in crustacean abundance and taxa richness at the four ZID-area stations relative to each of the reference stations. This pattern may indicate a trend related to proximity to the diffuser. Relatively low values of crustacean abundance and taxa richness were recorded in 2000 at ZID station HZ and ZID-boundary stations HB3 and HB4. However, there were no statistically significant differences among the ZID, ZID-boundary, and reference stations in either mean crustacean abundance or mean number of crustacean taxa in 2000. Also, mean crustacean abundance and taxa richness were slightly greater at ZID-boundary station HB2 than at reference station HB1. The presence of pollution-sensitive taxa like amphipods (especially the phoxocephalid *Paraphoxus* sp. A) indicates that the diminished crustacean fauna at the ZID and ZID-boundary stations may be related to a noncontaminant factor.

Taxa diversity (H') and evenness (J) were very similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment by Pearson and Rosenberg (1978) proposes that in the transition zone on an enrichment gradient, a few taxa 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 indication of the types of changes in bottom communities predicted by the organic enrichment hypothesis. Maurer et al. (1993) proposed that the Pearson–Rosenberg model may be inappropriate for erosional continental shelf environments. Their study of an outfall on the continental shelf off California found that even with some organic enrichment near the diffuser, there was no evidence of elimination of rare species, even though three species did achieve numerical dominance. The response of the benthic community near the Barbers Point Ocean Outfall does not show the alternate response pattern described by Maurer et al. (1993), presumably because sediment organics there do not show even the moderate enrichment found near the Orange County outfall.

In conclusion, there is little evidence of adverse effects of the Barber Point Ocean Outfall on the macrobenthic community in 2000. The only indication of an effect lies in the crustacean component where there were fewer, but not significantly fewer, individuals and taxa at ZID-boundary stations HB3 and HB4 and ZID station HZ than at the reference stations. However, other analyses do not suggest an adverse effect of the outfall on crustaceans, especially the more abundant and taxa rich crustacean assemblage at ZID-boundary station HB2. The presence of eight amphipod species at the ZID and ZID-boundary stations indicates that alterations in the crustacean component may be related to a noncontaminant factor. The analyses of the noncrustacean fauna clearly demonstrate the presence of a diverse and abundant macrobenthos within and near the ZID of the Barber Point Ocean Outfall.

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TABLE 1. Abundance of Numerically Dominant Nonmollusk Taxa, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, February–March 2000

Taxon	Number of Individuals Station							Total
	HB1	HB2	HB3	HB4	HZ	HB6	HB7	
Aspidosiphon muelleri	118*	69*	146*	96*	193*	94*	103*	819
Synelmis acuminata	45*	59*	25	34	46*	87*	166*	462
Pionosyllis heterocirrata	52*	48*	48*	102*	54*	41*	70*	415
Euchone sp. B	3	224*	15	15	13	95*		365
Prionospio cirrobranchiata	40*	33*	44*	32	42*	37	23	251
Myriochele oculata	4	21	13	69*	41*	97*	5	250
Podarke angustifrons	4	16	34*	52	36	34	13	189
Polydora normalis		1	1	122*	2	4		130
Augeneriella dubia	10	2	29*	31	1	21	5	99
Micropodarke sp. A	14	20	4	15	6	5	24*	88
Eriopisella sechellensis	13	5	8	9	3	5	24*	67
Pionosyllis spinisetosa		2		58*				60
Progoniada sp. A	17*	5	3			1	3	29

*Ranked among the five most abundant nonmollusk taxa at individual stations.

TABLE 2. Abundance of Numerically Dominant Mollusk Taxa, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, February–March 2000

Taxon	Number of Individuals Station							Total
	HB1	HB2	HB3	HB4	HZ	HB6	HB7	
Diala scopulorum	330*	579*	242*	352*	274*	121*	92*	1,990
Cerithidium perparvulum	524*	254*	72*	255*	90*	47*	466*	1,708
Scaliola spp.	348*	260*	49	99	24	17	100*	897
Finella pupoides	2	3	264*	273*	235*	116*		893
Diala semistriata	165*	129*	51*	122*	40*	56*	270*	833
Balcis spp.	104*	102*	117*	175*	89*	116*	81*	784

*Ranked among the five most abundant nonmollusk taxa at individual stations.

TABLE A.1. Position and Depth for Replicate Grab Samples, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, February–March 2000

Station	Sampling Date	Replicate	Location		Depth (m)
			Latitude	Longitude	
HB1	9 February	1	21° 16' 50.5"	157° 59' 12.9"	61.9
		2	21° 16' 50.3"	157° 59' 13.0"	62.2
		3	21° 16' 50.4"	157° 59' 12.9"	61.9
		4	21° 16' 50.1"	157° 59' 13.0"	62.2
		5	21° 16' 50.3"	157° 59' 13.2"	62.2
HB2	15 February	1	21° 17' 00.1"	158° 01' 20.2"	61.0
		2	21° 17' 00.0"	158° 01' 20.3"	61.0
		3	21° 16' 59.9"	158° 01' 20.4"	61.0
		4	21° 17' 00.0"	158° 01' 20.4"	61.0
		5	21° 17' 00.1"	158° 01' 20.3"	61.0
HB3	17 February	1	21° 16' 53.5"	158° 01' 29.1"	66.4
		2	21° 16' 53.4"	158° 01' 28.9"	66.8
		3	21° 16' 53.6"	158° 01' 29.0"	66.8
		4	21° 16' 53.5"	158° 01' 29.0"	66.8
		5	21° 16' 53.5"	158° 01' 29.1"	66.4
HB4	8 March	1	21° 16' 47.5"	158° 01' 38.5"	61.0
		2	21° 16' 48.0"	158° 01' 38.3"	61.0
		3	21° 16' 47.9"	158° 01' 38.3"	61.3
		4	21° 16' 47.7"	158° 01' 38.3"	61.3
		5	21° 16' 48.0"	158° 01' 38.3"	61.0
HZ	8 March	1	21° 16' 53.4"	158° 01' 30.4"	64.0
		2	21° 16' 53.4"	158° 01' 30.4"	64.0
		3	21° 16' 53.6"	158° 01' 30.3"	63.7
		4	21° 16' 53.3"	158° 01' 30.5"	63.7
		5	21° 16' 53.4"	158° 01' 30.4"	64.0
HB6	10 February	1	21° 16' 32.3"	158° 01' 46.6"	61.6
		2	21° 16' 32.3"	158° 01' 46.6"	61.6
		3	21° 16' 32.4"	158° 01' 46.6"	61.6
		4	21° 16' 32.3"	158° 01' 46.5"	61.6
		5	21° 16' 32.4"	158° 01' 46.6"	61.6
HB7	16 February	1	21° 15' 33.0"	158° 03' 14.1"	63.4
		2	21° 15' 33.0"	158° 03' 14.1"	63.4
		3	21° 15' 33.0"	158° 03' 14.1"	63.4
		4	21° 15' 33.0"	158° 03' 14.0"	63.1
		5	21° 15' 33.0"	158° 03' 14.1"	63.4

SOURCE: Oceanographic Team, Department of Environmental Services, City and County of Honolulu.

TABLE A.2. Sediment Chemical Characterization of Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, February–March 2000

Station-Replicate	PD (cm)	ORP (+mV)	TOC (% dry weight)
HB1-1	10.0	55	<0.01
HB1-2	10.0	105	<0.01
HB1-3	12.0	110	0.03
HB1-4	10.0	115	
HB1-5	10.0	110	
HB2-1	9.0	55	<0.01
HB2-2	7.0	75	
HB2-3	10.0	80	0.03
HB2-4	9.0	105	0.01
HB2-5	9.0	45	
HB3-1	9.0	130	<0.01
HB3-2	9.0	155	0.02
HB3-3	9.0	125	<0.01
HB3-4	8.0	120	
HB3-5	9.0	130	
HB4-1	6.5	65	
HB4-2	9.0	125	0.05
HB4-3	9.0	155	<0.01
HB4-4	9.0	145	<0.01
HB4-5	7.0	135	
HZ-1	9.0	150	0.02
HZ-2	8.0	165	0.02
HZ-3	6.0	130	
HZ-4	8.0	160	0.02
HZ-5	6.0	160	
HB6-1	10.0	130	0.02
HB6-2	10.0	135	0.10
HB6-3	10.0	145	0.02
HB6-3 (rep)			0.02
HB6-4	11.0	160	
HB6-5	10.0	120	
HB7-1	9.0	110	0.02
HB7-2	11.0	115	0.11
HB7-2 (rep)			0.03
HB7-3	12.0	140	0.02
HB7-4	9.0	150	
HB7-5	9.0	140	

SOURCE: PD (penetration depth) and ORP (oxidation-reduction potential) data from Oceanographic Team, Department of Environmental Services, City and County of Honolulu; TOC (total organic carbon) data from Severn Trent Laboratories (Colchester, Vermont).

NOTE: <0.01% = analyte not detected at stated detection limit of 100 mg/kg.

TABLE A.3. Sediment Grain-Size Analysis of Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, February–March 2000

Station-Replicate	Sample Weight Distribution (%) Phi Size -2	-1	0	1	2	3	4	>4–12
HB1-1	0.82	2.35	8.75	20.51	25.64	27.16	8.36	3.89
HB1-2	0.49	2.39	10.53	22.62	25.06	25.16	8.58	4.04
HB1-3	0.94	3.37	12.45	23.42	25.69	23.33	6.10	3.33
HB2-1	0.11	1.04	4.35	16.76	26.35	27.68	15.77	6.51
HB2-3	0.07	1.87	7.07	24.24	26.58	21.31	11.63	5.92
HB2-4	0.31	2.47	6.82	22.00	25.82	22.39	12.88	6.10
HB3-1	0.09	0.33	1.48	7.75	28.20	45.63	11.80	3.05
HB3-1 (rep)	0.12	0.27	1.85	8.88	30.72	45.38	10.65	3.58
HB3-2	0.43	1.05	3.18	11.27	32.24	40.53	8.47	2.68
HB3-3	0.00	0.54	2.62	10.01	29.65	42.25	10.99	3.11
HB4-2	1.59	1.62	6.41	18.85	28.03	27.38	10.69	4.62
HB4-3	0.57	1.63	5.62	16.88	27.76	32.06	10.76	3.46
HB4-4	0.13	0.98	5.29	15.31	27.50	34.28	10.93	3.16
HZ-1	0.65	1.06	3.72	12.91	30.35	36.72	9.56	4.12
HZ-2	0.23	1.29	4.12	14.43	31.76	35.47	8.05	4.22
HZ-4	0.00	0.52	2.85	11.07	30.28	41.62	9.16	3.35
HZ-4 (rep)	0.31	0.96	3.17	11.88	30.44	40.44	9.01	3.74
HB6-1	0.00	0.80	6.54	15.08	24.20	36.58	10.73	4.21
HB6-2	0.13	2.50	9.19	15.94	23.32	34.86	9.52	4.11
HB6-2 (rep)	0.29	1.67	8.40	14.86	23.23	36.32	10.55	4.34
HB6-3	0.17	1.01	6.03	15.66	25.68	38.83	9.53	3.71
HB7-1	0.86	2.60	10.70	18.65	25.57	27.95	7.12	4.68
HB7-2	1.68	4.00	7.55	12.83	26.37	35.64	7.31	4.40
HB7-3	0.61	2.14	8.40	17.04	28.59	30.39	5.57	4.06

SOURCE: Environmental Quality Laboratory, Department of Environmental Services, City and County of Honolulu.

NOTE: The values listed indicate the fraction percentage of the estimated dry weight of the sediment samples. The coarse fraction (-2 to +4) was analyzed by the sieve method. The fine fraction (greater than +4 to +12) was analyzed by the pipette method.

TABLE B.1. Basic Statistics for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, February–March 2000
(Sample Size n = 5)

				Station			
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	169.80	237.20	189.00	312.60	185.20	247.80	205.60
Standard Deviation	53.96	63.55	79.08	59.48	51.39	45.04	50.15
Standard Error of the Mean	24.13	28.42	35.37	26.60	22.98	20.14	22.43
95% of CI Mean	66.99	78.90	98.18	73.84	63.80	55.91	62.26
Skewness	1.21	0.01	0.39	1.31	0.52	0.26	-0.81
Kurtosis	0.92	-2.32	-0.58	1.26	-0.85	-1.94	1.67
Median	144.00	231.00	192.00	293.00	185.00	234.00	204.00
Normality Test (D)	0.284ns	0.210ns	0.164ns	0.229ns	0.200ns	0.220ns	0.279ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant.

TABLE B.2. Basic Statistics for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, February–March 2000
(Sample Size n = 5)

				Station			
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	40.60	46.80	31.00	42.40	31.40	40.40	35.80
Standard Deviation	8.17	10.99	5.34	3.36	7.57	4.83	6.14
Standard Error of the Mean	3.66	4.91	2.39	1.50	3.39	2.16	2.75
95% of CI Mean	10.15	13.64	6.63	4.17	9.40	5.99	7.62
Skewness	0.49	0.02	-1.64	1.46	0.05	2.19	0.02
Kurtosis	-1.10	-2.19	2.89	2.97	1.28	4.83	-1.67
Median	40.00	47.00	32.00	42.00	32.00	38.00	34.00
Normality Test (D)	0.190ns	0.188ns	0.300ns	0.347*	0.216ns	0.414*	0.215ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant, * = $p < 0.05$.

TABLE B.3. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, February–March 2000

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	72,677.37	6	12,112.9	3.54	0.01
Experimental Error	95,705.60	28	3,418.1		
Total	168,382.97	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	169.80	237.20	189.00	312.60	185.20	247.80	205.60
Standard Deviation	53.96	63.55	79.08	59.48	51.39	45.04	50.15

F_{max} test for equal variance: Untransformed data, $F_{max} = 3.08$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean nonmollusk abundance between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB1	HZ	HB3	HB7	HB2	HB6	HB4
HB1		–	–	–	–	–	*
HZ			–	–	–	–	*
HB3				–	–	–	*
HB7					–	–	*
HB2						–	–
HB6							–

– = not significant; * = $p < 0.05$.

TABLE B.4. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, February–March 2000

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	1,029.49	6	171.58	3.48	0.01
Experimental Error	1,382.40	28	49.37		
Total	2,411.89	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	40.60	46.80	31.00	42.40	31.40	40.40	35.80
Standard Deviation	8.17	10.99	5.34	3.36	7.57	4.83	6.14

F_{max} test for equal variance: Untransformed data, $F_{max} = 10.68$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean nonmollusk taxa number between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB3	HZ	HB7	HB6	HB1	HB4	HB2
HB3		–	–	–	–	–	*
HZ			–	–	–	–	*

HB7	–	–	–	–
HB6		–	–	–
HB1			–	–
HB4				–

– = not significant; * = $p < 0.05$.

TABLE B.5. Analysis of Variance for Untransformed Crustacean Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, February–March 2000

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	1,459.89	6	243.31	2.40	0.05
Experimental Error	2,840.40	28	101.44		
Total	4,300.29	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	17.20	20.20	9.40	14.00	8.40	25.40	25.40
Standard Deviation	10.01	14.75	7.06	12.55	2.70	6.47	11.65

F_{max} test for equal variance: Untransformed data, $F_{max} = 29.82$, not significant at $p > 0.05$.

Conclusion: There are no significant differences in mean crustacean abundance among the seven stations.

TABLE B.6. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Crustacean Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, February–March 2000

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	117.49	6	19.58	2.90	0.025
Experimental Error	188.80	28	6.74		
Total	306.29	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	7.80	8.00	4.60	5.20	4.60	9.00	8.80
Standard Deviation	2.17	3.00	2.97	2.17	1.67	2.92	2.95

F_{max} test for equal variance: Untransformed data, $F_{max} = 3.21$, not significant at $p > 0.05$.

Conclusion: ANOVA indicates there are significant differences in mean crustacean taxa number among the seven stations. However, Student–Newman–Keuls tests showed that no pairwise multiple contrasts were significantly different at $p = 0.05$.

Table C.1. Basic Statistics for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, February–March 2000
(Sample Size n = 5)

	Station						
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	406.80	304.20	198.00	308.00	181.80	123.20	290.20
Standard Deviation	38.37	38.48	58.40	20.33	21.14	24.18	35.25
Standard Error of the Mean	17.16	17.21	26.12	9.09	9.45	10.81	15.77
95% of CI Mean	47.63	47.77	72.50	25.24	26.24	30.02	43.76
Skewness	0.88	-1.55	-0.49	0.40	-0.56	-0.88	-0.60
Kurtosis	-1.76	2.59	-2.94	-0.12	-0.11	1.03	-0.14
Median	381.00	309.00	222.00	312.00	178.00	126.00	294.00
Normality Test (D)	0.349*	0.298ns	0.259ns	0.203ns	0.210ns	0.199ns	0.143ns

Note: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant; * = $p < 0.05$.

Table C.2. Basic Statistics for Untransformed Mollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, February–March 2000
(Sample Size n = 5)

	Station						
Statistic	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	35.20	25.40	27.20	30.60	23.00	22.20	35.80
Standard Deviation	4.49	5.94	5.26	3.78	2.55	3.42	3.77
Standard Error of the Mean	2.01	2.66	2.35	1.69	1.14	1.53	1.69
95% of CI Mean	5.58	7.38	6.53	4.69	3.17	4.25	4.68
Skewness	1.93	-0.30	0.58	0.79	0.00	-0.84	-0.86
Kurtosis	3.80	0.42	0.61	-1.25	-2.26	0.70	1.09
Median	33.00	26.00	28.00	29.00	23.00	23.00	36.00
Normality Test (D)	0.318ns	0.143ns	0.240ns	0.264ns	0.184ns	0.192ns	0.216ns

Note: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant.

TABLE C.3. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, February–March 2000

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Among Stations	276,923.54	6	46,153.92	35.70	<0.001
Experimental Error	36,204.00	28	1,293.00		
Total	313,127.54	34			

Untransformed Data

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	406.80	304.20	198.00	308.00	181.80	123.20	290.20
Standard Deviation	38.37	38.48	58.40	20.33	21.14	24.18	35.25

F_{max} test for equal variance: Untransformed data, $F_{max} = 8.25$, significant at $p < 0.05$.

Conclusion: There are significant differences in mean mollusk abundance between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB6	HZ	HB3	HB7	HB2	HB4	HB1
HB6		*	*	*	*	*	*
HZ			–	*	*	*	*
HB3				*	*	*	*
HB7					–	–	*
HB2						–	*
HB4							*

– = not significant; * = $p < 0.05$.

TABLE C.4. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, February–March 2000

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	919.14	6	153.19	8.26	<0.001
Experimental Error	519.60	28	18.56		
Total	1,438.74	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	35.20	25.40	27.20	30.60	23.00	22.20	35.80
Standard Deviation	4.49	5.94	5.26	3.78	2.55	3.42	3.77

F_{max} test for equal variance: Untransformed data, $F_{max} = 5.43$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean mollusk taxa between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB6	HZ	HB2	HB3	HB4	HB1	HB7
HB6		–	–	–	*	*	*
HZ			–	–	*	*	*
HB2				–	–	*	*
HB3					–	*	*
HB4						–	–
HB1							–

– = not significant; * = $p < 0.05$.

BENTHIC FAUNAL SAMPLING ADJACENT TO THE BARBERS POINT OCEAN OUTFALL, O‘AHU, HAWAI‘I, JANUARY 2001

Richard C. Swartz
Julie H. Bailey–Brock
William J. Cooke
E. Alison Kay

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WATER RESOURCES RESEARCH CENTER
University of Hawai'i at Mānoa
Honolulu, Hawai'i 96822

ABSTRACT

Benthic infauna in the vicinity of the Barbers Point Ocean Outfall was sampled at seven stations on 13–15 January 2001 with a modified van Veen grab sampler. The stations are located along the diffuser isobath (61 m) as follows: Station HZ within the zone of initial dilution (ZID); Stations HB2, HB3, and HB4 on the ZID boundary; Station HB6 at 0.5 km from the ZID; and Stations HB1 and HB7 at 3.5 km from the ZID.

Sediments were predominantly (>93%) sand at all stations. The coarse-sediment fraction was moderately higher and the fine-sand fraction moderately lower at Stations HB1, HB2, and HB7 than at the other stations. Total organic carbon in the sediments at all stations was less than 0.20%. There were no significant differences among stations in mean oil and grease measurements. Values for oxidation-reduction potential showed no evidence of reducing conditions at the surface of sediments at any station.

A total of 8,818 nonmollusk individuals from 186 taxa were collected. Polychaetes represented 45.9%, nematodes 20.8%, crustaceans 12.7%, oligochaetes 9.1%, and sipunculans 6.0% of total nonmollusk abundance. Mean total nonmollusk abundance ranged from 181.6 individuals per sample (40,031/m^2, at Station HB1) to 399.6 individuals per sample (88,086/m^2, at Station HB4). Mean crustacean abundance ranged from 17.6 (3,880/m^2, at Station HB4) to 60.6 (13,358/m^2, at Station HZ). Mollusks were analyzed separately because they represent time-averaged collections of live and dead shells. Mean mollusk abundance ranged from 189.2 individuals/10 cm^3 (at Station HB6) to 529.8 individuals/10 cm^3 (at Station HB1). Crustacean abundance and taxa richness increased in 2001 from the low levels recorded in 2000. Crustacean abundance and taxa richness recorded in 2001 at ZID-boundary stations HB2, HB3, and HB4 were low relative to the reference stations. However, crustacean abundance at ZID station HZ was significantly higher than at all three reference stations (HB1, HB6, and HB7). Mean crustacean abundance averaged over the entire study period (1986 to 2001) was significantly lower at ZID-boundary station HB3 than at reference station HB6. There is a historic pattern of reductions in crustacean abundance and taxa richness at the four ZID-area stations relative to each of the reference stations, although the differences are usually not statistically significant and the pattern has not been observed in every previous sampling year. This pattern may indicate a trend related to proximity to the diffuser. The very high crustacean abundance and taxa richness at ZID station HZ in 2001 is a major exception to this historic pattern. The collection of a variety of pollution-sensitive amphipod taxa at the ZID or ZID-boundary stations in 2001 and earlier years indicates that the diminished crustacean fauna at the ZID-area stations may be due to a noncontaminant factor. There were significant differences in abundance and taxa richness for

both mollusks and nonmollusks, but they do not indicate a spatial pattern related to the outfall. There has been a significant trend of increased abundance for nonmollusks within the entire study area since 1990. Since 1993, there has been a trend of increased abundance for mollusks. Diversity and evenness values were generally similar among all stations in 2001, although lowest values occurred at ZID-boundary stations HB3 and HB2 for nonmollusks and mollusks, respectively. Separate cluster analyses of nonmollusk and mollusk data confirmed that all stations were relatively similar to one another in terms of species composition and relative abundance, although the similarity of mollusks among stations may have been enhanced by the inclusion of empty shell counts in the analysis. Except for a diminished crustacean fauna at ZID-boundary stations, there is no indication of any marked alteration of the benthic community composition related to station proximity to the diffuser. The analyses of the noncrustacean fauna clearly demonstrate the presence of a diverse and abundant macrobenthos within and near the ZID of the Barbers Point Ocean Outfall.

INTRODUCTION

The Honouliuli Wastewater Treatment Plant is a primary treatment system. Wastewaters of mainly domestic origin are treated at the plant prior to discharge in Mā mala Bay through an 84-in. (2.13-m) diameter outfall located off the southern coast of O'ahu, Hawai'i.

A waiver of secondary treatment for sewage discharge through the Barbers Point Ocean Outfall has been granted to the City and County of Honolulu (CCH) by the Region IX office of the U.S. Environmental Protection Agency (EPA). However, since September 1996 approximately one-fourth to one-half of the discharge has been secondary-treated effluent from the 'Ewa Water Reclamation Facility. The EWRF discharge will eventually be reused offsite. This report provides the results of the thirteenth survey in an ongoing series of studies of the macrobenthic, soft-bottom community in the vicinity of the discharge; it also provides an overview of trends in biological communities adjacent to the outfall over the sixteen-year period from 1986 to 2001. The first benthic survey took place in 1986. The samples on which this report is based were collected on 13–15 January 2001.

PROJECT ORGANIZATION

General coordination for this project is provided by James E.T. Moncur, director of the Water Resources Research Center of the University of Hawai'i at Mā noa and project principal investigator. The principal members of the project team (listed in alphabetical order) and their contributions to this study are as follows:

Julie H. Bailey-Brock	Polychaete, oligochaete, and sipunculan analysis and report
William J. Cooke	Crustacean analysis and report
E. Alison Kay	Mollusk analysis and report
Richard C. Swartz	Statistical analysis and final report preparation
Ross S. Tanimoto	City and County of Honolulu project representative and coordinator for sediment grain-size, total organic carbon, oil and grease, and oxidation-reduction potential analyses

MATERIALS AND METHODS

Specific locations of the sampling stations are provided in Figure 1, and a general vicinity map for the area serviced by the Honouliuli Wastewater Treatment Plant is provided in

Figure 2. Seven stations previously established along the approximate diffuser isobath (61 m) were surveyed. In 1990 survey station names were changed from those used in the 1986 survey (Nelson et al. 1987). Survey stations (1986 station names are in parenthesis) and their locations are as follows:

Station HB1 (A)	Approximately 3.5 km east of the zone of initial dilution (ZID) boundary to evaluate effects far-field and beyond the ZID
Station HB2 (B)	On the northeast ZID boundary
Station HB3 (C)	On the southeast ZID boundary
Station HB4 (D)	On the southwest ZID boundary
Station HZ (Z)	Within the ZID to evaluate diffuser effects
Station HB6 (E)	Approximately 0.5 km southwest of the ZID boundary as a near-field reference station
Station HB7 (F)	Approximately 3.5 km southwest of the ZID boundary as a far-field reference station

Station Positioning

The exact position of each station was determined using the Garmin differential global positioning system. Station locations in relation to latitude, longitude, and bathymetric contours are shown in Figure 1. Positions for each replicate grab sample at each station are given in Appendix Table A.1. Depths for all stations fell within the range of 60.7 to 67.1 m. Station positions within and on the boundaries of the ZID were located precisely during the original sampling using the submersible *Makali'i* in coordination with its mother ship (Nelson et al. 1987).

Sampling Methods

The sampling methodology used in this study generally follows the recommendations of Swartz (1978) and guidelines of the U.S. Environmental Protection Agency (1987a, 1987b), hereafter referred to as EPA procedures. The 1986 through 1997 reports on the benthic monitoring adjacent to the Barbers Point Ocean Outfall (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b, 1995, 1996, 1997a) will be hereafter referred to as "Nelson et al. reports." The 1998 through 2000 reports on benthic monitoring at this outfall (Swartz et al. 1998, 1999, 2000a, 2000b) will be hereafter referred to as "Swartz et al. reports."

In 1994, the modified 0.1-m^2 van Veen grab sampler previously used was replaced by a 0.16-m^2 van Veen grab sampler. The new grab, which was deployed from a stern-mounted A-frame on the City's research vessel *Noi I Kai*, was used to obtain bottom samples at all seven stations. Sampling dates were 13–15 January 2001. Penetration of the sampler was adequate for all replicates. The minimum penetration depth was 7.0 cm, and the maximum was 11.0 cm (Appendix Table A.2).

Five replicate grab samples were taken at each station. From each replicate sample, a subsample 7.6 cm in diameter by 5 cm deep was taken for infaunal analysis and a subsample 4.8 cm in diameter by 5 cm deep for mollusk analysis. Subsampling was necessary because the epifauna and infauna in the area are known to be both small and abundant (Nelson 1986; Russo et al. 1988). Replicated grab samples at each station, rather than replicated subsamples from one grab sample, were taken to provide information on intrastation variability. All five biological subcores for nonmollusk analysis were processed on a 0.5-mm screen and the organisms retained and preserved as appropriate for subsequent identification.

Samples for geochemical analyses (total organic carbon [TOC], oil and grease [O&G], and oxidation-reduction potential [ORP]) and for grain-size analyses were obtained from the grabs from which the biological subcores were taken because each replicate grab contained more than enough sediment for both purposes (methods established by National Pollutant Discharge Elimination System permit no. HI0020877). Three subsamples (one from each of three different grab samples) were taken for all stations. The top 2 cm of sediment from each subsample were used for geochemical analysis. Samples for TOC and O&G analyses were put in screw-cap jars, which were placed on ice, and taken to the laboratory. Sediment ORP was measured on board the research vessel immediately after each sample was obtained. Laboratory analyses of sediment grain size and O&G followed EPA procedures. Analysis of TOC was carried out using EPA procedures by Severn Trent Laboratories (Colchester, Vermont). It performed the analysis using a modification of the Lloyd Kahn method, which utilizes an infrared detector to measure carbon dioxide. Inorganic carbon was removed from the samples by treating them with a 1:1 solution of hydrochloric acid prior to TOC analysis.

Sample Processing

Handling, processing, and preservation of the biological samples followed EPA procedures. Nonmollusk samples were fixed with buffered 10% formalin for a minimum of 24 hours. Following fixation, all samples were placed in 70% ethanol. Mollusk samples were placed in labeled jars in the field, then placed on ice and transported to the laboratory where they were refrigerated. Samples were washed in freshwater (to minimize loss of fine sediments), fixed in 75% isopropyl alcohol for 24 hours, and then air dried. A subsample in a 10-cm^3 aliquot was removed from each mollusk sample for sorting.

The fixed nonmollusk samples were elutriated using the technique of Sanders et al. (1965). This method removes from the sediment all organisms that are not heavily calcified (Nelson et al. 1987). Samples were washed several times, and the water from each was poured through 0.5-mm-mesh sieves. Polychaetes and other invertebrates retained on the sieve were transferred to alcohol, stained with rose bengal solution, and stored in 70% ethanol.

Because the biological subcores had to be processed using two different procedures—one for mollusks and the other for all other organisms—the two components of the fauna were not directly comparable and thus were analyzed separately. Because the mollusk specimens were not separated into living and dead shell fractions, they represent time-averaged samples. Mollusks have been extensively analyzed by Kay (1975, 1978, 1979, 1982), Kay and Kawamoto (1980, 1983), Nelson (1986), and Russo et al. (1988).

All specimens were identified to the lowest taxonomic level possible. A selected bibliography for the identification of marine benthic species in Hawai‘i is provided in Nelson et al. (1987, appendix D). An additional source used for the identification of polychaetes in Hawai‘i is Blake et al. (1995). Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained for six years at the University of Hawai‘i.

In previous benthic sampling reports for Barbers Point, name changes for several polychaete taxa were indicated. A review of specimens and the literature led to several additional name changes this year. The genus *Tharyx* was emended, such that *Tharyx marioni* is now referred to as *Aphelochaeta marioni* (Blake 1991). *Eumida* sp. A was changed to *Eumida sanguinea*. *Sphaerodoropsis* sp. A was found to be *Sphaerodoropsis* sp. C. *Ophryotrocha* sp. A was further identified as *Ophryotrocha adherens* (Paavo et al. 2000).

The following taxa were newly found at the Barbers Point study site but have been found at other O‘ahu outfall sites (Sand Island, Waianae, and Mokapu): *Laonome* sp. C, *Paramphinome* sp. A, *Protoaricia* sp. A, and *Syllides bansei*. Taxa new to the Barbers Point study site and not previously collected at other outfall sites include *Apophryotrocha* sp. A, *Caulleriella* sp. A, Cirratulidae sp. B, *Demonax* sp. A, *Pseudobranchiomma* sp. A, Sabellidae sp. A, and *Trypanosyllis* sp. A.

Among the crustaceans, one name change was made this year and two new taxa were found at the Barbers Point study site. The gammarid amphipod previously listed as *Anamixis stebbingi* and *Leucothoides* ? *pottsi* is now called *Anamixis torrida*. Newly found crustacean taxa include one amphipod, *Lysianassa ewa*, and one crab, tentatively identified as *Nucia* (?)

sp. A. *L. ewa* Barnard, 1970, has been placed in *Arugella* (as *A. ewa*) by Barnard and Karaman (1991), but since the discriminatory characters are both limited and subjective, the species is recorded by its original name until the status of the genus is more fully settled. *L. ewa* has been collected from the Mokapu outfall study area but not from the Waianae or Sand Island outfall study areas. The small crab identified as *Nucia* (?) sp. A has also been previously collected from other outfall study areas. It is an incomplete specimen, so a full identification cannot be made, although it appears similar to *Nucia perlata* from Japan (Sakai 1965).

Among the mollusks the name of *Mitrolumna alphonsiana* has been corrected (listed incorrectly in previous reports as *Mitromorpha alphonsiana*). Newly found mollusk taxa at Barbers Point include the bivalves *Lioconcha hieroglyphica*, *Pillucina spaldingi*, *Pillucina* sp., and *Tellina oahuana*; and the gastropods *Emarginula dilecta*, *Euchelus* sp., *Meioceras sandwichensis*, *Mitrella loyaltensis*, and *Odostomia* sp. B.

Data Analysis

All data for both nonmollusks and mollusks were tested for assumptions of normality (Kolmogorov–Smirnov test; Sokal and Rohlf 1995) and heterogeneity of variances (F_{max} test) prior to statistical analysis. Where data sets failed tests of assumptions, square root or $\log_{10}$ transformation was applied. Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following a significant result using ANOVA, a posteriori Student–Newman–Keuls tests were used to determine which differences in means among stations were significant. All statistical analyses were performed using Prophet and Microsoft Excel software. Detailed statistical results are provided in Appendixes B and C.

Overall comparisons of taxa composition among stations were carried out using cluster analysis (Pielou 1984). The Bray–Curtis similarity index (Bloom 1981) on double square root transformed data was performed using the group-average sorting strategy. Separate cluster analyses were conducted for the mollusk and nonmollusk faunal fractions because of differences in sample collection and processing. To make analysis more manageable, only those taxa that contributed at least 0.05% to the total abundance were included. Using this criterion, only mollusk taxa represented by a total of more than five individuals were included in the data set, which was reduced from 129 to 60 taxa. Also, only nonmollusk taxa represented by a total of more than four individuals were included in the data set, which was reduced from 186 to 100 taxa. The similarity matrices were computed with Microsoft Excel software. Cumulative counts of crustacean taxa are based on collections since 1990.

The Shannon–Wiener diversity index (H') (ln) 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 using Microsoft Excel software.

To examine trends over the entire study period, comparisons were made among mean values for all sampling dates and sampling stations using two-way ANOVA without replication and a posteriori Student–Newman–Keuls tests.

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 four grain-size categories, are compared in Figure 3. The grain-size categories (Folk 1968) are as follows: coarse sediment, retained on a +1-phi sieve; medium sand, passed through a +1-phi sieve but 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.

There were relatively small differences among stations in sediment grain-size distribution, especially in the proportion of the silt-and-clay fraction (range: 2.7% to 6.2%) and the medium- sand fraction (range: 22.9% to 33.9%) (Appendix Table A.3, Figure 3). The coarse-sediment fraction was higher at Stations HB1, HB2, and HB7 (range: 29.7% to 36.9%) than at the other stations (range: 15.8% to 29.1%). Conversely, the fine-sand fraction was lower at Stations HB1, HB2, and HB7 (range: 34.1% to 36.3%) than at the other stations (range: 38.3% to 49.4%). This spatial pattern of grain-size distribution is similar to those seen in 1997 (Nelson et al. 1997a), 1998 (Swartz et al. 1998), 1999 (Swartz et al. 1999), and 2000 (Swartz et al. 2000b), although sediments at Station HB2 were less coarse in 1997 and 1998 than in 1999, 2000, and 2001. Results of replicate sediment sample analysis for all seven stations indicated substantial homogeneity in grain size within stations, with the possible exception of replicate 3 at Station HB4, which contained coarser sediment than the other replicates at that station (Appendix Table A.3). Analysis of duplicate samples at Stations HB3, HZ and HB6 indicated consistency of analytical techniques.

Direct electrode measurements of ORP ranged from +120 to +215 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 there were significant differences among the seven stations ($F = 16.32, p = 0.0001$). ORP was significantly higher at Stations HZ, HB4, and HB6 than at Stations HB1, HB2, and HB3; significantly higher at Station HB7 than at Stations HB1 and HB2; and significantly higher at

Station HB3 than at Station HB1. ORP measurements obtained for the 2001 survey were higher at all stations than those obtained for the 1999 (Swartz et al. 1999) and 2000 (Swartz et al. 2000b) surveys.

Oil and grease measurements ranged from 84 to 911 mg/wet kg (Appendix Table A.2).Comparison of mean O&G per station (one-way ANOVA) showed there were no significant differences among the seven stations (F = 2.40, $p = 0.08$). The highest mean O&G measurement was recorded for reference station HB7.

Total organic carbon in the sediments was less than 0.20% in all samples (Appendix Table A.2). Comparison of mean TOC per station (one-way ANOVA) showed there were no significant differences among the seven stations (F = 1.41, $p = 0.28$). Although TOC measurements were low in all 2001 samples, none was below the detection limit of 0.01%. TOC in many samples collected in the 1997, 1998, 1999, and 2000 surveys was reported as below the detection limit (Nelson et al. 1997a; Swartz et al. reports).

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, nematodes, platyhelminths, echinoderms, a poriferan, an anthozoan, hydrozoans, kinorhynchs, a chaetognath, a hemichordate, nemerteans, sipunculans, insects, priapulids, a phoronid species, a chordate species, mites, a pycnogonid species, copepods, ostracods, cumaceans, mysids, tanaids, amphipods, isopods, and decapods.

The 8,818 nonmollusk specimens counted and identified for all stations and replicates represent 186 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (4,050 individuals, 45.9%) and taxa richness (116 taxa, 62.4%). Nematodes comprised the second most dominant nonmollusk taxon in terms of abundance (1,834 individuals, 20.8%). Crustaceans constituted 12.7% (1,122 individuals) of numerical abundance, oligochaetes contributed 9.1% (803 individuals), and sipunculans contributed 6.0% (528 individuals). The 51 crustacean taxa, 18 of which were amphipods, represented 27.4% of the total number of nonmollusk taxa. Abundance estimates for each taxon from each replicate are given for each of the seven stations 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 taxa). Except for nonmollusk taxa number at Station HB1, data were normal for all stations (Appendix Table B.2).

Mean total nonmollusk abundance ranged from 181.6 individuals per sample ($40{,}031/m^2$, at Station HB1) to 399.6 individuals per sample ($88{,}086/m^2$, at Station HB4) (Figure 4). Variances were homogeneous (Appendix Table B.3). According to the ANOVA on untransformed data, there were significant differences in mean abundance among stations (Appendix Table B.3). Mean abundance was significantly higher at Station HB4 than at all other stations except Station HZ. No other pairwise comparisons of means were significantly different.

Mean number of nonmollusk taxa per sample ranged from 29.0 (at Station HB3) to 45.0 (at Station HB1) (Figure 5). Variances were homogeneous (Appendix Table B.4). According to the ANOVA on untransformed data, there were significant differences in mean number of nonmollusk taxa among stations (Appendix Table B.4). Mean number of nonmollusk taxa was significantly less at Station HB3 than at Stations HB1, HB2, HB6, and HB7. No other pairwise comparisons of means were significantly different.

Composite station diversity (H') and evenness (J) for the nonmollusks are shown in Figure 6. Values for both parameters were similar for all stations. Values for diversity ranged from 2.62 (at Station HB3) to 3.44 (at Station HB1). The range of values was similar to that of samples collected in 1999 and 2000 but slightly higher than that of samples taken in years prior to 1999 (Nelson et al. reports; Swartz et al. reports). Evenness ranged from 0.63 (at Station HB3) to 0.74 (at Stations HB1 and HB6), which was also slightly higher than the range of values observed in years prior to 1999 (Nelson et al. reports; Swartz et al. 1998). Diversity and evenness were slightly lower at ZID station HZ and ZID-boundary stations HB2 and HB4 than at the three reference stations (HB1, HB6, and HB7). The depression in diversity and evenness was more pronounced at ZID-boundary station HB3.

The results of cluster analysis indicating the relative similarity of stations based on the 100 most abundant nonmollusk taxa are shown in Figure 7. All stations were grouped at similarity values greater than 66.0%, indicating similar taxa composition and abundance among all stations. There was some sorting among stations with regard to proximity to the diffuser. Reference stations HB1 and HB7 clustered together. However, reference station HB6 clustered closely with ZID station HZ and ZID-boundary station HB2.

Polychaetes

A total of 4,050 polychaetes representing 116 taxa were collected; they comprised 45.9% of total nonmollusk abundance. Polychaete abundance and taxa richness were higher in 2001 than in most recent years: 2,685 polychaetes representing 90 taxa in 1994 (Nelson et al. 1994b), 2,527 polychaetes representing 87 taxa in 1995 (Nelson et al. 1995), 3,836 polychaetes representing 95 taxa in 1996 (Nelson et al. 1996), 2,811 polychaetes representing 93 taxa in 1997 (Nelson et al. 1997a), 3,521 polychaetes representing 85 taxa in 1998 (Swartz et al. 1998), 4,261 polychaetes representing 113 taxa in 1999 (Swartz et al. 1999), and 3,489 polychaetes representing 109 taxa in 2000 (Swartz et al. 2000b). The highest mean number of polychaetes per sample was found at Station HB4 (231.2 individuals), followed in decreasing order of abundance by Stations HB2 (127.0 individuals), HZ

(124.6 individuals), HB7 (97.6 individuals), HB6 (92.8 individuals), and HB1 and HB3 (both with 68.4 individuals) (Figure 8). Polychaetes were the most taxa-rich group at all stations (Appendix Tables D.1 through D.7). Maximum mean number of polychaete taxa per sample occurred at Station HB4 (31.6 taxa), followed in decreasing order by Stations HB2 (27.2 taxa), HB6 (25.4 taxa), HZ and HB1 (both with 24.2 taxa), HB7 (21.8 taxa), and HB3 (17.4 taxa) (Figure 9).

Polychaetes accounted for 9 of the 12 taxa that ranked among the five most abundant taxa at individual stations (Table 1). Six taxa represented 54% of the polychaete individuals collected at the Barbers Point Ocean Outfall this year: *Pionosyllis heterocirrata* (14%), *Prionospio cirrobranchiata* (10%), *Polydora normalis* (10%), *Synelmis acuminata* (9%), *Euchone* sp. B (6%), and *Myriochele oculata* (5%). Dominant polychaete taxa differed at several stations. *Pionosyllis heterocirrata* was dominant at Stations HZ (17%) and HB3 (23%). This syllid species has dominated at Station HB3 since 1997. In 1999, 2000, and 2001, *Synelmis acuminata* replaced *P. heterocirrata* as the dominant polychaete at Station HB7. Although *S. acuminata* was the most dominant polychaete species only at Station HB7 (24%), this pilargid also appeared as an abundant species at all other stations.

Synelmis acuminata, *Pionosyllis heterocirrata*, and *Prionospio cirrobranchiata* replaced the sabellid *Euchone* sp. B as the most dominant polychaete species at Station HB1 in 1999, 2000, and 2001, respectively. At that station *Euchone* sp. B substantially decreased in abundance from 42% in 1998 to 1% in 1999, 2000, and 2001. However, at Station HB2 this sabellid was the most abundant species this year (36%), as has been the case since 1993. In addition to its dominance at Station HB1, *Prionospio cirrobranchiata* replaced the oweniid *Myriochele oculata* as the most numerous polychaete at Station HB6 (16%). *Myriochele oculata* ranked among the five most dominant species at Stations HZ (9%) and HB6 (13%), but it was not the most abundant polychaete at any station in 2001. The spionid *Polydora normalis*, which has been an abundant species at Stations HZ and HB4 since 1993, represented the most abundant species at Station HB4 (30%) in 2001. In fact, the high occurrence of this spionid shifted from being primarily at Station HZ (1993 through 1998) to being Station HB4 (1999 through 2001).

Ophryotrocha adherens (formerly *Ophryotrocha* sp. A) is of particular interest as it has been cited as an indicator of organic enrichment (Bailey–Brock 1996). It was abundant at ZID-boundary station HB4 (5%) and ZID station HZ (7%). After an initial spike in abundance of 17% at Station HB4 in 1996, *O. adherens* returned to a lower level (<1%) for the next two years and then increased again in 1999, 2000, and 2001. This species has also increased in abundance at ZID-boundary station HB3 (from 0% in 1997 to 4% this year) and ZID station HZ (from 0% in 1997 to 7% this year). The other indicator of organic enrichment, *Neanthes arenaceodentata*, was rare at Barbers Point and other outfalls off Oʻahu in 2001.

Individuals of the families Syllidae, Serpulidae, and Nereididae were represented by reproducing individuals this year. Stations HB4 and HZ had the most as well as the widest variety of species reproducing. The syllids *Sphaerosyllis* sp. G (at Stations HB4 and HZ), *Sphaerosyllis riseri* (at Stations HB4 and HB7), *Pionosyllis spinisetosa* and *Brania rhopalophora* (at Station HB4), *Exogone longicornis* (at Stations HB1, HB4, and HB6), and *Exogone* sp. C (at Station HB3) had embryos or juveniles attached to the external body wall. Many syllids reproduce by epitoky, which is a complex form of reproduction involving the production of buds (stolons or epitokes) from the external body wall (Schroeder and Hermans 1975). *Langerhansia cornuta* (at Stations HB1 and HB3), *Pionosyllis heterocirrata* (at Station HZ), and the nereidid *Neanthes arenaceodentata* (at Station HB4) showed characteristics of a swimming stage. These characteristics include enlarged eyes and elongated capillary setae that facilitate spawning in the water column (Schroeder and Hermans 1975). The serpulid *Salmacina dysteri* (at Stations HZ and HB6) had reproduced by schizoparity. No reproducing individuals were seen at Station HB2.

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

1. Detritivores. Of the four trophic categories, deposit-feeding polychaetes were the most abundant group at Stations HB1 (39% of all polychaete individuals), HB3 (42%), HB4 (57%), HZ (48%), and HB6 (43%) and the most speciose group at all seven stations. The percentage of all polychaete taxa represented by detritivores ranged from 33% (at Station HB1) to 50% (at Station HZ). The number of detritivorous taxa ranged from 17 (at Station HB3) to 30 (at Station HZ). The dominant deposit-feeding polychaetes were the spionids *Polydora normalis* (30% at Station HB4) and *Prionospio cirrobranchiata* (14% at both Stations HB1 and HB6).

2. Omnivores. The highest number of omnivorous worms was collected at Station HB4, where they accounted for 26% of all polychaetes (297 individuals). Omnivores were the most abundant trophic group only at Station HB7 (50%, 242 individuals), where they have been

dominant since 1986 (Nelson et al. reports; Swartz et al. reports). Omnivorous worms were never the least abundant group of the four trophic categories at any station. The percentage of all polychaete taxa represented by omnivores ranged from 17% (at both Stations HB2 and HZ) to 30% (at Station HB4). The number of omnivorous taxa ranged from 10 (at Station HZ) to 17 (at Station HB4). *Pionosyllis heterocirrata* was the dominant omnivore at five stations: HB1 (12% of all polychaetes), HB2 (11%), HB3 (23%), HB4 (11%), and HZ (17%). *Synelmis acuminata* was the dominant omnivore at Stations HB6 (11%) and HB7 (24%).

3. Suspension feeders. Suspension feeders were dominant at Station HB2 (41% of all polychaetes, 260 individuals), primarily due to the large numbers of the sabellid *Euchone* sp. B (36%, 228 individuals). This polychaete taxa was dominant at Station HB6 (17%, 95 individuals) in 2000, but it ranked sixth in abundance among polychaetes at that station in 2001 (5%, 23 individuals). *Euchone* sp. B was rare at Station HB1 in 1999 through 2001, after being the most dominant polychaete at that station from 1996 to 1998. Another sabellid, *Augeneriella dubia*, was the dominant suspension feeder at Stations HB1 (2%), HB3 (13%), and HB4 (9%). The serpulid *Salmacina dysteri* was dominant at Stations HZ (4%) and HB6 (7%) and the spionid *Aonides* sp. A at Station HB7 (1%). Of the four trophic categories, suspension feeders were the least abundant group at Stations HB1 (10% of all polychaetes, 34 individuals), HZ (9%, 56 individuals), and HB7 (3%, 14 individuals). The percentage of all polychaete taxa represented by suspension feeders ranged from 11% (at Station HB7) to 23% (at Station HB2). Of the four trophic categories, suspension feeders were the least speciose group at Stations HB1 (19% of polychaete taxa), HB3 (12%), HB4 (14%, tied with carnivores), HZ (13%), and HB7 (11%). The number of suspension-feeding taxa ranged from 5 (at Station HB3) to 15 (at Station HB2).

4. Carnivores. Carnivorous polychaetes were present at all stations, with their greatest abundance occurring at Station HB7 (18% of all polychaetes, 88 individuals). Carnivores were least abundant at four stations: HB2 (6% of all polychaetes, 35 individuals), HB3 (7%, 24 individuals), HB4 (6%, 72 individuals), and HB6 (10%, 47 individuals). The percentage of all polychaete taxa represented by carnivores ranged from 14% (at Station HB4) to 28% (at Station HB7). The number of taxa ranged from 7 (at Station HB3) to 15 (at Station HB7). The hesionid *Podarke angustifrons* was the dominant carnivore at six stations: HB2 (2%), HB3 (4%), HB4 (3%), HZ (6%), HB6 (5%), and HB7 (6%). Another hesionid, *Micropodarke* sp. A, dominated at Station HB1 (4%).

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

1. Tubicolous polychaetes. Of the three motility categories, tubicolous polychaetes were the most abundant group at Station HB2 (47% of all polychaetes, 298 individuals), the

second most abundant group at Station HB6 (36%, 169 individuals), and the least abundant at the other five stations. This group had the fewest taxa at all stations, although they tied with discretely motile polychaetes as the least speciose group at Stations HB1 (20% of taxa) and HB2 (27%). The number of taxa ranged from 6 (at Station HB3) to 18 (at Station HB2). The dominant tubicolous polychaete taxa included the sabellid *Euchone* sp. B at Station HB2 (36%); the oweniid *Myriochele oculata* at Stations HB1 (5%), HZ (9%), HB6 (13%), and HB7 (3%); and the sabellid *Augeneriella dubia* at Stations HB3 (13%) and HB4 (9%). *Salmacina dysteri* was another abundant tubicolous species at Station HB6 (7%).

2. Motile polychaetes. Of the three motility categories, motile polychaetes were the most abundant group at Stations HB1 (53% of all polychaetes, 181 individuals), HB3 (49%, 168 individuals), HB4 (46%, 529 individuals), HZ (51%, 318 individuals), HB6 (37%, 170 individuals), and HB7 (68%, 333 individuals). In addition, they had the highest percentage of polychaete taxa at each of the seven stations, ranging from 45% (at Station HB2) to 61% (at Station HB7). The number of motile polychaete taxa ranged from 27 (at Station HB6) to 33 (at Stations HB4, HZ, and HB7). The syllid *Pionosyllis heterocirrata* was the dominant motile polychaete at Stations HB1 (12%), HB2 (11%), HB3 (23%), HB4 (11%), and HZ (17%). This syllid also showed high levels of abundance at Stations HB6 (8%) and HB7 (19%). *Synelmis acuminata*, a pilargid, was the dominant motile polychaete at Stations HB6 (11%) and HB7 (24%); it also showed high levels of abundance at Stations HB1 (11%), HB2 (7%), and HB3 (7%). *Podarke angustifrons* at Station HB7 (6%) and *Ophryotrocha adherens* at Stations HB4 (5%) and HZ (7%) were also abundant motile polychaetes this year.

3. Discretely motile polychaetes. Of the three motility categories, discretely motile polychaetes were least abundant group at Stations HB2 (22% of all polychaetes, 137 individuals) and HB6 (27%, 125 individuals). They ranked second in abundance at the other five stations. This group ranked second in percentage of polychaete taxa at Stations HB3 (29%), HB4 (28%), HZ (30%), H6 (29%), and HB7 (26%) and tied with tubicolous polychaetes for third at Stations HB1 (20%) and HB2 (27%). The number of taxa ranged from 11 (at Station HB1) to 18 (at Stations HB2 and HZ). The dominant discretely motile species were all spionids: *Prionospio cirrobranchiata* at Stations HB1 (14% of all polychaetes), HB2 (9%), HB3 (20%), HZ (15%), HB6 (14%), and HB7 (11%); and *Polydora normalis* at Station HB4 (30%). Another abundant discretely motile spionid polychaete was *Prionospio cirrifera* at Stations HB1 (8%), HB2 (5%), HB3 (2%), and HB7 (9%).

Crustaceans

A total of 1,122 crustaceans, mites, and pycnogonids—representing 12.7% of the nonmollusk abundance—were collected. Abundance for each taxon from each replicate is provided for each station in Appendix Tables D.8 through D.14. Mean abundance (no./sample) ranged from 17.6 (3,880/m^2, at Station HB4) to 60.6 (13,358/m^2, at Station HZ) (Figure 14). Variances were homogeneous for untransformed data (Appendix Table B.5). There were significant differences in mean abundance among the seven stations (ANOVA, Appendix Table B.5). Mean number of crustacean individuals in 2001 was significantly greater at Station HZ than at all other stations. In contrast, crustacean abundance in 2000 was less at Station HZ than at all other stations.

A total of 51 crustacean, mite, and pycnogonid taxa (copepods were not identified to the species level) were collected; of these, 18 taxa (35.3%) were amphipods. Mean number of taxa ranged from 5.0 (at Station HB4) to 14.2 (at Station HB1) (Figure 15). Variances were homogeneous, and data were normally distributed. ANOVA indicated significant differences in mean number of taxa among the seven stations (Appendix Table B.6). The mean number of crustacean taxa was significantly less at Stations HB3 and HB4 than at Stations HB1, HB6, HB7, and HZ.

Amphipods, tanaids, and copepods were the numerically dominant taxa, making up 38.7%, 28.0%, and 19.8%, respectively, of total crustacean, mite, and pycnogonid abundance. No taxon was uniformly most abundant at all stations. Copepods, the amphipod *Eriopisella sechellensis*, and the tanaids *Tanaissus* sp. A and *Leptochelia dubia* were present at all stations and were generally among the most abundant crustaceans. The amphipod *Konatopus paao* was the only other crustacean that was collected at all stations. *Eriopisella sechellensis* and *Tanaissus* sp. A were the only crustaceans that ranked among the five most abundant nonmollusk taxa at any station: *E. sechellensis* was the second most abundant nonmollusk at Station HB1 and third most abundant at Station HB6; *Tanaissus* sp. A ranked fourth in abundance at Station HZ (Table 1).

Crustacean, mite, and pycnogonid abundance (1,122 individuals) and taxa number (51) were substantially greater than numbers counted in 2000 (600 individuals, 39 taxa) and comparable to the then record numbers counted in 1999 (1,377 individuals, 49 taxa). The 2001 count of 51 taxa is a new record for the Barbers Point outfall study area. Abundance and taxa richness in 1999 and 2001 equaled or exceeded the maximum values observed in collection years prior to 1999 (range for 1986 and for 1990 through 1998 collections: 164 to 1,121 individuals [mean = 653], 34 to 49 taxa [mean = 39.6]). A low count of 27 is excluded from the range for taxa richness because of procedural differences in 1997 (Nelson et al. 1997a).

The ranges for total number of crustacean individuals and taxa collected at the ZID-boundary stations (88 to 106 individuals; 12 to 19 taxa; Stations HB2, HB3, and HB4) were below the ranges observed at the reference stations (152 to 201 individuals; 20 to 36 taxa; Stations HB1, HB6, and HB7). However, unusually high numbers of taxa (28) and individuals (303) were collected at ZID station HZ. These number contrast with those of the previous year, when only 12 crustacean taxa and 42 individuals were collected at Station HZ. Despite the rich and abundant crustacean fauna at the ZID station in 2001, the monitoring data suggest a pattern of crustacean depression near the ZID.

One amphipod, *Lysianassa ewa*, and one crab, tentatively identified as *Nucia* (?) sp. A, were newly collected at the Barbers Point monitoring site this year. Lysianassids are known to be scavengers and predators of smaller invertebrates, so relatively small populations and sporadic collections of this taxa are not unexpected. Previously, *L. ewa* had been collected from the Mokapu outfall study area but not from either the Waianae or Sand Island outfall study areas. The small crab identified as *Nucia* (?) sp. A had also been previously collected at other outfall study areas. Larger (2 cm and up) shrimps and crabs have very low probabilities of being collected, given the small areal coverage (7.6 cm diameter) of the sampling replicates. The collection of a new decapod in 2001 is, therefore, not unexpected.

This brings the total number of discretely identified/reported taxa from the study area since 1990 to 107. The gammarid amphipod previously listed separately as *Anamixis stebbingi* and *Leucothoides ? pottsi* has been combined and is now listed as *Anamixis torrida*. This change in identification reduces this year's cumulative taxa by one, such that the increase of the two new taxa over last year's cumulative number of 106 is reported not as 108 but as 107. The true number of individual crustacean taxa present in the study area is actually higher. Copepods are enumerated as a single taxon, although several different taxa are certainly present. Cumaceans and mysids are similarly enumerated. Between two and eight taxa have been newly collected each year since 1990 and 1991 when a total of 62 taxa were collected. The spike of eight new taxa seen in 1999 was not repeated in 2000 or 2001, suggesting that anomaly probably represented a particularly efficient year in terms of collection, sample processing, and recovery, rather than a shift in the composition of the overall crustacean community. The Barbers Point outfall study area does not appear to be subject to extremely large swings in benthic community composition or consistency. It seems to be generally a rather stable environment. This should aid in identifying any impacts associated with the outfall itself.

Mollusks

A total of 10,419 mollusks representing 129 taxa were collected. Mean abundance of mollusks per sample (no./10 cm^3) ranged from 189.2 (at Station HB6) to 529.8 (at Station HB1) (Figure 16). Data were normally distributed at all stations (Appendix Table C.1). Complete basic statistics for total mollusk abundance data are shown in Appendix Table C.1.

Mean number of mollusk taxa per sample ranged from 24.6 (at Station HB6) to 38.8 (at Station HB1) (Figure 17). Data were normally distributed at all stations (Appendix Table C.2). Complete basic statistics for number of mollusk taxa at all stations are shown in Appendix Table C.2.

Variances were homogeneous for untransformed mollusk abundance data (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. Mean abundance was also significantly greater at Station HB2 than at Stations HB6, HZ, HB3, HB7, and HB4 and significantly greater at Stations HB4 and HB7 than at Station HB6.

Variances for number of mollusk taxa data were homogeneous (Appendix Table C.4). There were significant differences in mean mollusk taxa number among stations (ANOVA, Appendix Table C.4). Mean number of mollusk taxa was significantly greater at Station HB1 than at Stations HB6, HZ, HB4, HB2, and HB3 and significantly greater at Station HB7 than at Stations HB6 and HZ.

Diversity (H') ranged from 2.11 (at Station HB2) to 2.84 (at Station HB7) (Figure 18). Evenness (J) ranged from 0.53 (at Station HB2) to 0.69 (at Station HB7). Diversity values for mollusks were relatively high at Station HB7 and relatively low at Station HB2. Evenness values were generally similar for all stations (Figure 18).

The mollusk abundance patterns are consistent with those of all previous sampling years (Nelson et al. reports; Swartz et al. reports). Mollusk abundance for each taxon from each replicate is provided for each station in Appendix E. The molluscan fauna was very similar at all stations, especially among the dominant taxa (Table 2). The gastropod taxa *Diala scopulorum*, *Cerithidium perparvulum*, *Diala semistriata*, and *Balcis* spp. were abundant at all stations. *Finella pupoides* was abundant at all stations except Stations HB1, HB2, and HB7. *Scaliola* spp. was most abundant at stations where *Finella pupoides* was least abundant. *Cerithium* spp. was most abundant at Stations HB1 and HB7. These seven dominant mollusk taxa accounted for 79.0% of all individuals collected.

The results of cluster analysis indicating the relative similarity of the molluscan assemblage at the seven stations are shown in Figure 19. The analysis indicated that all stations were very similar to one another (similarity index for final cluster: 67.7%). The dendrogram shows a main cluster of four stations with very high similarity (>77%). The cluster includes three ZID-boundary stations (HB2, HB3, and HB4) and one reference station (HB6). Reference stations HB1 and HB7 linked together but were not greatly different from the main cluster (73% similarity). ZID station HZ linked with the first two clusters at a high similarity index value of 67.7%. A station cluster pattern similar to that shown in Figure 19 was also seen in 1998, 1999, and 2000 (Swartz et al. 2000a, 2000b), although the separation of Station HZ was more distinct in 2001.

The mollusk specimens collected in these surveys were not separated into living and dead shell material and therefore represent time-averaged collections that integrate conditions over a longer period. The living component of the mollusk fauna which is exposed to current discharge and effluent conditions may respond more quickly than is evident in the time-averaged collections. Thus, the evidence for high similarity of the mollusks among sampling stations may have been enhanced by the inclusion of empty shell counts in the cluster analysis.

DISCUSSION

In 2001 statistically significant differences among stations in mean total nonmollusk abundance and mean total number of nonmollusk taxa do not reflect an influence of the Barbers Point effluent discharge. Nonmollusk abundance was significantly greater at ZID-boundary station HB4 and quantitatively greater at ZID station HZ than at all of the reference stations (HB1, HB6, and HB7). Also, the number of nonmollusk taxa was quantitatively greater at ZID-boundary station HB4 and ZID station HZ than at reference stations HB6 and HB7. These results for the nonmollusks are similar to those obtained in most previous survey years for samples taken near the Barbers Point Ocean Outfall. The nonmollusks have generally been just as abundant and speciose at the stations near the outfall (HB2, HB3, HB4, and HZ) as at the reference stations (HB1, HB6, and HB7) (Nelson et al. reports; Swartz et al. reports).

The 2001 results for the crustaceans show mixed evidence of a trend for reduced crustacean abundance and taxa richness near the outfall. Crustacean abundance was significantly greater at ZID station HZ that at reference stations HB1, HB6, and HB7. The number of crustacean taxa was quantitatively greater at Station HZ than at Stations HB6 and HB7. However, there were quantitatively fewer individuals and statistically fewer taxa at ZID-boundary stations HB3 and HB4 than at reference stations HB1, HB6, and HB7. A depauperate crustacean fauna was evident at Stations HB3, HB4, and HZ in 2000 (Swartz et al. 2000b). Conditions improved greatly at ZID station HZ but not at ZID-boundary stations

HB3 and HB4 in 2001. Also, in 2001, several specimens of the stress-sensitive indicator species *Paraphoxus* sp. A were collected at ZID station HZ and ZID-boundary station HB2.

Statistical comparisons of mollusk abundance and taxa richness in 2001 also do not indicate spatial patterns that are consistently related to the outfall discharge. For example, reference station HB6 had the lowest mollusk abundance of all stations, while reference station HB1 had significantly higher mollusk abundance than all other stations. Also, mollusk abundance was significantly greater at ZID-boundary station HB2 than at reference stations HB6 and HB7. As in the case of abundance, mean mollusk taxa richness was lower at reference station HB6 and higher at reference station HB1 than at all other stations. Also, mollusk taxa richness was significantly greater at reference station HB1 than at reference station HB6, ZID station HZ, and ZID-boundary stations HB2, HB3, and HB4. Thus there was no general statistically significant pattern with regard to mollusk abundance or taxa richness and proximity to the diffuser. Also, there are annual fluctuations in the abundance of mollusks among stations. Mollusks were most abundant at Station HB1 in 1992, 1993, 1994, 1995, 1997, 1998, 2000, and 2001, but they were third in abundance in 1996 (behind Stations HB4 and HZ) and in 1999 (behind Stations HZ and HB7) (Nelson et al. reports; Swartz et al. reports).

Mean crustacean taxa richness per replicate may not be as useful as total taxa richness per station as an indicator of outfall effects, given the high intrastation variability encountered. The total number of crustacean taxa collected at ZID station HZ increased from 12 in 2000 to 28 in 2001, more than were collected at reference stations HB6 (20 taxa) and HB7 (25 taxa). Only 13 and 12 crustacean taxa were collected at ZID-boundary stations HB3 and HB4, respectively—substantially less than the minimum (19 taxa) found at the other five stations.

The increases in crustacean abundance and taxa richness between 2000 and 2001 were evident at most stations but were particularly dramatic at Station HZ. The average percent increase in mean crustacean abundance was 53% at reference stations HB1, HB6, and HB7; 48% at ZID-boundary stations HB2, HB3, and HB4; and 621% at ZID station HZ. The average percent increase in mean number of crustacean taxa was 40% at the reference stations, 10% at the ZID-boundary stations, and 174% at the ZID station.

Reductions in crustacean abundance and taxa richness near the Barbers Point Ocean Outfall relative to reference stations have not been observed in every previous sampling year. Although in some years (e.g., 1991, Nelson et al. 1992a) taxa richness appeared to be reduced adjacent to the outfall, this pattern had not been seen for several years until 1998. It was seen again in 2000 and, to a lesser extent, in 2001. In 1999 the crustacean community of the study area was more abundant and diverse than in 1998, 2000, 2001, and most other years. The shifting patterns of number of taxa and abundance from year to year appear to be more strongly influenced by other factors, such as small-scale differences in bottom topography or a subtle variation in sediment composition. The presence of eleven species of stress-sensitive gammaridean amphipods at the ZID and ZID-boundary stations also indicates that any changes in the crustacean assemblage near the outfall in 2001 are associated with factors other than chemical contamination by the effluent discharge.

Taxonomic diversity (expressed here simply as the number of discretely recorded taxa) is considered to be a better measure of the state of the crustacean communities at these sampling stations than the number of recorded individuals. For the smaller crustaceans (tanaids, isopods, and amphipods) and pycnogonids, abundance can be strongly influenced by a large number of juveniles released from brooding adults. Abundance data generated from other taxa (such as mollusks, most polychaetes, and many decapods) represent a settlement from the plankton of a larval form which has found the site suitable for habitation. While high crustacean abundance data (particularly if juveniles are being produced) clearly indicate that the site is suitable, low abundance data are not necessarily indicative of unsuitability.

A rather comprehensive picture of the crustacean communities in the study area has been developed (at least for crustaceans smaller than 1 cm) despite the rather small areal coverage (7.6 cm diameter) of the sampling replicates. This reef slope crustacean community remains dominated by the smaller crustacean groups (copepods, ostracods, tanaids, isopods, and amphipods), with scattered collections of small decapods. The number of new taxa recorded in 2001 (two) is lower than the average (about four) for each annual survey since 1991. Larger (2 cm and up) shrimp and crabs, while certainly present in the study area, have almost no chance of being collected. In general, the crustacean community in the Barbers Point outfall study area is less diverse than that near the Wai‘anae outfall and more diverse than that near the Sand Island outfall.

Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. Diversity and evenness values were lowest at Station HB3 for nonmollusks and at Station HB2 for mollusks. Lower nonmollusk diversity and evenness values were reported for Station HB2 in 1993, but this pattern has not been repeated since (Nelson et al. 1994a, 1994b, 1995, 1996, 1997a; Swartz et al. reports). There is little evidence that the outfall is having an effect on taxa richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis similarity index indicated that nonmollusk abundance and taxa composition were broadly similar at most stations (>66% similarity index value). The three most similar stations were from the ZID (Station HZ), ZID-boundary (Station HB2), and reference (Station HB6) areas. These stations were also clustered together in 1999 and 2000 (Swartz et al. 1999, 2000a). In the period from 1986 to 1993, cluster analysis consistently intermixed ZID, ZID-boundary, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). In 1994 and 1995, some separation between stations in or near the ZID and far-field reference stations was observed (Nelson et al. 1994b, 1995). In 1996 (Nelson et al. 1996), 1997 (Nelson et al. 1997a), 1998 (Swartz et al. 1998), 1999 (Swartz et al. 1999), and 2000 (Swartz et al. 2000a) stations were again generally interspersed in the cluster analysis. The clustering of far-field reference stations HB1 and HB7 in 2001 indicates some separation between near-ZID and far-field stations, but the clustering of near-field reference station HB6 with the ZID and ZID-boundary stations suggests the nonmollusk fauna near the ZID is not greatly different from the reference assemblage. In comparing the 1996 through 2001 cluster results with those of earlier years, some caution is necessary since the clustering algorithm was changed in 1996 from flexible to group-average sorting in order to conform to current recommendations for optimum methodologies (Carr 1993).

Sediment grain sizes in the 2001 samples were broadly similar among stations. Sand accounted for >93% of the sediment weight at all stations. The coarse-sediment fraction was moderately higher at Stations HB1, HB2, and HB7 (range: 29.7% to 36.9%) than at the other stations (range: 15.8% to 29.1%). Conversely, the fine-sand fraction was moderately lower at Stations HB1, HB2, and HB7 (range: 34.1% to 36.3%) than at the other stations (range: 38.3% to 49.4%). The percentage of fine sediments at ZID station HZ was less in 2001 (3.7%) than in 2000 (4.0%), but greater than in 1997 (3.2%), 1998 (3.0%), and 1999 (2.8%) (Nelson et al. 1997a; Swartz et al. reports), although these differences are probably of no ecological significance. The increase in the silt-and-clay fraction of the sediments observed in 1993 for all stations began to moderate in 1996, and this trend continued in 1997, 1998, and 1999 (for comparison see figure 3 in Nelson et al. 1992b, 1994a, 1994b, 1995, 1996, 1997a and in Swartz et al. reports). The mean percentage of the silt-and-clay fraction in 2001 (4.2%) and 2000 (4.2%, Swartz et al. 2000b) is less than that observed in 1997 (4.8%, Nelson et al. 1997a) and 1998 (4.9%, Swartz et al. 1998) but slightly more than that observed in 1999 (4.1%, Swartz et al. 1999). The increase in fine sediments in 1993 occurred at all seven stations, thus it is unlikely to have been an effect of the outfall discharge.

ORP analysis showed no evidence of reducing conditions at the surface of sediments at any station in 2001; this has been the consistent pattern for this parameter. ORP measurements were highest at ZID station HZ. They were significantly lower at reference station HB1 than at Stations HZ, HB4, HB6, HB7, and HB3; significantly lower at ZID-boundary station HB2 than at Stations HZ, HB4, HB6, and HB7; and significantly lower at ZID-boundary station HB3 than at Stations HZ, HB4, and HB6. Station ORP values were higher at all stations in 2001 than in 1999 and 2000.

There were no significant differences among stations in mean O&G measurements. The highest mean O&G measurement (589 mg/wet kg) was recorded at reference station HB7. O&G measurements have varied substantially between years. The maximum mean O&G measurements were 258 mg/wet kg and 148 mg/wet kg in 1997 and 1998, respectively, and there were no significant differences among stations in either of those years (Nelson et al. 1997a; Swartz et al. 1998). The maximum mean O&G measurement in 1999 (758 mg/wet kg at ZID-boundary station HB2) was significantly greater than at all other stations (Swartz et al. 1999). O&G was not analyzed in 2000.

Sediment TOC was 0.19% or less in all replicate samples in 2001. Thus there continues to be no evidence of sediment organic enrichment near the outfall. The absence of detectable sediment TOC was reported for all samples collected in 1996 and 1997 and for many samples in 1998, 1999, and 2000. The analytical laboratory used for TOC analyses after 1995 removes all traces of the organic carbon from the sediment during acid digestion to remove inorganic carbon. TOC values in years prior to 1996 were low, but above detection limits. Analytical methods used from 1996 through 2000 may have consistently underestimated sediment TOC (Nelson et al. 1997b; Swartz et al. reports). This problem appears to have been resolved because there were no below detection limit TOC measurements recorded in 2001.

The total number of nonmollusk taxa recorded in 2001 (186) is the highest value recorded in the thirteen years of monitoring at the Barbers Point Ocean Outfall (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, 144 in 1993, 159 in 1994, 151 in 1995, 147 in 1996, 138 in 1997, 140 in 1998, 183 in 1999, and 164 in 2000). The 51 crustacean, mite, and pycnogonid taxa collected in 2001 was also greater than all values observed in earlier years, when counts ranged from 34 to 49 taxa. That range does not include the low value of 27 taxa collected in 1997, when counts were reduced because of differences in sample handling. 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 2001.

Mean nonmollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2001 (Figures 20 and 21). Two-way ANOVA results showed significant differences both among sampling dates ($p <$ 0.0001) and among sampling stations ($p < 0.0001$). Numerous pairwise comparisons among dates showed significant differences, generally with values for recent dates being higher than values for earlier dates. The abundance of nonmollusks in 2001 was quantitatively, but not significantly, greater than that in 2000 and significantly greater than that observed in 1986, 1990, and 1991. This temporal pattern of increasing nonmollusk abundance was confirmed by a linear regression analysis of data from 1990 to 2001, which found a trend of significantly increasing mean abundance over this period ($p = 0.0002$, $y = 14.7x - 35.6$, where y = mean nonmollusk abundance and x = year code: 1990 = 10 through 2001 = 21). The slightly lower mean nonmollusk abundance in 1997 versus 1996 and 1998 through 2001 is partly explained by the processing differences for the crustaceans during 1997.

The Student–Newman–Keuls test showed only three significant pairwise multiple contrasts among stations for mean nonmollusk abundance based on data collected in 1986 and from 1990 through 2001. Nonmollusk abundance for the thirteen combined surveys was greater at ZID-boundary station HB4 than at ZID-boundary station HB3 and reference stations HB1 and HB7.

Mean nonmollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2001 (Figures 22 and 23). Two-way ANOVA results showed significant differences among sampling dates ($p < 0.0001$) but not among sampling stations ($p = 0.07$). Mean nonmollusk taxa richness was significantly lower in 1990 than in all other years and significantly lower in 1997 than in 1992, 1993, 1994, 1996, 1999, 2000, and 2001 (Figure 22). The low counts for 1997 are due to methodological problems that impacted the number of crustacean taxa collected. Mean nonmollusk taxa richness was also significantly lower in 1986 than in 1992, 1993, 1994, 1996, 1999, 2000, and 2001; significantly lower in 1991 than in 1994, 1999, and 2001; and significantly lower in 1998 than in 1999. Nonmollusk taxa richness was less in 2001 than in 1999, when it was quantitatively greater than in any previous year. No temporal trend comparable to that for abundance was seen for nonmollusk taxa richness, nor was any apparent spatial trend seen for this parameter in relation to proximity to the outfall.

Mean crustacean abundance was also compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2001 (Figures 24 and 25). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p = 0.0020$). Mean crustacean abundance in 2001 (32.1 individuals/sample) increased substantially, but not significantly, over the mean recorded in 2000 (17.1 individuals/ sample). Mean crustacean abundance in 1999 was quantitatively higher than in all other years and significantly higher than in all years except 1993, 1994, and 2001. Crustacean abundance in 1993, 1994, and 2001 was significantly higher than in 1990 and 1997. The decreased abundance in 1990 is consistent with the overall pattern of nonmollusk abundance for that year. Interannual variations in abundance are not related solely to differences in the time of year that samples were taken. The 1990, 1992, 1994 through 1998, and 2001 samples—all of which were taken in January or February—show considerable variation in mean crustacean abundance. When all data through 2001 were pooled for station comparisons, mean crustacean abundance was significantly greater at reference station HB6 than at ZID-boundary station HB3. The same result was obtained for the historic data set through 1997, 1999, and 2000 (Nelson et al. 1997a; Swartz et al. 1999, 2000b) but not through 1998 (Swartz et al. 1998).

Mean number of crustacean taxa was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2001 (Figures 26 and 27). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean crustacean taxa richness was significantly lower in 1990 than in all years except 1986 and 1997; significantly lower in 1997 than in 1993, 1994, 1999, and 2001; and significantly lower in 1986 than in 1994, 1999, and 2001. The low mean number of taxa counted in 1990 reflects the low total abundance of crustaceans collected that year. The reduction in crustacean taxa richness in 1997 was due to procedural differences in sample handling. The increase in the number of crustacean taxa collected in 1998 and 1999 reversed a temporal decline that was evident from 1994 through 1997 (Figure 26). The number of crustacean taxa collected in 2001 was quantitatively greater than that collected in all years except 1994. Student–Newman–Keuls tests showed that the mean number of crustacean taxa was significantly greater at reference station HB6 than at ZID-boundary station HB4. There is a historic pattern of reduced crustacean taxa richness at all ZID and ZID-boundary stations (Figure 27). In fact, the pooled data for all years show that all stations near the diffuser have fewer crustacean taxa than all reference stations. The overall pattern is consistent with an effect of the diffuser effluent on crustacean taxa. There was a major exception to the historic pattern of a diminished crustacean fauna at the ZID and ZID-boundary stations in 2001: more crustacean taxa were collected at ZID station HZ than at reference stations HB6 and HB7 and significantly more crustacean individuals were collected at Station HZ than at all other stations. Any impact the Barbers Point discharge may have on crustaceans was not consistent across the ZID in 2001.

Dominant taxa of the nonmollusk fauna were similar to those of previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that of previous sampling years. The polychaete *Pionosyllis heterocirrata* and the sipunculan *Aspidosiphon muelleri* were the most and second-most abundant taxa in 2001, respectively (Table 1). The dominant polychaete taxa since 1994 showed some variation from earlier sampling years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). Other dominant taxa in 2001 were similar to those found in 1994 through 2000 (Nelson et al. 1994b, 1995, 1996, 1997a; Swartz et al. reports) and included the polychaetes

Prionospio cirrobranchiata, *Polydora normalis*, *Synelmis acuminata*, *Euchone* sp. B, *Myriochele oculata*, *Prionospio cirrifera*, *Augeneriella dubia*, and *Ophryotrocha adherens*, as well as the amphipod *Eriopisella sechellensis* and the tanaid *Tanaissus* sp. A (Table 1).

Mean mollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2001 (Figures 28 and 29). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk abundance was significantly greater in 1998 and 2001 than in 1986, 1990, 1991, 1992, 1993, 1994, and 1995 and significantly greater in 2000 than in 1986, 1990, 1991, 1992, and 1993. Mean mollusk abundance was significantly greater at reference station HB1 than at all other stations. Neither the temporal nor spatial pattern of differences indicates a negative effect of the diffuser effluent on mollusk abundance.

Because the mollusk specimens were 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 was generally much less for the mollusk fraction than for the nonmollusk fraction prior to 1996. There has been a temporal trend of increasing mollusk abundance since 1993 (Figure 28). The pattern of abundance in the sampling area on all dates shows that Station HB1 has historically had the greatest number of mollusk individuals (Figure 29). Consistent with the historic pattern, Station HB1 had significantly higher mean mollusk abundance than all other stations in 2001 (Table C.3).

Mean mollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2001 (Figures 30 and 31). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk taxa richness was significantly greater in 1998 than in 1986, 1990, 1991, 1992, 1993, 1994, and 1995; significantly greater in 1996 and 2001 than in 1990, 1992, and 1993; significantly greater in 1997 than in 1986, 1990, 1992, 1993, 1994, and 1995; and significantly greater in 1999 and 2000 than in 1990 and 1992. Mean mollusk taxa richness was significantly greater at Stations HB1 and HB7 than at Station HB2 and HB6 and significantly greater at Station HB4 that at Station HB2. Ten of the twelve possible pairwise comparisons of mollusk taxa richness between reference stations (HB1, HB6, and HB7) and ZID or ZID-boundary stations (HB2, HB3, HB4, and HZ) were not statistically significant. There has been a temporal pattern of increasing number of mollusk taxa since 1992 (Figure 30). Neither the temporal nor spatial pattern of differences indicates a consistent negative effect of the diffuser effluent on mollusk taxa richness.

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show little evidence of a buildup of organic matter in the vicinity of the Barbers Point Ocean Outfall diffuser. High ORP measurements at all stations indicated the absence of reducing conditions. Sediment TOC was less than 0.20% in all samples in 2001 and was very low or undetectable from 1996 through 2000. In years prior to 1996, mean sediment TOC was in the narrow range of 0.04% to 0.47%, except in 1993 when methodological problems were experienced with the analyses and values ranged from 0.56% to 1.40%. The ocean outfall in Orange County, California, discharges onto the continental shelf in an erosional benthic environment (Maurer et al. 1993) which may be somewhat similar to that found in Māmala Bay, Oʻahu. In the vicinity of the Orange County outfall, sediment TOC ranged from approximately 0.3% to 0.9% (Maurer et al. 1993). In areas which possess more depositional benthic environments, the percentage of organic content in the sediments is typically much higher. For example, this percentage 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 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 near the Barbers Point Ocean Outfall suggests that little particulate matter from the diffuser ever reaches the sediment surface in the study area.

The spatial patterns of organism abundance and taxa richness in relation to the outfall varied depending on the taxonomic grouping. There were no consistent, statistically significant patterns of reductions of either organism abundance or taxa richness of nonmollusks and mollusks near the diffuser in 2001. The macrobenthos was much more similar than dissimilar among the seven sampling stations. Separate cluster analyses of nonmollusk and mollusk data indicated that all stations were similar to one another in terms of taxa composition and relative abundance (similarity >66% for nonmollusks, >67% for mollusks). The dominant mollusk taxa were almost identical at all stations. Only seven taxa are on the list of mollusks that rank among the five most abundant taxa at any one of the seven stations.

The abundance of nonmollusks and mollusks in the study area has increased in recent years. However, there is no consistent spatial pattern in the historic abundance or taxa richness of either nonmollusks or mollusks that indicates an effect of the outfall effluent. The respective numbers of nonmollusk and mollusk individuals and taxa collected in 2001 were all near the top of their historic range.

The abundance and taxa richness of crustaceans increased in 2001 from the low levels recorded in 2000, especially at ZID station HZ. The number of crustacean taxa collected in 2001 was the highest among the thirteen survey years. There is a historic pattern of reductions in crustacean abundance and taxa richness at the four ZID-area stations relative to each of the reference stations. This pattern may indicate a trend related to proximity to the diffuser. Relatively low values of crustacean abundance and taxa richness were recorded in 2001 at ZID-boundary stations HB2, HB3, and HB4. However, crustacean abundance at ZID station HZ was significantly higher than at all other stations, including the three reference stations. Also, mean crustacean taxa richness was greater at ZID station HZ than at reference stations HB6 and HB7. The presence of pollution-sensitive taxa like amphipods (especially the phoxocephalid *Paraphoxus* sp. A) indicates that the diminished crustacean fauna at the ZID and ZID-boundary stations may be related to a noncontaminant factor.

Taxa diversity (H') and evenness (J) were generally similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment by Pearson and Rosenberg (1978) proposes that in the transition zone on an enrichment gradient, a few taxa 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 indication of the types of changes in bottom communities predicted by the organic enrichment hypothesis. Maurer et al. (1993) proposed that the Pearson–Rosenberg model may be inappropriate for erosional continental shelf environments. Their study of an outfall on the continental shelf off California found that even with some organic enrichment near the diffuser, there was no evidence of elimination of rare species, even though three species did achieve numerical dominance. The response of the benthic community near the Barbers Point Ocean Outfall does not show the alternate response pattern described by Maurer et al. (1993), presumably because sediment organics there do not show even the moderate enrichment found near the Orange County outfall.

In conclusion, there is little evidence of adverse effects of the Barber Point Ocean Outfall on the macrobenthic community in 2001. The only indication of an effect lies in the crustacean component: there were fewer individuals and taxa at ZID-boundary stations HB2, HB3, and HB4 than at the reference stations. However, other analyses do not suggest an adverse effect of the outfall on crustaceans, especially the very abundant and taxa-rich crustacean assemblage at ZID station HZ. The presence of eleven amphipod species at the ZID and ZID-boundary stations indicates that alterations in the crustacean component may be related to a noncontaminant factor. The analyses of the noncrustacean fauna clearly demonstrate the presence of a diverse and abundant macrobenthos within and near the ZID of the Barber Point Ocean Outfall.

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TABLE 1. Abundance of Numerically Dominant Nonmollusk Taxa, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January 2001

Taxon	Number of Individuals							Total
	Station							
	HB1	HB2	HB3	HB4	HZ	HB6	HB7	
Pionosyllis heterocirrata	41*	71*	78*	129*	108*	37*	92*	556
Aspidosiphon muelleri	78*	50*	63*	83*	166*	37*	44*	521
Prionospio cirrobranchiata	49*	56*	69*	33	91*	65*	52*	415
Polydora normalis		6		343*	42			391
Synelmis acuminata	38*	46*	24*	31	37	51*	118*	345
Euchone sp. B	5*	228*		3		23		259
Myriochele oculata	16	27	19	28	53*	62*	13	218
Eriopisella sechellensis	53*	21	3	2	36	57*	30	202
Prionospio cirrifera	29	33	7	35	34	14	44*	196
Augeneriella dubia	7	3	45*	105*	19	14	2	195
Tanaissus sp. A	14	27	19	3	60*	22	4	149
Ophryotrocha adherens		1	15	59*	41	1		117

*Ranked among the five most abundant nonmollusk taxa at individual stations.

TABLE 2. Abundance of Numerically Dominant Mollusk Taxa, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January 2001

Taxon	Number of Individuals							Total
	Station							
	HB1	HB2	HB3	HB4	HZ	HB6	HB7	
Diala scopulorum	353*	571*	318*	292*	320*	171*	77*	2,102
Cerithidium perparvulum	740*	411*	110*	242*	84*	142*	330*	2,059
Diala semistriata	378*	137*	80*	159*	86*	95*	218*	1,153
Finella pupoides	2	19	342*	242*	252*	214*	2	1,073
Scaliola spp.	331*	327*	52	108	37	42	132*	1,029
Balcis spp.	139*	73*	67*	123*	97*	122*	70*	691
Cerithium spp.	41	1	4	7	1	1	70*	125

*Ranked among the five most abundant mollusk taxa at individual stations.

TABLE A.1. Position and Depth for Replicate Grab Samples, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2001

Station	Sampling Date	Replicate	Position		Depth (m)
			Latitude	Longitude	
HB1	13 January	1	21°16'50.5"	157°59'13.6"	62.5
		2	21°16'50.6"	157°59'13.6"	62.2
		3	21°16'50.5"	157°59'13.4"	62.2
		4	21°16'50.4"	157°59'13.3"	62.5
		5	21°16'50.4"	157°59'13.4"	62.2
HB2	13 January	1	21°16'59.9"	158°01'20.3"	61.3
		2	21°17'00.2"	158°01'20.0"	61.3
		3	21°17'00.2"	158°01'20.1"	61.3
		4	21°17'00.3"	158°01'20.2"	61.0
		5	21°17'00.1"	158°01'20.0"	61.3
HB3	13 January	1	21°16'53.5"	158°01'29.2"	66.4
		2	21°16'53.6"	158°01'29.0"	67.1
		3	21°16'53.6"	158°01'29.1"	66.8
		4	21°16'53.5"	158°01'29.1"	67.1
		5	21°16'53.6"	158°01'29.2"	66.4
HB4	14 January	1	21°16'48.0"	158°01'38.6"	60.7
		2	21°16'47.9"	158°01'38.4"	61.0
		3	21°16'47.8"	158°01'38.3"	61.0
		4	21°16'48.0"	158°01'38.4"	61.0
		5	21°16'47.9"	158°01'38.5"	61.0
HZ	15 January	1	21°16'53.5"	158°01'30.3"	63.7
		2	21°16'53.4"	158°01'30.4"	64.0
		3	21°16'53.5"	158°01'30.2"	63.7
		4	21°16'53.5"	158°01'30.5"	63.7
		5	21°16'53.5"	158°01'30.4"	63.7
HB6	14 January	1	21°16'32.3"	158°01'46.6"	62.2
		2	21°16'32.4"	158°01'46.7"	62.2
		3	21°16'32.4"	158°01'46.8"	61.9
		4	21°16'32.5"	158°01'46.6"	62.2
		5	21°16'32.3"	158°01'46.8"	61.9
HB7	14 January	1	21°15'33.0"	158°03'13.9"	63.4
		2	21°15'33.2"	158°03'13.9"	63.1
		3	21°15'33.0"	158°03'14.0"	63.1
		4	21°15'33.0"	158°03'13.8"	63.1
		5	21°15'32.9"	158°03'13.8"	63.4

SOURCE: Oceanographic Team, Department of Environmental Services, City and County of Honolulu.

TABLE A.2. Sediment Chemical Characterization of Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2001

Station (Replicate)	PD (cm)	ORP (+mV)	O&G (mg/wet kg)	TOC (% dry weight)
HB1 (1)	9.0	120	237	0.12
HB1 (2)	9.0	150	157	0.09
HB1 (3)	8.0	150	262	0.06
HB1 (4)	10.0	170		
HB1 (5)	11.0	165		
HB2 (1)	8.0	160	84	0.09
HB2 (2)	8.0	160	93	0.15
HB2 (3)	11.0	170	288	0.07
HB2 (4)	8.0	160		
HB2 (5)	7.0	165		
HB3 (1)	7.0	175		
HB3 (2)	10.0	165	378	0.14
HB3 (3)	8.0	185		
HB3 (4)	9.0	170	268	0.11
HB3 (5)	8.0	170	572	0.09
HB4 (1)	8.0	195	225	0.10
HB4 (2)	7.0	195		
HB4 (3)	8.0	195	477	0.10
HB4 (4)	9.0	205	414	0.10
HB4 (5)	9.0	205		
HZ (1)	8.0	205	464	0.12
HZ (2)	8.0	195	351	0.11
HZ (3)	7.0	200		
HZ (4)	8.0	215	283	0.13
HZ (5)	7.0	195		
HB6 (1)	8.0	210	216	0.08
HB6 (2)	8.0	200	194	0.08
HB6 (3)	8.0	200	211	0.10
HB6 (4)	8.0	190		
HB6 (5)	7.0	190		
HB7 (1)	10.0	170	657	0.12
HB7 (2)	8.0	195	200	0.19
HB7 (3)	8.0	200	911	0.11
HB7 (4)	7.0	170		
HB7 (5)	9.0	195		

SOURCE: PD (penetration depth), ORP (oxidation-reduction potential), and O&G (oil and grease) data from Oceanographic Team and Environmental Quality Laboratory, Department of Environmental Services, City and County of Honolulu; TOC (total organic carbon) data from Severn Trent Laboratories (Colchester, Vermont).

TABLE A.3. Sediment Grain-Size Analysis of Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2001

Station-Replicate	Sample Weight Distribution (%)							
	Phi Size							
	-2	-1	0	1	2	3	4	>4–12
HB1-1	0.50	2.10	10.63	19.40	21.55	25.58	12.40	5.78
HB1-2	1.00	4.38	12.55	21.58	22.76	23.43	8.18	4.17
HB1-3	0.30	3.02	12.59	22.71	24.31	24.65	7.94	3.76
HB2-1	0.28	0.95	4.61	17.90	25.63	26.11	15.76	6.47
HB2-2	0.11	2.37	7.40	20.68	26.62	22.53	12.82	6.41
HB2-3	0.53	2.68	9.49	22.10	24.30	20.09	11.68	5.71
HB3-2	0.36	0.70	3.37	12.52	32.52	39.75	7.91	2.49
HB3-2 (dup)	0.48	0.79	3.49	12.26	31.32	39.13	7.73	2.51
HB3-4	0.24	0.56	3.38	13.12	34.83	36.39	6.87	3.04
HB3-5	0.19	0.98	3.64	12.72	34.87	36.73	6.54	2.67
HB4-1	0.53	1.47	5.73	16.61	28.05	32.40	11.50	4.15
HB4-3	1.43	3.31	11.34	25.86	27.71	18.05	6.94	4.48
HB4-4	0.10	0.88	4.55	15.49	26.88	32.98	13.16	3.56
HZ-1	0.31	0.93	2.89	11.07	30.30	39.81	9.05	3.75
HZ-2	0.12	0.90	3.86	13.00	30.62	38.48	8.51	3.65
HZ-4	0.58	1.56	2.41	9.62	29.53	42.48	9.77	3.54
HZ-4 (dup)	0.54	0.74	2.82	10.04	29.57	42.24	9.96	3.61
HB6-1	0.16	1.46	6.20	14.14	25.29	37.78	9.05	3.66
HB6-1 (dup)	0.10	1.52	5.91	14.01	23.14	37.72	10.46	4.00
HB6-2	0.06	1.16	6.48	14.83	23.24	37.38	10.37	3.67
HB6-3	0.00	2.18	9.94	14.72	22.57	33.16	10.90	5.53
HB7-1	0.09	4.42	10.71	17.05	26.32	28.68	5.55	4.10
HB7-2	0.27	4.66	11.06	18.25	26.03	27.59	6.00	3.78
HB7-3	0.57	2.92	9.99	16.68	25.24	30.64	7.72	4.16

SOURCE: Environmental Quality Laboratory, Department of Environmental Services, City and County of Honolulu.

NOTE: The values listed indicate the fraction percentage of the estimated dry weight of the sediment samples. The coarse fraction (-2 to +4) was analyzed by the sieve method. The fine fraction (greater than +4 to +12) was analyzed by the pipette method.

TABLE B.1. Basic Statistics for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, January 2001
(Sample Size n = 5)

Statistic	Station						
	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	181.60	228.20	204.60	399.60	328.40	216.80	204.40
Standard Deviation	52.68	83.68	169.38	109.93	83.90	39.00	73.68
Standard Error of the Mean	23.56	37.42	75.75	49.16	37.52	17.44	32.95
95% of CI Mean	65.40	103.89	210.28	136.48	104.16	48.41	91.47
Skewness	-1.56	-0.47	0.64	1.13	1.42	0.37	-0.23
Kurtosis	2.36	-1.65	-1.27	1.21	2.60	-1.61	-2.91
Median	203.00	265.00	136.00	357.00	308.00	205.00	221.00
Normality Test (D)	0.258ns	0.270ns	0.257ns	0.251ns	0.278ns	0.219ns	0.250ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant.

TABLE B.2. Basic Statistics for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, January 2001
(Sample Size n = 5)

Statistic	Station						
	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	45.00	42.20	29.00	43.60	43.00	42.80	39.20
Standard Deviation	7.28	8.32	11.25	6.54	6.52	5.22	6.22
Standard Error of the Mean	3.26	3.72	5.03	2.93	2.92	2.33	2.78
95% of CI Mean	9.04	10.33	13.96	8.12	8.09	6.47	7.72
Skewness	-2.22	-0.64	-0.14	-0.42	-0.09	1.02	0.96
Kurtosis	4.93	-0.28	-2.44	1.22	-1.72	1.59	1.96
Median	48.00	41.00	31.00	44.00	44.00	41.00	38.00
Normality Test (D)	0.460*	0.226ns	0.213ns	0.203ns	0.178ns	0.235ns	0.249ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant, * = $p < 0.05$.

TABLE B.3. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2001

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	194,484.4	6	32,414.0	3.52	0.010
Experimental Error	258,161.6	28	9,220.1		
Total	452,646.0	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	181.60	228.20	204.60	399.60	328.40	216.80	204.40
Standard Deviation	52.68	83.68	169.38	109.93	83.90	39.00	73.68

F_{max} test for equal variance: Untransformed data, $F_{max} = 18.87$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean nonmollusk abundance between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB1	HB7	HB3	HB6	HB2	HZ	HB4
HB1		–	–	–	–	–	*
HB7			–	–	–	–	*
HB3				–	–	–	*
HB6					–	–	*
HB2						–	*
HZ							–

– = not significant; * = $p < 0.05$.

TABLE B.4. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2001

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	889.94	6	148.32	2.60	0.040
Experimental Error	1,599.60	28	57.13		
Total	2,489.54	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	45.00	42.20	29.00	43.60	43.00	42.80	39.20
Standard Deviation	7.28	8.32	11.25	6.54	6.52	5.22	6.22

F_{max} test for equal variance: Untransformed data, $F_{max} = 4.65$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean nonmollusk taxa number between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB3	HB7	HB2	HB6	HZ	HB4	HB1
HB3		*	*	*	–	–	*
HB7			–	–	–	–	–
HB2				–	–	–	–

HB6	–	–	–
HZ		–	–
HB4			–

– = not significant; * = $p < 0.05$.

TABLE B.5. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Crustacean Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2001

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	6,807.49	6	1,134.59	5.91	0.0004
Experimental Error	5,378.40	28	192.09		
Total	12,185.89	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	40.20	21.20	20.00	17.60	60.60	34.40	30.40
Standard Deviation	18.35	7.26	21.62	8.17	15.73	6.84	11.26

F_{max} test for equal variance: Untransformed data, $F_{max} = 9.99$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean crustacean abundance between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB4	HB3	HB2	HB7	HB6	HB1	HZ
HB4		–	–	–	–	–	*
HB3			–	–	–	–	*
HB2				–	–	–	*
HB7					–	–	*
HB6						–	*
HB1							*

– = not significant; * = $p < 0.05$.

TABLE B.6. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Crustacean Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2001

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	355.89	6	59.31	6.34	0.0003
Experimental Error	262.00	28	9.36		
Total	617.89	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	14.20	9.20	5.40	5.00	12.60	10.40	10.80
Standard Deviation	4.38	3.27	3.85	1.73	2.70	1.95	2.59

F_{max} test for equal variance: Untransformed data, $F_{max} = 6.40$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean crustacean taxa number between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB4	HB3	HB2	HB6	HB7	HZ	HB1
HB4		–	–	*	*	*	*
HB3			–	*	*	*	*
HB2				–	–	–	–

HB6	–	–	–
HB7		–	–
HZ			–

– = not significant; * = $p < 0.05$.

TABLE C.1. Basic Statistics for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, January 2001
(Sample Size n = 5)

Statistic	Station						
	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	529.80	353.80	243.80	277.40	214.20	189.20	275.60
Standard Deviation	24.74	68.00	19.77	34.20	53.39	14.10	64.91
Standard Error of the Mean	11.07	30.41	8.84	15.29	23.88	6.30	29.03
95% of CI Mean	30.72	84.42	24.54	42.45	66.28	17.50	80.58
Skewness	-0.57	1.70	0.76	-0.06	1.52	-1.21	0.43
Kurtosis	0.97	3.01	-1.21	1.71	1.83	0.79	-2.70
Median	530.00	328.00	237.00	280.00	184.00	195.00	249.00
Normality Test (D)	0.207ns	0.275ns	0.240ns	0.246ns	0.314ns	0.260ns	0.259ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant.

TABLE C.2. Basic Statistics for Untransformed Mollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, January 2001
(Sample Size n = 5)

Statistic	Station						
	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	38.80	29.20	30.40	28.60	25.60	24.60	34.80
Standard Deviation	5.59	4.32	5.32	2.51	5.68	3.85	4.21
Standard Error of the Mean	2.50	1.93	2.38	1.12	2.54	1.72	1.88
95% of CI Mean	6.93	5.37	6.60	3.12	7.06	4.78	5.22
Skewness	-0.73	-0.04	-1.10	-0.20	0.59	-0.59	0.60
Kurtosis	-1.61	-2.37	1.39	-3.03	0.44	-0.02	0.27
Median	41.00	29.00	32.00	29.00	26.00	25.00	35.00
Normality Test (D)	0.253ns	0.210ns	0.255ns	0.250ns	0.203ns	0.141ns	0.188ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{.05} = 0.337$; ns = not significant.

TABLE C.3. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, January 2001

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Among Stations	397,731.5	6	66,288.59	33.03	<0.0001
Experimental Error	56,197.6	28	2,007.06		
Total	453,929.1	34			

Untransformed Data

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	529.80	353.80	243.80	277.40	214.20	189.20	275.60
Standard Deviation	24.74	68.00	19.77	34.20	53.39	14.10	64.91

F_{max} test for equal variance: Untransformed data, $F_{max} = 23.27$, not significant at $p < 0.05$.

Conclusion: There are significant differences in mean mollusk abundance between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB6	HZ	HB3	HB7	HB4	HB2	HB1
HB6		–	–	*	*	*	*
HZ			–	–	–	*	*
HB3				–	–	*	*
HB7					–	*	*
HB4						*	*
HB2							*

– = not significant; * = $p < 0.05$.

TABLE C.4. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, January 2001

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Among Stations	756.34	6	126.06	5.93	0.0004
Experimental Error	595.20	28	21.26		
Total	1,351.54	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	38.80	29.20	30.40	28.60	25.60	24.60	34.80
Standard Deviation	5.59	4.32	5.32	2.51	5.68	3.85	4.21

F_{max} test for equal variance: Untransformed data, $F_{max} = 5.13$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean number of mollusk taxa between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB6	HZ	HB4	HB2	HB3	HB7	HB1
HB6		–	–	–	–	*	*
HZ			–	–	–	*	*
HB4				–	–	–	*
HB2					–	–	*
HB3						–	*
HB7							–

– = not significant; * = $p < 0.05$.

BENTHIC FAUNAL SAMPLING ADJACENT TO THE BARBERS POINT OCEAN OUTFALL, O‘AHU, HAWAI‘I, JANUARY 2002

Richard C. Swartz
Julie H. Bailey–Brock
William J. Cooke
E. Alison Kay

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WATER RESOURCES RESEARCH CENTER
University of Hawaiʻi at Mānoa
Honolulu, Hawaiʻi 96822

ABSTRACT

Benthic infauna in the vicinity of the Barbers Point Ocean Outfall was sampled at seven stations on 21–22 January 2002 with a modified van Veen grab sampler. Sediment samples for total organic carbon analysis were collected on 7 and 13 February 2002. The stations are located along the diffuser isobath (61 m) as follows: Station HZ within the zone of initial dilution (ZID); Stations HB2, HB3, and HB4 on the ZID boundary; Station HB6 at 0.5 km from the ZID; and Stations HB1 and HB7 at 3.5 km from the ZID.

Sediments were predominantly (>92%) sand at all stations. The coarse-sediment fraction was moderately higher and the fine-sand fraction moderately lower at Stations HB1, HB4, and HB7 than at the other stations. Total organic carbon in the sediments at all stations was less than 0.40%. There were no significant differences among stations in mean oil and grease measurements. Values for oxidation-reduction potential showed no evidence of reducing conditions at the surface of sediments at any station.

A total of 6,692 nonmollusk individuals from 191 taxa were collected. Polychaetes represented 42.5%, nematodes 18.2%, sipunculans 13.5%, oligochaetes 11.4%, and crustaceans 7.6% of total nonmollusk abundance. Mean total nonmollusk abundance ranged from 146.6 individuals per sample (32,316/m^2, at Station HZ) to 238.2 individuals per sample (52,508/m^2, at Station HB7). Mean crustacean abundance ranged from 5.4 individuals per sample (1,190/m^2, at Station HZ) to 30.6 (6,745/m^2, at Station HB7). Mollusks were analyzed separately because they represent time-averaged collections of live and dead shells. Mean mollusk abundance ranged from 202.2 individuals/10 cm^3 (at Station HB3) to 476.8 individuals/10 cm^3 (at Station HB1). Crustacean abundance and taxa richness decreased in 2002 from the high levels recorded in 2001. Crustacean abundance and taxa richness recorded in 2002 at ZID-boundary stations HB3, HB4, and HZ were low relative to the reference stations. Very low mean values were recorded for crustacean abundance at Station HZ (5.4 individuals/sample) and for number of crustacean taxa at Station HB4 (1.4 taxa/sample). There is a historic pattern of reductions in crustacean abundance and taxa richness at the four ZID-area stations relative to each of the reference stations, although the differences are usually not statistically significant and the pattern has not been observed in every sampling year. This pattern may indicate a trend related to proximity to the diffuser. The collection of a variety of pollution-sensitive amphipod taxa at the ZID-area stations in 2002 and earlier years indicates that the diminished crustacean fauna at these stations may be due to a noncontaminant factor. There were significant differences in abundance and taxa richness for both mollusks and nonmollusks, but they do not indicate a consistent spatial pattern related to the outfall. There has been a significant trend of increased abundance for

nonmollusks within the entire study area since 1990, although mean nonmollusk abundance in 2002 was the lowest since 1995. Since 1993, there has been a trend of increased abundance for mollusks. Diversity and evenness values were generally similar among all stations in 2002, although lowest values occurred at ZID-boundary stations HB3 and HB2 for nonmollusks and mollusks, respectively. Separate cluster analyses of nonmollusk and mollusk data confirmed that all stations were relatively similar to one another in terms of species composition and relative abundance, although the similarity of mollusks among stations may have been enhanced by the inclusion of empty shell counts in the analysis. Except for a diminished crustacean fauna at the ZID-area stations, there is no indication of any marked alteration of the benthic community composition related to station proximity to the diffuser. The analyses of the noncrustacean fauna clearly demonstrate the presence of a diverse and abundant macrobenthos within and near the ZID of the Barbers Point Ocean Outfall.

INTRODUCTION

The Honouliuli Wastewater Treatment Plant (WWTP) is a primary treatment system. Wastewaters of mainly domestic origin are treated at the plant prior to discharge in Māmala Bay through an 84-in. (2.13-m) diameter outfall located off the southern coast of Oʻahu, Hawaiʻi.

A waiver of secondary treatment for sewage discharge through the Barbers Point Ocean Outfall has been granted to the City and County of Honolulu (CCH) by the Region IX office of the U.S. Environmental Protection Agency (EPA). However, from September 1996 to July 2000, approximately one-fourth to one-half of the discharge had been secondary-treated effluent from the ʻEwa Water Reclamation Facility (EWRF). A privately operated tertiary treatment plant has been receiving effluent from the EWRF since July 25, 2000. Some of the tertiary treated water is transmitted offsite for irrigation and industrial water use. The rest is returned to the Honouliuli WWTP for in-plant use or discharged through the outfall. This report provides the results of the fourteenth survey in an ongoing series of studies of the macrobenthic, soft-bottom community in the vicinity of the discharge; it also provides an overview of trends in biological communities adjacent to the outfall over the seventeen-year period from 1986 to 2002. The first benthic survey took place in 1986. The samples on which this report is based were collected on 21–22 January 2002.

PROJECT ORGANIZATION

General coordination for this project is provided by James E.T. Moncur, director of the Water Resources Research Center of the University of Hawaiʻi at Mānoa and project principal investigator. The principal members of the project team (listed in alphabetical order) and their contributions to this study are as follows:

Julie H. Bailey–Brock	Polychaete, oligochaete, and sipunculan analysis and report
William J. Cooke	Crustacean analysis and report
E. Alison Kay	Mollusk analysis and report
Richard C. Swartz	Statistical analysis and final report preparation
Ross S. Tanimoto	City and County of Honolulu project representative and coordinator for sediment grain-size, total organic carbon, oil and grease, and oxidation-reduction potential analyses

MATERIALS AND METHODS

Specific locations of the sampling stations are provided in Figure 1, and a general vicinity map for the area serviced by the Honouliuli Wastewater Treatment Plant is provided in Figure 2. Seven stations previously established along the approximate diffuser isobath (61 m) were surveyed. In 1990 survey station names were changed from those used in the 1986 survey (Nelson et al. 1987). Survey stations (1986 station names are in parenthesis) and their locations are as follows:

Station HB1 (A)	Approximately 3.5 km east of the zone of initial dilution (ZID) boundary to evaluate effects far-field and beyond the ZID
Station HB2 (B)	On the northeast ZID boundary
Station HB3 (C)	On the southeast ZID boundary
Station HB4 (D)	On the southwest ZID boundary
Station HZ (Z)	Within the ZID to evaluate diffuser effects
Station HB6 (E)	Approximately 0.5 km southwest of the ZID boundary as a near-field reference station
Station HB7 (F)	Approximately 3.5 km southwest of the ZID boundary as a far-field reference station

ZID-boundary stations HB2, HB3, and HB4 and ZID station HZ collectively are called ZID-area stations in this report.

Station Positioning

The exact position of each station was determined using the Garmin differential global positioning system. Station locations in relation to latitude, longitude, and bathymetric contours are shown in Figure 1. Positions for each replicate grab sample at each station are given in Appendix Table A.1. Depths for all stations fell within the range of 60.7 to 67.1 m. Station positions within and on the boundaries of the ZID were located precisely during the original sampling using the submersible *Makali'i* in coordination with its mother ship (Nelson et al. 1987).

Sampling Methods

The sampling methodology used in this study generally follows the recommendations of Swartz (1978) and guidelines of the U.S. Environmental Protection Agency (1987a, 1987b), hereafter referred to as EPA procedures. The 1986 through 1997 reports on the benthic monitoring adjacent to the Barbers Point Ocean Outfall (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a, 1994b, 1995, 1996, 1997a) will be hereafter referred to as "Nelson et al. reports." The 1998 through 2001 reports on benthic monitoring at this outfall (Swartz et al. 1998, 1999, 2000a, 2000b, 2001) will be hereafter referred to as "Swartz et al. reports."

In 1994, the modified 0.1-m^2 van Veen grab sampler previously used was replaced by a 0.16-m^2 van Veen grab sampler. The new grab, which was deployed from a stern-mounted A-frame on the City's research vessel *Noi I Kai*, was used to obtain bottom samples at all seven stations. Sampling dates were 21–22 January 2002. Penetration of the sampler was adequate for all replicates. The minimum penetration depth was 6.0 cm, and the maximum was 11.0 cm (Appendix Table A.2).

Five replicate grab samples were taken at each station. From each replicate sample, a subsample 7.6 cm in diameter by 5 cm deep was taken for infaunal analysis and a subsample 4.8 cm in diameter by 5 cm deep for mollusk analysis. Subsampling was necessary because the epifauna and infauna in the area are known to be both small and abundant (Nelson 1986; Russo et al. 1988). Replicated grab samples at each station, rather than replicated subsamples from one grab sample, were taken to provide information on intrastation variability. All five biological subcores for nonmollusk analysis were processed on a 0.5-mm screen and the organisms retained and preserved as appropriate for subsequent identification.

Samples for geochemical analyses (total organic carbon [TOC], oil and grease [O&G], and oxidation-reduction potential [ORP]) and for grain-size analyses were obtained from the grabs from which the biological subcores were taken because each replicate grab contained more than enough sediment for both purposes (methods established by National Pollutant Discharge Elimination System permit no. HI0020877). Three subsamples (one from each of three different grab samples) were taken for all stations. The top 2 cm of sediment from each subsample were used for geochemical analysis. Samples for TOC and O&G analyses were put in screw-cap jars, which were placed on ice, and taken to the laboratory. Sediment ORP was measured on board the research vessel immediately after each sample was obtained. Laboratory analyses of sediment grain size and O&G followed EPA procedures. The original sediment samples for TOC analysis were damaged during shipment. A replacement set of samples was collected on 7 and 13 February 2002 (three replicates at each of the seven stations). Sediment TOC was measured by Columbia Analytical Services (Kelso, Washington) using the method of Plumb (1981).

Sample Processing

Handling, processing, and preservation of the biological samples followed EPA procedures. Nonmollusk samples were fixed with buffered 10% formalin for a minimum of 24 hours. Following fixation, all samples were placed in 70% ethanol. Mollusk samples were placed in labeled jars in the field, then placed on ice and transported to the laboratory where they were refrigerated. Samples were washed in freshwater (to minimize loss of fine sediments), fixed in 75% isopropyl alcohol for 24 hours, and then air dried. A subsample in a 10-cm^3 aliquot was removed from each mollusk sample for sorting.

The fixed nonmollusk samples were elutriated using the technique of Sanders et al. (1965). This method removes from the sediment all organisms that are not heavily calcified (Nelson et al. 1987). Samples were washed several times, and the water from each was poured through 0.5-mm-mesh sieves. Polychaetes and other invertebrates retained on the sieve were transferred to alcohol, stained with rose bengal solution, and stored in 70% ethanol.

Because the biological subcores had to be processed using two different procedures—one for mollusks and the other for all other organisms—the two components of the fauna were not directly comparable and thus were analyzed separately. Because the mollusk specimens were not separated into living and dead shell fractions, they represent time-averaged samples. Mollusks have been extensively analyzed by Kay (1975, 1978, 1979, 1982), Kay and Kawamoto (1980, 1983), Nelson (1986), and Russo et al. (1988).

All specimens were identified to the lowest taxonomic level possible. A selected bibliography for the identification of marine benthic species in Hawai‘i is provided in Nelson et al. (1987, appendix D). An additional source used for the identification of polychaetes in Hawai‘i is Blake et al. (1995). Voucher specimens were submitted to taxonomic specialists for verification when necessary. All specimens were archived and will be maintained for six years at the University of Hawai‘i.

In previous benthic sampling reports for Barbers Point, name changes for several polychaete taxa were indicated. A review of specimens and the literature led to several additional name changes this year. *Oriopsis* sp. B and *Oriopsis* sp. C changed to *Amphicorina* sp. B and *Amphicorina* sp. C, respectively (Rouse 1994); *Polydora normalis, P. pilikia*, and *Polydora* sp. A to *Dipolydora normalis, D. pilikia*, and *Dipolydora* sp. A, respectively (Blake 1996); *Brania mediodentata* to *Grubeosyllis mediodentata* (Díaz-Castañeda and San Martín 2001); *Podarke angustifrons* and *Podarke* sp. A to *Ophiodromus angustifrons* and *Ophiodromus* sp. A, respectively (Pleijel 1998); and *Langerhansia cornuta* and *Langerhansia* sp. A to *Typosyllis cornuta* and *Typosyllis* sp. G, respectively (Licher 1999). After further examination of specimens, *Eunice* sp. A was changed to *Eunice havaica*, Capitellidae sp. C to *Notomastus tenuis*, *Pholoe* sp. F to Sigalionidae sp. A, and *Exogone* sp. A to *Sphaerosyllis* sp. D.

A name change for the sipunculan *Apionsoma misakiana* (e.g., Cutler and Cutler 1980, Popkov 1993) to *A. misakianum* has recently taken place in the literature (Staton and Rice 1999; Pechenik and Rice 2001). We will be following this revised declension.

The following nonmollusk taxa were newly found at the Barbers Point study site but have been found at other Oʻahu outfall sites (Sand Island, Waiʻanae, and Mōkapu): *Amphiglena* sp. B, Capitellidae sp. E, Hesionidae sp. D, Hesionidae sp. G, *Monticellina* sp. A, *Palmyra* sp. A, *Protodrilus* sp. A, *Pseudopolydora* sp. A, *Syllides* sp. B, Arachnida, Sipuncula sp. Q, and Sipuncula sp. R. Taxa new to the Barbers Point study site and not previously collected at other outfall sites include Capitellidae sp. H, Capitellidae sp. I, Capitellidae sp. J, Capitellidae sp. K, *Ceratonereis pietschmanni*, *Exogone* sp. F, *Progoniada* sp. B, *Mesochaetopterus* sp. C, Sipuncula sp. O, and Sipuncula sp. S. No new crustacean taxa were found this year.

Newly found mollusk taxa at Barbers Point include the bivalves Cardiidae sp., *Ctena* sp., *Lima hawaiana*, and *Rochefortina* sp.; and the gastropods *Acteocina sandwichensis*, *Architectonica* sp., *Cerithium echinatum*, *Diodora granifera*, *Duplicaria gouldi*, *Glyphostoma kihikihi*, Liotiinae sp., *Merelina wanawana*, *Miralda* sp., *Modulus tectum*, *Nesiodostomia montforti*, *Odostomia oxia*, *Rissoella confusa*, *R. longispira*, *Scissurella* sp., *Sinezona insignis*, *Syrnola lacteola*, *Volvarina* sp., and *Xenuroturris* sp.

Data Analysis

All data for both nonmollusks and mollusks were tested for assumptions of normality (Kolmogorov–Smirnov test; Sokal and Rohlf 1995) and heterogeneity of variances (F_{max} test) prior to statistical analysis. Where data sets failed tests of assumptions, square root or $\log_{10}$ transformation was applied. Comparisons of mean values among stations were made with one-way analysis of variance (ANOVA). Following a significant result using ANOVA, a posteriori Student–Newman–Keuls tests were used to determine which differences in means among stations were significant. All statistical analyses were performed using Prophet and Microsoft Excel software. Detailed statistical results are provided in Appendixes B and C.

Overall comparisons of taxa composition among stations were carried out using cluster analysis (Pielou 1984). The Bray–Curtis similarity index (Bloom 1981) on double square root transformed data was performed using the group-average sorting strategy. Separate cluster analyses were conducted for the mollusk and nonmollusk faunal fractions because of differences in sample collection and processing. To make analysis more manageable, only those taxa that contributed at least 0.05% to the total abundance were included. Using this criterion, only mollusk taxa represented by a total of more than four individuals were included in the data set, which was reduced from 126 to 64 taxa. Also, only nonmollusk taxa represented by a total of more than three individuals were included in the data set, which was reduced from 191 to 109 taxa. The similarity matrices were computed with BioDiversity Pro software. Cumulative counts of crustacean taxa are based on collections since 1990.

The Shannon–Wiener diversity index (H') (ln) 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 using Microsoft Excel software.

To examine trends over the entire study period, comparisons were made among mean values for all sampling dates and sampling stations using two-way ANOVA without replication and a posteriori Student–Newman–Keuls tests.

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 four grain-size categories, are compared in Figure 3. The grain-size categories (Folk 1968) are as follows: coarse sediment, retained on a +1-phi sieve; medium sand, passed through a +1-phi sieve but 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.

There were relatively small differences among stations in sediment grain-size distribution, especially in the mean proportion of the silt-and-clay fraction (range: 3.4% to 7.2%) and the mean medium-sand fraction (range: 22.1% to 31.2%) (Appendix Table A.3, Figure 3). The coarse-sediment fraction was higher at Stations HB1, HB4, and HB7 (range: 34.3% to 40.8%) than at the other stations (range: 18.6% to 29.2%). Conversely, the fine-sand fraction was lower at Stations HB1, HB4, and HB7 (range: 29.4% to 34.9%) than at the other stations (range: 36.6% to 47.6%). This spatial pattern of grain-size distribution is similar to those seen in 1997 (Nelson et al. 1997) and 1998 through 2001 (Swartz et al. 1998, 1999, 2000b, 2001), although sediments at Station HB2 were less coarse in 1997 and 1998 than in 1999 through 2002. Results of replicate sediment sample analysis for all seven stations indicated substantial homogeneity in grain size within stations (Appendix Table A.3). Analysis of duplicate samples at Stations HB3, HZ, and HB6 indicated consistency of analytical techniques.

Direct electrode measurements of ORP ranged from +30 to +185 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 there were significant differences among the seven stations (F = 10.50, $p < 0.0001$). ORP was significantly lower at Station HB1 than at all other stations; significantly lower at Station HB2 than at Stations HB3 and HZ; and significantly lower at Station HB4 than at Station HB3. ORP measurements obtained for the 2002 survey were similar to those obtained for the 2001 survey (Swartz et al. 2001).

Oil and grease measurements ranged from <5 to 295 mg/dry kg (Appendix Table A.2). Comparison of mean O&G per station (one-way ANOVA) showed there were no significant differences among the seven stations (F = 0.84, $p = 0.56$). The highest mean O&G measurement was recorded for ZID-boundary station HB3.

Total organic carbon in the sediments was less than 0.40% in all samples (Appendix Table A.2). Comparison of mean TOC per station (one-way ANOVA) showed there were significant differences among the seven stations (F = 3.81, $p = 0.018$). However, the Student–Newman–Keuls test showed that no pairwise multiple contrasts were significantly different at $p = 0.05$. TOC measurements obtained for the 2002 survey were similar to those obtained for the 2001 survey (Swartz et al. 2001). Although TOC measurements were low in all 2002 samples, none was below the detection limit of 0.01%. TOC in many samples collected in the 1997, 1998, 1999, and 2000 surveys was reported as below the detection limit (Nelson et al. 1997a; Swartz et al. reports).

Biological Parameters

Nonmollusks

The nonmollusk fraction of the benthic fauna included polychaetes, oligochaetes, nematodes, platyhelminths, echinoderms, poriferans, anthozoans, hydrozoans, kinorhynchs, a chaetognath, a hemichordate, nemerteans, sipunculans, an arachnid, insects, priapulids, a phoronid species, chordates, mites, a pycnogonid species, copepods, ostracods, cumaceans, mysids, amphipods, isopods, and decapods.

The 6,692 nonmollusk specimens counted and identified for all stations and replicates represent 191 taxa. Polychaetes were the dominant nonmollusk taxon in terms of both abundance (2,843 individuals, 42.5%) and taxa richness (118 taxa, 61.8%). Nematodes comprised the second most dominant nonmollusk taxon in terms of abundance (1,216 individuals, 18.2%). Sipunculans contributed 13.5% (903 individuals) of numerical abundance, oligochaetes contributed 11.4% (763 individuals), and crustaceans constituted 7.6% (508 individuals). The 46 crustacean taxa, 18 of which were amphipods, represented 24.1% of the total number of nonmollusk taxa. Abundance estimates for each taxon from each replicate are given for each of the seven stations 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 taxa). Except for nonmollusk taxa number at Station HB7, data were normal for all stations (Appendix Table B.2).

Mean total nonmollusk abundance ranged from 146.6 individuals per sample (32,316/m^2, at Station HZ) to 238.2 individuals per sample (52,508/m^2, at Station HB7) (Figure 4). Variances were homogeneous (Appendix Table B.3). According to the ANOVA on untransformed data, there were no significant differences in mean nonmollusk abundance among stations (Appendix Table B.3).

Mean number of nonmollusk taxa per sample ranged from 30.8 (at Station HZ) to 43.4 (at Station HB1) (Figure 5). Data for nonmollusk taxa were both square root and $\log_{10}$ transformed, but neither transformation resulted in the data set passing the test of homogeneity of variance (Appendix Table B.4). Differences in nonmollusk taxa number among stations were therefore compared by the nonparametric Kruskal–Wallis test. The Kruskal–Wallis statistic was barely significant ($p = 0.036$), but the nonparametric comparison showed no statistically significant multiple contrasts among the seven stations.

Composite station diversity (H') and evenness (J) for the nonmollusks are shown in Figure 6. Values for both parameters were similar for all stations. Values for diversity ranged from 2.92 (at Station HB3) to 3.49 (at Station HB1). The range of values was similar to that of samples collected in 1999, 2000, and 2001 but slightly higher than that of samples taken in years prior to 1999 (Nelson et al. reports; Swartz et al. reports). Evenness ranged from 0.67 (at Station HB3) to 0.77 (at Station HB1), which was also slightly higher than the range of values observed in years prior to 1999 (Nelson et al. reports; Swartz et al. 1998). There was little difference between reference and ZID-area stations in diversity and evenness, except for the relatively low values of both parameters at ZID-boundary station HB3.

The results of cluster analysis indicating the relative similarity of stations based on the 109 most abundant nonmollusk taxa are shown in Figure 7. All stations were grouped at similarity values greater than 63.8%, indicating similar taxa composition and abundance among all stations. There was little difference in sorting among stations with regard to proximity to the diffuser. Reference stations HB1 and HB7 clustered together at 76.0% similarity, but they formed a six-station cluster with ZID station HZ, ZID-boundary stations HB2 and HB3, and reference station HB6 at a high similarity of 72.8%. ZID-boundary station HB4 was somewhat distinct, joining the six-station cluster at a similarity of 63.8%. Although most of the abundant species at Station HB4 were also abundant at other stations, two of the dominants at Station HB4 (the polychaetes *Ophryotrocha adherens* and *Pionosyllis spinisetosa*) were rare or absent at all other stations (Table 1).

Polychaetes

A total of 2,843 polychaetes representing 118 taxa were collected; they comprised 42.5% of total nonmollusk abundance. Total polychaete abundance was less in 2002 than in most recent years, but more polychaete taxa were collected in 2002 than in any previous year: 2,685 polychaetes representing 90 taxa in 1994 (Nelson et al. 1994b), 2,527 polychaetes representing 87 taxa in 1995 (Nelson et al. 1995), 3,836 polychaetes representing 95 taxa in 1996 (Nelson et al. 1996), 2,811 polychaetes representing 93 taxa in 1997 (Nelson et al. 1997a), 3,521 polychaetes representing 85 taxa in 1998 (Swartz et al. 1998), 4,261 polychaetes representing 113 taxa in 1999 (Swartz et al. 1999), 3,489 polychaetes representing 109 taxa in 2000 (Swartz et al. 2000b), and 4,050 polychaetes representing 116 taxa in 2001 (Swartz et al. 2001). The highest mean number of polychaetes per sample was found at Station HB4 (102.2 individuals), followed in decreasing order of abundance by Stations HB6 (91.2 individuals), HB7 (86.8 individuals), HB3 (83.4 individuals), HB2 (83.0 individuals), HZ (61.2 individuals), and HB1 (60.8 individuals) (Figure 8). Polychaetes were the most taxa-rich group at all stations (Appendix Tables D.1 through D.7). Maximum mean number of polychaete taxa per sample occurred at Station HB4 (26.8 taxa), followed in decreasing order by Stations HB6 (26.6 taxa), HB2 (25.4 taxa), HB3 and HB1 (both with 24.2 taxa), HB7 (21.4 taxa), and HZ (20.2 taxa) (Figure 9).

Polychaetes accounted for 12 of the 14 taxa that ranked among the five most abundant taxa at individual stations (Table 1). Ten taxa represented 61.8% of the polychaete individuals collected at the Barbers Point Ocean Outfall this year: *Pionosyllis heterocirrata* (12.7%), *Synelmis acuminata* (12.1%), *Euchone* sp. B (9.4%), *Ophiodromus angustifrons* (5.0%), *Myriochele oculata* (5.0%), *Prionospio cirrifera* (4.0%), *Myriochele* sp. A (3.9%), *Augeneriella dubia* (3.3%), *Prionospio cirrobranchiata* (3.3%), and *Fabricia* sp. A (3.1%). All of these taxa, except for *Euchone* sp. B, were found at all stations.

Dominant polychaete taxa differed at several stations. *Pionosyllis heterocirrata* was the most abundant polychaete at Station HB4 (19.0%) and among the most abundant taxa at Stations HB7 (17.6%), HB1 (13.5%), HB3 (12.2%), HB6 (11.4%), HZ (7.2%), and HB2 (5.5%). This syllid usually dominates at Station HB3, but an oweniid, *Myriochele* sp. A, was most abundant there this year (13.2%). *Myriochele* sp. A shared dominance with another oweniid, *Myriochele oculata*, at Station HZ (10.8% each). *Synelmis acuminata* was the most abundant polychaete at Stations HB7 (33.2%) and HB1 (16.8%) and among the most abundant taxa at Stations HB6 (9.6%), HB3 (9.4%), HB2 (8.2%), and HZ (7.5%). *Euchone* sp. B was the most abundant taxon at Stations HB2 (33.5%) and HB6 (24.1%); at other stations it was rare or absent. This sabellid has been the most abundant polychaete at Station HB2 since 1993. It was the most abundant polychaete at Station HB1 in 1998 (42%) but has been rare there since then.

The spionid *Dipolydora normalis* (formerly *Polydora normalis*) did not rank among the five most abundant taxa at any station in 2002. It was a dominant species at Station HB4 from 1999 through 2001 and at Station HZ from 1993 through 1998.

Ophryotrocha adherens (formerly *Ophryotrocha* sp. A) is of particular interest as it has been cited as an indicator of organic enrichment (Bailey–Brock 1996). It was the second most abundant polychaete this year at Station HB4, where it was also abundant in 1996 and in 1999 through 2001. *Ophryotrocha adherens* was abundant at Station HZ in 2001, but only one specimen was collected there in 2002. The other indicator of organic enrichment, *Neanthes arenaceodentata,* was not a dominant at any Barbers Point station in 2001 and 2002. The syllid *Pionosyllis spinisetosa* had a distribution similar to that of *O. adherens* in 2002: it was one of the dominants at Station HB4 but was rare or absent at the other stations (Table 1).

Individuals of the families Syllidae, Serpulidae, Spionidae, Capitellidae, Ampharetidae, Sabellidae, Hesionidae, Goniadidae, Pilargidae and Nereididae were represented by reproducing individuals this year. Stations HB6 and HB1 had the most as well as the widest variety of taxa reproducing. The syllids *Sphaerosyllis* sp. G (at Stations HB1, HB3, HZ, and HB7), *Grubeosyllis mediodentata* (at Station HZ), and *Brania rhopalophora* (at Stations HB1 and HB6), *Exogone longicornis* (at Stations HB4 and HB7), and *Exogone* sp. E (at Stations HB1 and HB2) had embryos attached to the external body wall. Many syllids reproduce by epitoky, which is a complex form of reproduction involving the production of buds (stolons or epitokes) from the posterior end (Schroeder and Hermans 1975). Taxa with gametes developing in the coelom include the syllids *Sphaerosyllis* sp. G (at Stations HB1, HB2, HB3, and HB6), *Sphaerosyllis riseri* (at Station HB1), *Pionosyllis heterocirrata* (at Stations HB4 and HB7), *Syllides bansei* (at Station HB4), *Odontosyllis* sp. B (at Stations HB6 and HB7), and *Exogone longicornis* (at Stations HZ and HB6); the ampharetid *Lysippe* sp. A (at Station HB1); the serpulid *Neodexiospira preacuta* (at Station HB7); the spionids *Aonides* sp. A and *Malacoceros* sp. A (at Station HB1); and the hesionids *Ophiodromus angustifrons* (at Stations HB2, HB4, HB6, and HB7) and *Micropodarke* sp. A (at Station HB6). Taxa which showed characteristics of a swimming stage include the syllids *Sphaerosyllis riseri* (at Station HB6), *Exogone longicornis* (at Station HB6), and *Pionosyllis heterocirrata* (at Stations HB2, HB3, HB4, HB6, and HB7); the goniadids *Progoniada* sp. A (at Stations HB3 and HB7) and *Progoniada* sp. B (at Station HB2); and the nereidid *Ceratonereis pietschmanni* (at Station HB7). These features can include enlarged eyes and elongated capillary setae that facilitate spawning in the water column (Schroeder and Hermans 1975). The serpulid *Salmacina dysteri* (at Stations HB1 and HZ) had reproduced by schizoparity. The capitellid *Capitella capitata* (at all stations except Station HB7) had copulatory hooks present in male individuals.

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

1. Detritivores. Of the four trophic categories, deposit-feeding polychaetes were the most abundant group at Stations HZ (45.8% of all polychaete individuals) and HB3 (42.9%) and the most speciose group at all seven stations. The percentage of all polychaete individuals represented by detritivores ranged from 18.1% (at Station HB2) to 45.8% (at Station HZ). The number of detritivorous individuals ranged from 75 (at Station HB2) to 200 (at Station HB4). The percentage of all polychaete taxa represented by detritivores ranged from 36.5% (at Station HB1) to 50.0% (at Station HZ). The number of detritivorous taxa ranged from 19 (at Station HB1) to 25 (at both Stations HZ and HB6). The dominant deposit-feeding polychaetes were the spionids *Prionospio cirrobranchiata* (8.6% at Station HB1) and *Prionospio cirrifera* (4.8% at Station HB6, 6.2% at Station HB7, and 5.3% at Station HB2), the oweniids *Myriochele oculata* (10.8% at Station HZ) and *Myriochele* sp. A (13.2% at Station HB3 and 10.8% at Station HZ), and the dorvilleid *Ophryotrocha adherens* (11.0% at Station HB4). Another abundant deposit-feeder was the sabellid *Fabricia* sp. A (7.5% at Station HZ).

2. Omnivores. Omnivores were most abundant at Station HB7 (57.8% of all polychaetes, 251 individuals), where they have been dominant since 1986 (Nelson et al. reports; Swartz et al. reports). They were also the most abundant trophic group at Stations HB1 (41.4%, 126 individuals) and HB4 (39.9%, 204 individuals). Omnivores were least abundant at Station HZ (18.0%, 55 individuals). Omnivorous worms were never the least abundant group of the four trophic categories at any station. The percentage of all polychaete taxa represented by omnivores ranged from 18.0% (at Station HB3) to 30.2% (at Station HB4). The number of omnivorous taxa ranged from 9 (at Station HB3) to 16 (at Station HB4). The syllid *Pionosyllis heterocirrata* was the dominant omnivore at Stations HB4 (19.0% of all polychaetes), HB3 (12.2%), and HB6 (11.4%), whereas the pilargid *Synelmis acuminata* was the dominant omnivore at Stations HB7 (33.2%), HB1 (16.8%), HB2 (8.2%), and HZ (7.5%). Both species were among the most abundant omnivorous taxa at all stations.

3. Suspension feeders. Of the four trophic categories, suspension feeders were the least abundant group at Stations HB1 (11.5% of all polychaetes, 35 individuals) and HB7 (4.8%, 21 individuals). The percentage of all polychaete taxa represented by suspension feeders ranged from 12.3% (at Station HB7) to 24.6% (at Stations HB2 and HB6). Of the four trophic categories, suspension feeders were the least speciose group at Stations HB1 (19.2% of polychaete taxa, tied with carnivores), HB3 (16.0%), and HB7 (12.3%). The number of suspension-feeding taxa ranged from 7 (at Station HB7) to 15 (at Stations HB2 and HB6). Suspension feeders were dominant at Stations HB2 (51.1% of all polychaetes, 212 individuals) and HB6 (39.3%, 179 individuals), primarily due to the large numbers of the sabellid *Euchone* sp. B (33.5%, 139 individuals at Station HB2; 24.1%, 110 individuals at Station HB6). *Euchone* sp. B tied with the serpulid *Salmacina dysteri* as the most numerous suspension feeder at Station HB1, although neither species was particularly abundant at that station (2.3% each, 7 individuals). Another sabellid, *Augeneriella dubia*, was the dominant suspension feeder at Stations HB4 (7.0%), HB3 (6.7%), and HB7 (2.1%). *Laonome* sp. A, yet another sabellid, was the dominant suspension feeder at Station HZ (6.9%); it was also abundant along with the chaetopterid *Phyllochaetopterus* sp. A at Station HB2 (4.7% each).

4. Carnivores. Carnivorous polychaetes were present at all stations, with their greatest abundance occurring at Station HB7 (15.7% of all polychaetes, 68 individuals). Carnivores were least abundant at five stations: HB2 (8.0% of all polychaetes, 33 individuals), HB3 (12.9%, 54 individuals), HB4 (7.6%, 39 individuals), HZ (7.5%, 23 individuals), and HB6 (13.8%, 63 individuals). The percentage of all polychaete taxa represented by carnivores ranged from 7.5% (at Station HB4) to 24.6% (at Station HB7). The number of taxa ranged from 4 (at Station HB4) to 14 (at Station HB7). The hesionid *Ophiodromus angustifrons* (formerly *Podarke angustifrons*) was the dominant carnivore at six stations: HB2 (2.9%), HB3 (7.0%), HB4 (4.7%), HZ (5.2%), HB6 (5.7%), and HB7 (5.6%). Another hesionid, *Micropodarke*
sp. A, dominated at Station HB1 (4.0%).

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

1. Tubicolous polychaetes. Of the three motility categories, tubicolous polychaetes were the most abundant group at Station HB2 (52.0% of all polychaetes, 216 individuals), HZ (50.3%, 154 individuals), and HB6 (44.3%, 202 individuals) and the least abundant at Stations HB1 (15.5%, 47 individuals) and HB7 (5.1%, 22 individuals). This group had the fewest taxa at Stations HB3 (18.0 % of taxa), HB4 (18.9%), and HB7 (15.8%), and they tied with discretely motile polychaetes as the least speciose group at Stations HB1 (21.2%) and HB6 (27.9%). The number of taxa ranged from 9 (at Stations HB3 and HB7) to 17 (at

Stations HB2 and HB6). The dominant tubicolous polychaete species included *Euchone* sp. B at Stations HB2 (33.5%) and HB6 (24.1%); *Myriochele oculata* at Stations HB1 (4.6%), and HZ (10.8%, shared with *Myriochele* sp. A); *Myriochele* sp. A at Stations HB3 (13.2%) and HZ (10.8%, shared with *M. oculata*); *Augeneriella dubia* at Stations HB4 (7.0%) and HB7 (2.1%). Other abundant tubicolous species were *Laonome* sp. A and *Phyllochaetopterus* sp. A at Station HB2 (4.6% each).

2. Motile polychaetes. Of the three motility categories, motile polychaetes were the most abundant group at Stations HB1 (60.9% of all polychaetes, 185 individuals), HB3 (40.5%, 169 individuals), HB4 (67.7%, 346 individuals), and HB7 (77.4%, 336 individuals). In addition, they had the highest percentage of polychaete taxa at each of the seven stations, ranging from 42.0% (at Station HZ) to 64.9% (at Station HB7). The number of motile polychaete taxa ranged from 21 (at Station HZ) to 37 (at Station HB7). The syllid *Pionosyllis heterocirrata* was the dominant motile polychaete at Stations HB3 (12.2%), HB4 (19.0%), and HB6 (11.4%). *Synelmis acuminata*, a pilargid, was the dominant motile polychaete at Stations HB1 (16.8%), HB2 (8.2%), HZ (7.5%), and HB7 (33.2%). *Pionosyllis heterocirrata* and *Synelmis acuminata* were abundant at all stations. *Ophiodromus angustifrons* at Station HB3 (7.0%) and *Ophryotrocha adherens* at Station HB4 (11.0%) were also abundant motile polychaetes this year.

3. Discretely motile polychaetes. Of the three motility categories, discretely motile polychaetes were least abundant group at Stations HB2 (14.9% of all polychaetes, 62 individuals), HB3 (20.1%, 84 individuals), HB4 (11.5%, 59 individuals), HZ (19.6%, 60 individuals), and HB6 (15.6%, 71 individuals). They ranked second in abundance at the other two stations. This group ranked second in percentage of polychaete taxa at Stations HB3 (30.0%), HB4 (20.8%), HZ (34.0%), and HB7 (19.3%) and tied with tubicolous polychaetes for second at Stations HB1 (21.2%) and HB6 (27.9%). The number of taxa ranged from 11 (at Stations HB1, HB4, and HB7) to 17 (at Stations HZ and HB6). The dominant discretely motile species were all spionids: *Prionospio cirrobranchiata* at Station HB1 (8.6% of all polychaetes); *P. cirrifera* at Stations HB2 (5.3%), HB6 (4.8%), and HB7 (6.2%); *Dipolydora normalis* at Station HZ (5.6%); *P. steenstrupi* at Station HB4 (3.5%); and *Aonides* sp. A at Station HB3 (2.2%). *P. cirrifera* also ranked second at Station HB1 (7.6%).

Crustaceans

A total of 508 crustaceans, mites, and pycnogonids—representing 7.6% of the nonmollusk abundance—were collected. Abundance for each taxon from each replicate is provided for each station in Appendix Tables D.8 through D.14. Mean abundance (no./sample) ranged from 5.4 (1,190/m^2, at Station HZ) to 30.6 (6,745/m^2, at Station HB7) (Figure 14). Variances were homogeneous for untransformed data (Appendix Table B.5). There were significant differences in mean abundance among the seven stations (ANOVA, Appendix

Table B.5). Mean number of crustacean individuals in 2002 was significantly greater at Station HB7 than at all other stations except Station HB1. In contrast, crustacean abundance in 2001 was greater at Station HZ than at all other stations.

A total of 46 crustacean, mite, and pycnogonid taxa (copepods were not identified to the species level) were collected; of these, 18 taxa (39.1%) were amphipods. Mean number of taxa ranged from 1.4 (at Station HB4) to 12.0 (at Station HB7) (Figure 15). Variances were heterogeneous for untransformed data but became homogeneous after square root transformation (Appendix Table B.6). ANOVA indicated significant differences in mean number of taxa among the seven stations (Appendix Table B.6). The mean number of crustacean taxa was significantly less at Stations HB4 and HZ than at Stations HB7, HB1, HB2, and HB6, and significantly less at Station HB4 than at Station HB3.

Amphipods, copepods, and tanaids were the numerically dominant taxa, making up 27.6%, 25.6%, and 20.9%, respectively, of total crustacean, mite, and pycnogonid abundance. No taxon was uniformly most abundant at all stations. Copepoda was the only taxon present at all stations. The ostracod Myodocope sp. A, the tanaids *Tanaissus* sp. A and *Leptochelia dubia,* the isopod *Munna acarina*, and the amphipod *Paraphoxus* sp. A were found at all stations except Station HB4. The most abundant noncopepod taxa remained the same, but their total abundances declined sharply from the previous year. *Eriopisella sechellensis* declined from 202 individuals in 2001 to 46 individuals in 2002, *Tanaissus* sp. A from 149 to 38 individuals, and *Leptochelia dubia* from 116 to 60 individuals. *L. dubia* was the only crustacean that ranked among the five most abundant nonmollusk taxa at any station: this tanaid tied for the fifth most abundant species at both Stations HB1 and HB7 (Table 1). Most specimens of *L. dubia* (49 of 60) were collected at the reference stations.

Crustacean, mite, and pycnogonid abundance (508 individuals) in 2002 was less than half of the abundance in 2001 (1,122 individuals) and well below the mean abundance (741 individuals) for the 1986 and 1990 through 2001 collections. However, the number of taxa collected in 2002 (46 taxa) was close to the record 2001 total (51 taxa) and greater than the mean number of taxa (41.3) recorded for previous collections. The 2002 totals are comparable to the 600 individuals and 39 taxa collected in 2000.

The ranges for total number of crustacean individuals and taxa collected at the ZID-area stations (27 to 61 individuals; 3 to 18 taxa) were almost entirely below the ranges observed at the reference stations (62 to 153 individuals; 18 to 27 taxa). The crustaceans were particularly diminished at ZID-boundary station HB4, where only 2 noncopepod individuals representing 2 taxa were collected this year. In 2001, 46 noncopepod individuals representing 11 taxa were collected at Station HB4. The unusually high numbers of individuals (303) and taxa (28) collected at ZID station HZ in 2001 declined to 27 individuals and 15 taxa in 2002, reflecting counts that are more typical of Station HZ in previous survey years. The reductions were also evident for collections at the reference stations where 152 to 201 individuals and 20 to 36 taxa were collected in 2001. Nonetheless, the 2002 monitoring data suggest a pattern of crustacean depression near the ZID.

No new crustacean taxa were collected in 2002. The total number of discretely identified/reported taxa from the study area since 1990 remains at 107. Given the lower abundance in 2002 and the long-term sampling effort at these stations, the failure to collect new, rare taxa is not surprising. The true number of individual crustacean taxa present in the study area is actually higher. Copepods are enumerated as a single taxon, although several different taxa are certainly present. Cumaceans and mysids are similarly enumerated. Between two and eight taxa have been newly collected each year since the combined 1990 and 1991 years when the total taxa collected was 62. The spike of eight new taxa seen in 1999 was not repeated since, suggesting that anomaly probably represented a particularly efficient year in terms of collection, sample processing, and recovery, rather than a shift in the composition of the overall crustacean community. The Barbers Point outfall study area does not appear to be subject to extremely large swings in benthic community composition or consistency. It seems to be generally a rather stable environment. This should aid in identifying any impacts associated with the outfall itself.

Mollusks

A total of 9,798 mollusks representing 126 taxa were collected. Mean abundance of mollusks per sample (no./10 cm^3) ranged from 202.2 (at Station HB3) to 476.8 (at Station HB1) (Figure 16). Data were normally distributed at all stations except Station HB1 (Appendix Table C.1). Complete basic statistics for total mollusk abundance data are shown in Appendix Table C.1.

Mean number of mollusk taxa per sample ranged from 22.2 (at Station HB2) to 37.0 (at Station HB7) (Figure 17). Data were normally distributed at all stations (Appendix Table C.2). Complete basic statistics for number of mollusk taxa at all stations are shown in Appendix Table C.2.

Variances were homogeneous for untransformed mollusk abundance data (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. Mean abundance was also significantly greater at Station HB7 than at Stations HB3, HZ, HB2, and HB6 and significantly greater at Station HB4 than at Stations HB3, HZ, and HB2.

Variances for number of mollusk taxa data were homogeneous (Appendix Table C.4). There were significant differences in mean mollusk taxa number among stations (ANOVA, Appendix Table C.4). Mean number of mollusk taxa was significantly greater at Station HB7 than at Stations HB2, HZ, HB4, and HB3 and at Station HB6 than at Station HB2.

Diversity (H') ranged from 2.14 (at Station HB2) to 2.82 (at Station HB7) (Figure 18). Evenness (J) ranged from 0.58 (at Station HB2) to 0.68 (at Station HB3). Diversity values for mollusks were relatively high at Station HB7 and relatively low at Station HB2. Evenness values were generally similar for all stations (Figure 18).

The mollusk abundance patterns are consistent with those of all previous sampling years (Nelson et al. reports; Swartz et al. reports). Mollusk abundance for each taxon from each replicate is provided for each station in Appendix E. The molluscan fauna was similar at all stations, especially among the dominant taxa (Table 2). The gastropod taxa *Diala scopulorum*, *Cerithidium perparvulum*, *Diala semistriata*, *Scaliola* spp., and *Balcis* spp. were abundant at all stations. *Finella pupoides* was abundant at all stations except Stations HB1 and HB7. *Scaliola* spp. was most abundant at stations where *Finella pupoides* was least abundant. *Lophocochlias minutissimus* was most abundant at Stations HB1. These seven dominant mollusk taxa accounted for 75.7% of all individuals collected.

The results of cluster analysis indicating the relative similarity of the molluscan assemblage at the seven stations are shown in Figure 19. The analysis indicated that all stations were very similar to one another (similarity index for final cluster: 66.5%). The dendrogram shows a main cluster of four stations with very high similarity (>75%). The cluster includes two ZID-boundary stations (HB3 and HB4), the ZID station (HZ), and one reference station (HB6). Reference stations HB1 and HB7 were not greatly different from the main cluster (71.6% similarity). ZID-boundary station HB2 was the last station added to the cluster, linking with the other stations at a high similarity index value of 66.5%. A station cluster pattern similar to that shown in Figure 19 was also seen in 1998, 1999, 2000, and 2001 (Swartz et al. 2000a, 2000b, 2001), although Station HZ was more distinct from the other stations in 2001.

The mollusk specimens collected in these surveys were not separated into living and dead shell material and therefore represent time-averaged collections that integrate conditions over a long period. The living component of the mollusk fauna which is exposed to current discharge and effluent conditions may respond more quickly than is evident in the time-averaged collections. Thus, the evidence for high similarity of the mollusks among sampling stations may have been enhanced by the inclusion of empty shell counts in the cluster analysis.

DISCUSSION

In 2002 there were no statistically significant differences among stations in mean total nonmollusk abundance and mean total number of nonmollusk taxa. Nonmollusk abundance was quantitatively greater at all ZID-area stations than at reference station HB1. The number of nonmollusk taxa was quantitatively less at ZID station HZ and at ZID-boundary stations HB3 and HB4 than at all of the reference stations. These statistically insignificant differences do not reflect a major influence of the Barbers Point effluent discharge. The 2002 results for the nonmollusks are similar to those obtained in most previous survey years for samples taken near the Barbers Point Ocean Outfall. The nonmollusks have generally been just as abundant and speciose at the stations near the outfall (HB2, HB3, HB4, and HZ) as at the reference stations (HB1, HB6, and HB7) (Nelson et al. reports; Swartz et al. reports).

The 2002 results for the crustaceans provide evidence for reduced crustacean abundance and taxa richness at some stations near the outfall. Mean crustacean abundance was particularly low at ZID station HZ (5.4 individuals/sample, about half of the next lowest station mean). Mean crustacean abundance was significantly greater at reference station HB7 that at all of the ZID-area stations. The abundant crustaceans at Station HB7 were not characteristic of all reference stations since mean abundance there was also significantly greater than that at reference station HB6. There were no significant differences in crustacean abundance between all ZID-area stations and reference stations HB1 and HB6. Nonetheless, a pattern of reduced abundance near the ZID is evident since the range in mean abundance for the ZID-area stations (5.4 to 12.2 individuals/sample) was below the range for the reference stations (12.4 to 30.6 individuals/sample). The mean number of crustacean taxa was significantly greater at all reference stations than at ZID station HZ and ZID-boundary station HB4. There were no significant differences in crustacean taxa richness between the reference stations and ZID-boundary stations HB2 and HB3. The crustaceans were particularly diminished at ZID-boundary station HB4 where a total of only two noncopepod individuals were collected. A depauperate crustacean fauna was evident at Stations HB3, HB4, and HZ in 2000 (Swartz et al. 2000b). Conditions improved greatly at ZID station HZ but not at ZID-boundary stations HB3 and HB4 in 2001. Also, in 2001 and 2002, several specimens of the stress-sensitive indicator species *Paraphoxus* sp. A were collected at the ZID-area stations, except for Station HB4.

Statistical comparisons show that mollusk abundance and taxa richness in 2002 were highest at two of the reference stations, but they do not indicate spatial patterns that are consistently related to the outfall discharge. For example, reference stations HB1 and HB7 had the highest mollusk abundance, but more mollusk individuals were collected at ZID-boundary station HB4 than at reference station HB6. Also, mean number of mollusk taxa was higher at all reference stations than at any of the ZID-area stations, but the total number of mollusk taxa was slightly higher at ZID station HZ (48 taxa) and ZID-boundary stations HB3 (47 taxa) and HB4 (48 taxa) than at reference station HB1 (46 taxa). Nonetheless, 12 of the 24 possible comparisons of mollusk abundance or taxa richness among the reference and ZID-area stations resulted in significantly higher mean values at the reference stations. There were no cases where mollusk abundance or taxa richness was significantly higher at a ZID-area station than at a reference station. There are annual fluctuations in the abundance of mollusks among stations. Mollusks were most abundant at Station HB1 in 1992, 1993, 1994, 1995, 1997, 1998, 2000, 2001, and 2002, but they were third in abundance in 1996 (behind Stations HB4 and HZ) and in 1999 (behind Stations HZ and HB7) (Nelson et al. reports; Swartz et al. reports).

Mean crustacean taxa richness per replicate may not be as useful as total taxa richness per station as an indicator of outfall effects, given the high intrastation variability encountered. The total number of crustacean taxa collected at ZID station HZ increased from 12 in 2000 to 28 in 2001, but then declined to 15 in 2002. The total number of crustacean taxa at ZID-boundary station HB4 declined from 15 in 2000 to 12 in 2001 to 3 in 2002—substantially less than the minimum (15 taxa) found at the other six stations in 2002. Between 18 and 36 crustacean taxa were collected at each of the reference stations in 2000, 2001, and 2002.

The decreases in crustacean abundance and taxa richness between 2001 and 2002 were evident at most ZID-area and reference stations. The average percent decrease in mean crustacean abundance was 37% at reference stations HB1, HB6, and HB7; 45% at ZID-boundary stations HB2, HB3, and HB4; and 91% at ZID station HZ. The average percent decrease in mean number of crustacean taxa was 18% at the reference stations, 30% at the ZID-boundary stations, and 75% at the ZID station. The 2001–2002 decline at Station HZ was much greater than at all other stations, but the 2000–2001 increase at Station HZ was also much greater than at the other stations. The 2001–2002 decline was not evident at reference station HB7 where crustacean abundance and taxa richness increased slightly.

Reductions in crustacean abundance and taxa richness near the Barbers Point Ocean Outfall relative to reference stations have not been observed in every previous sampling year. Although in some years (e.g., 1991, Nelson et al. 1992a) taxa richness appeared to be reduced adjacent to the outfall, this pattern had not been seen for several years until 1998. It was seen again in 2000, to a lesser extent in 2001, and in 2002. In 1999 and 2001 the crustacean community of the study area was more abundant and diverse than in most other years. The shifting patterns of number of taxa and abundance from year to year appear to be more strongly influenced by other factors, such as small-scale differences in bottom topography or a subtle variation in sediment composition. The presence of nine species of stress-sensitive gammaridean amphipods (including *Paraphoxus* sp. A) at the ZID-area stations also indicates that any changes in the crustacean assemblage near the outfall in 2002 are associated with factors other than chemical contamination by the effluent discharge. However, the collection of only two noncopepod crustacean individuals in the five samples at ZID-boundary station HB4 (mean = 0.4 individuals/sample) suggests the influence of anthropogenic factors. For comparison, the number of noncopepod crustaceans collected in the 15 reference samples in the present survey ranged from 7 to 31 individuals/sample (mean = 17.9 individuals/sample). Also, the number of noncopepod crustaceans collected in the Māmala Bay regional monitoring survey within the depth range for Station HB4 ranged from 9 to 34 individuals/sample (mean = 18.0 individuals/sample, Swartz et al. 2002). The abundance of noncopepod crustaceans at Station HB4 is clearly below the range of natural variability for Māmala Bay. This reduction appears to be related to the proximity of Station HB4 to the Barbers Point outfall.

Taxonomic diversity (expressed here simply as the number of discretely recorded taxa) is considered to be a better measure of the state of the crustacean communities at these sampling stations than the number of recorded individuals. For the smaller crustaceans (tanaids, isopods, and amphipods) and pycnogonids, abundance can be strongly influenced by a large number of juveniles released from brooding adults. Abundance data generated from other taxa (such as mollusks, most polychaetes, and many decapods) represent a settlement from the plankton of a larval form which has found the site suitable for habitation. While high crustacean abundance data (particularly if juveniles are being produced) clearly indicate that the site is suitable, low abundance data are not necessarily indicative of unsuitability.

A rather comprehensive picture of the crustacean communities in the study area has been developed (at least for crustaceans smaller than 1 cm) despite the rather small areal coverage (7.6 cm diameter) of the sampling replicates. This reef slope crustacean community remains dominated by the smaller crustacean groups (copepods, ostracods, tanaids, isopods, and amphipods), with scattered collections of small decapods. An average of about four new taxa have been found during each annual survey since 1991. No new taxa were recorded in 2002. Larger (2 cm and up) shrimp and crabs, while certainly present in the study area, have almost no chance of being collected. In general, the crustacean community in the Barbers Point outfall study area is less diverse than that near the Wai'anae outfall and more diverse than that near the Sand Island outfall.

Both diversity and evenness values were generally similar among stations for both nonmollusks and mollusks. Diversity and evenness values were lowest at Station HB3 for nonmollusks and at Station HB2 for mollusks. Lower nonmollusk diversity and evenness values were reported for Station HB2 in 1993, but this pattern has not been repeated since (Nelson et al. 1994a, 1994b, 1995, 1996, 1997a; Swartz et al. reports). Except for the crustaceans, there is little evidence that the outfall is having an effect on taxa richness of the macrobenthos in the vicinity of the diffuser pipe.

Cluster analysis using the quantitative Bray–Curtis similarity index indicated that nonmollusk abundance and taxa composition were broadly similar at most stations (>63% similarity index value). Six of the stations clustered at very high similarity values in the narrow range of 73% to 76%. These included ZID station HZ, ZID-boundary stations HB2 and HB3, and all of the reference stations. ZID-boundary station HB4 was the last station to join the cluster (at 64% similarity). Although most of the abundant species at Station HB4 were also abundant at other stations, two of the dominants at Station HB4 (the polychaetes *Ophryotrocha adherens* and *Pionosyllis spinisetosa*) were rare or absent at all other stations (Table 1). *Ophryotrocha adherens* is considered an indicator of organic enrichment, although sediment TOC was not elevated at station HB4 (Appendix Table A.2; Bailey–Brock 1996). In the period from 1986 to 1993, cluster analysis consistently intermixed ZID, ZID-boundary, and reference stations (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). In 1994 and 1995, some separation between stations in or near the ZID and far-field reference stations was observed (Nelson et al. 1994b, 1995). In 1996 (Nelson et al. 1996), 1997 (Nelson et al. 1997a), 1998 (Swartz et al. 1998), 1999 (Swartz et al. 1999), 2000 (Swartz et al. 2000a), and 2001 (Swartz et al. 2001) stations were again generally interspersed in the cluster analysis. The clustering of far-field reference stations HB1 and HB7 in 2002 indicates some separation between near-ZID and far-field stations, but the clustering of near-field reference station HB6 with the ZID and ZID-boundary stations suggests the nonmollusk fauna near the ZID is not greatly different from the reference assemblage. In comparing the 1996 through 2002 cluster results with those of earlier years, some caution is necessary since the clustering algorithm was changed in 1996 from flexible to group-average sorting in order to conform to current recommendations for optimum methodologies (Carr 1993).

Cluster analysis of the mollusks also indicated relatively high similarity of abundance and taxa composition among stations (>66% similarity index value). The four most similar stations included two ZID-boundary stations (HB3 and HB4), the ZID station (HZ), and a reference station (HB6). Dominant mollusk taxa were remarkably similar. The list of taxa that ranked among the five most abundant taxa at any of the stations included only seven species. These seven species were ubiquitously distributed among stations, although *Scaliola* spp. was most abundant where *Finella pupoides* was least abundant. The dominant species and cluster analyses indicate considerable homogeneity of the mollusks among reference and ZID-area stations.

Sediment grain sizes in the 2002 samples were broadly similar among stations. Sand accounted for >92% of the sediment weight at all stations. The coarse-sediment fraction was moderately higher at Stations HB1, HB4, and HB7 (range: 34.3% to 40.8%) than at the other stations (range: 18.6% to 29.2%). Conversely, the fine-sand fraction was moderately lower at Stations HB1, HB4, and HB7 (range: 29.4% to 34.9%) than at the other stations (range: 36.6% to 47.6%). The percentage of fine sediments at ZID station HZ was slightly greater in 2002 (4.1%) than in 2001 (3.7%), 2000 (4.0%), 1999 (2.8%), 1998 (3.0%), and 1997 (3.2%) (Nelson et al. 1997; Swartz et al. reports), although these differences are probably of no ecological significance. The increase in the silt-and-clay fraction of the sediments observed in 1993 for all stations began to moderate in 1996, and this trend continued in 1997, 1998, and 1999 (for comparison see figure 3 in Nelson et al. reports and in Swartz et al. reports). The mean percentage of the silt-and-clay fraction in 2002 (4.5%), 2001 (4.2%), and 2000 (4.2%) was less than that observed in 1997 (4.8%,) and 1998 (4.9%) but slightly more than that observed in 1999 (4.1%) (Nelson et al. 1997; Swartz et al. reports). The increase in fine sediments in 1993 occurred at all seven stations, thus it is unlikely to have been an effect of the outfall discharge.

ORP analysis showed no evidence of reducing conditions at the surface of sediments at any station in 2002; this has been the consistent pattern for this parameter. ORP measurements were highest at ZID-boundary station HB3. They were significantly lower at reference station HB1 than at all other stations; significantly lower at ZID-boundary station HB2 than at Stations HB3 and HZ; and significantly lower at ZID-boundary station HB4 than at Station HB3. Since ORP values are inversely related to the potential for reducing conditions, these data indicate that anoxic sediment conditions are not likely to occur at the ZID-area stations. Station ORP values in 2002 were similar to those obtained in 2001.

There were no significant differences among stations in mean O&G measurements. The highest mean O&G measurements were recorded at ZID-boundary station HB3 (290 mg/dry kg) and at reference station HB1 (208 mg/dry kg). O&G measurements have varied substantially between years (Nelson et al. reports; Swartz et al. reports). The maximum mean O&G measurement in 2001 was 589 mg/dry kg, and there was no significant difference among stations (Swartz et al. 2001, originally reported erroneously as 589 mg/wet kg). O&G was not analyzed in 2000.

Sediment TOC was 0.38% or less in all replicate samples in 2002. Thus there continues to be no evidence of sediment organic enrichment near the outfall. The average TOC in 2002 (0.17%) was slightly higher than in 2001 (0.11%). The absence of detectable sediment TOC was reported for all samples collected in 1996 and 1997 and for many samples in 1998, 1999, and 2000. TOC values in years prior to 1996 were low, but above detection limits. The TOC analytical method used from 1996 through 2000, which removed organic carbon from the sediment during acid digestion, may have consistently underestimated sediment TOC (Nelson et al. 1997; Swartz et al. reports). This problem appears to have been resolved because there were no below-detection-limit TOC measurements recorded in 2001 or 2002.

The total number of nonmollusk taxa recorded in 2002 (191) is the highest value recorded in the fourteen years of monitoring at the Barbers Point Ocean Outfall (162 in 1986, 164 in 1990, 162 in 1991, 175 in 1992, 144 in 1993, 159 in 1994, 151 in 1995, 147 in 1996, 138 in 1997, 140 in 1998, 183 in 1999, 164 in 2000, and 186 in 2001). The 46 crustacean, mite, and pycnogonid taxa collected in 2002 was also greater than most values observed in earlier years, when counts ranged from 34 to 51 taxa. That range does not include the low value of 27 taxa collected in 1997, when counts were reduced because of differences in sample handling. 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 2002.

Mean nonmollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2002 (Figures 20 and 21). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Numerous pairwise comparisons among dates showed significant differences, generally with values for recent dates being higher than values for earlier dates. The abundance of nonmollusks in 2002 was quantitatively, but not significantly, less than that of all years from 1996 through 2001 and greater than of all years before 1996. The temporal pattern of increasing nonmollusk abundance was confirmed by a linear regression analysis of data from 1990 to 2002, which found a trend of significantly increasing mean abundance over this period ($p = 0.002$, $y = 8.10x + 11.52$, where y = mean nonmollusk abundance and x = year code: 1990 = 10 through 2002 = 22). The slightly lower mean nonmollusk abundance in 1997 versus 1996 and 1998 through 2001 is partly explained by the processing differences for the crustaceans during 1997.

The Student–Newman–Keuls test showed four significant pairwise multiple contrasts among stations for mean nonmollusk abundance based on data collected in 1986 and from 1990 through 2002. Nonmollusk abundance for the fourteen combined surveys was greater at ZID-boundary station HB4 than at ZID-boundary stations HB2 and HB3 and reference stations HB1 and HB7.

Mean nonmollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2002 (Figures 22 and 23). Two-way ANOVA results showed significant differences among sampling dates ($p < 0.0001$) but not among sampling stations ($p = 0.09$). Mean nonmollusk taxa richness was significantly lower in 1990 than in all other years and significantly lower in 1997 than in 1992, 1993, 1994, 1996, 1999, 2000, 2001, and 2002 (Figure 22). The low counts for 1997 are due to methodological problems that impacted the number of crustacean taxa collected. Mean nonmollusk taxa richness was also significantly lower in 1986 than in 1992, 1994, 1996, 1999, 2000, 2001, and 2002; significantly lower in 1991 than in 1994, 1999, and 2001; and significantly lower in 1998 than in 1999. Nonmollusk taxa richness was less in 2002 than in 1999, when it was quantitatively greater than in all other years. No temporal trend comparable to that for abundance was seen for nonmollusk taxa richness, nor was any apparent spatial trend seen for this parameter in relation to proximity to the outfall.

Mean crustacean abundance was also compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2002 (Figures 24 and 25). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p = 0.0012$). Mean crustacean abundance in 2002 (14.5 individuals/sample) decreased substantially, but not significantly, over the mean recorded in 2001 (32.1 individuals/sample) and was comparable to that recorded in 2000 (17.1 individuals/sample). Mean crustacean abundance in 1999 was quantitatively higher than in all other years and significantly higher than in all years except 1993, 1994, and 2001. In 1993, 1994, and 2001 it was significantly higher than in 1990 and 1997. The decreased abundance in 1990 is consistent with the overall pattern of nonmollusk abundance for that year. Interannual variations in abundance are not related solely to differences in the time of year that samples were taken. The 1990, 1992, 1994 through 1998, 2001, and 2002 samples—all of which were taken in January or February—show considerable variation in mean crustacean abundance. When all data through 2002 were pooled for station comparisons, Student–Newman–Keuls tests showed no significant differences in historic mean crustacean abundance among stations. Previous historic comparisons of crustacean abundance among stations have often shown significantly greater abundance at reference station HB6 than at ZID-boundary station HB3. This result was obtained for the historic data set through 1997, 1999, 2000, and 2001 (Nelson et al. 1997; Swartz et al. 1999, 2000b, 2001) but not through 1998 (Swartz et al. 1998) or 2002. The historic difference in crustacean abundance among Stations HB3 and HB6 is close to the critical value for statistical significance. Thus, the comparison is influenced by the results for the most recent sampling year. Mean crustacean abundance at Stations HB3 (10.2 individuals/sample) and HB6 (12.4 individuals/sample) were similar in 2002, and the historic comparison was not significant even though crustacean abundance was still greater at Station HB6.

Mean number of crustacean taxa was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2002 (Figures 26 and 27). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean crustacean taxa richness was significantly lower in 1990 than in 1993, 1994, 1995, 1996, 1999, 2000, and 2001; significantly lower in 1997 than in 1993, 1994, 1999, and 2001; and significantly lower in 1986 than in 1994 and 2001. The low mean number of taxa counted in 1990 reflects the low total abundance of crustaceans collected that year. The reduction in crustacean taxa richness in 1997 was due to procedural differences in sample handling. The increase in the number of crustacean taxa collected in 1998 and 1999 reversed a temporal decline that was evident from 1994 through 1997 (Figure 26). The mean number of crustacean taxa collected in 2002 (6.6 taxa/sample) was quantitatively less than that collected in 2001 (9.7 taxa/sample) but was not significantly different from the mean value for 2001 or any other year. Student–Newman–Keuls tests showed that the mean number of crustacean taxa was significantly greater at reference stations HB1 and HB6 than at ZID-boundary station HB4. There is a historic pattern of reduced crustacean taxa richness at all ZID-area stations (Figure 27). In fact, the pooled data for all years show that all stations near the diffuser have fewer crustacean taxa than all reference stations. The overall pattern is consistent with an effect of the diffuser effluent on crustacean taxa. There was a major exception to the historic pattern of a diminished crustacean fauna at the ZID-area stations in 2001: more crustacean taxa were collected at ZID station HZ than at reference stations HB6 and HB7, and significantly more crustacean individuals were collected at Station HZ than at all other stations. The historic pattern was evident in 2002 in the significantly fewer mean number of crustacean taxa collected at ZID station HZ and ZID-boundary station HB4 than at all of the reference stations. However, the mean number of crustacean taxa was quantitatively greater at ZID-boundary station HB2 than at reference station HB6 in 2002. Also, there were no significant differences in the mean number of crustacean taxa between ZID-boundary stations HB2 and

HB3 and any of the reference stations. Any impact the Barbers Point discharge may have on crustaceans was not consistent across the ZID in 2002.

Dominant taxa of the nonmollusk fauna were similar to those of previous sampling years. The representation of nematodes and oligochaetes as a percentage of total abundance was of similar magnitude to that of previous sampling years. The sipunculan *Aspidosiphon muelleri* and the polychaete *Pionosyllis heterocirrata* were the first- and second-most abundant taxa in 2002, respectively (Table 1). The dominant polychaete taxa since 1994 showed some variation from earlier sampling years (Nelson et al. 1987, 1991, 1992a, 1992b, 1994a). Other dominant taxa in 2002 were similar to those found in 1994 through 2001 (Nelson et al. 1994b, 1995, 1996, 1997a; Swartz et al. reports) and included the polychaetes *Synelmis acuminata*, *Euchone* sp. B, *Ophiodromus angustifrons*, *Myriochele oculata*, *Prionospio cirrifera*, *Myriochele* sp. A, *Augeneriella dubia*, *Prionospio cirrobranchiata*, *Fabricia* sp. A, *Ophryotrocha adherens*, and *Pionosyllis spinisetosa*, as well as the tanaid *Leptochelia dubia*. (Table 1). The amphipod *Eriopisella sechellensis* was a dominant species at reference stations HB1 and HB6 in 2001, but it was less abundant and did not qualify as a dominant at any station in 2002.

Mean mollusk abundance was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2002 (Figures 28 and 29). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$) and among sampling stations ($p < 0.0001$). Mean mollusk abundance was significantly greater in 1998, 2001, and 2002 than in 1986, 1990, 1991, 1992, 1993, 1994, and 1995 and significantly greater in 2000 than in 1986, 1991, 1992, and 1993. Mean mollusk abundance was significantly greater at reference station HB1 than at all other stations. Neither the temporal nor spatial pattern of differences indicates a negative effect of the diffuser effluent on mollusk abundance.

Because the mollusk specimens were not separated into living and dead shell material, they represent time-averaged collections that integrate conditions at a site over a long period. Temporal variability in abundance among sampling dates was generally much less for the mollusk fraction than for the nonmollusk fraction prior to 1996. There has been a temporal trend of increasing mollusk abundance since 1993 (Figure 28). The pattern of abundance in the sampling area on all dates shows that Station HB1 has historically had the greatest number of mollusk individuals (Figure 29). Consistent with the historic pattern, Station HB1 had significantly higher mean mollusk abundance than all other stations in 2002 (Table C.3).

Mean mollusk taxa richness was compared among sampling dates and among sampling stations for data collected in 1986 and from 1990 through 2002 (Figures 30 and 31). Two-way ANOVA results showed significant differences both among sampling dates ($p < 0.0001$)

and among sampling stations ($p < 0.0001$). Mean mollusk taxa richness was significantly greater in 1998 than in 1986, 1990, 1991, 1992, 1993, 1994, and 1995; significantly greater in 1997 than in 1990, 1992, and 1993; and significantly greater in 1996, 1999, 2000, 2001, and 2002 than in 1990 and 1992. Mean mollusk taxa richness was significantly greater at Station HB7 than at Stations HB2, HZ, and HB6 and significantly greater at Stations HB1 and HB4 that at Station HB2. Nine of the twelve possible pairwise comparisons of mollusk taxa richness between reference stations (HB1, HB6, and HB7) and ZID-area stations (HB2, HB3, HB4, and HZ) were not statistically significant. There has been a temporal pattern of increasing number of mollusk taxa since 1992 (Figure 30). Neither the temporal nor spatial pattern of differences indicates a consistent negative effect of the diffuser effluent on mollusk taxa richness.

SUMMARY AND CONCLUSIONS

Measurements of physical parameters continue to show little evidence of a buildup of organic matter in the vicinity of the Barbers Point Ocean Outfall diffuser. Positive ORP measurements at all stations indicated the absence of reducing conditions. Sediment TOC was less than 0.40% in all samples in 2001 and 2002 and was very low or undetectable from 1996 through 2000. In years prior to 1996, mean sediment TOC was in the narrow range of 0.04% to 0.47%, except in 1993 when methodological problems were experienced with the analyses and values ranged from 0.56% to 1.40%. The ocean outfall in Orange County, California, discharges onto the continental shelf in an erosional benthic environment (Maurer et al. 1993) which may be somewhat similar to that found in Māmala Bay, Oʻahu. In the vicinity of the Orange County outfall, sediment TOC ranged from approximately 0.3% to 0.9% (Maurer et al. 1993). In areas which possess more depositional benthic environments, the percentage of organic content in the sediments is typically much higher. For example, this percentage 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 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 near the Barbers Point Ocean Outfall suggests that little particulate matter from the diffuser ever reaches the sediment surface in the study area.

The spatial patterns of organism abundance and taxa richness in relation to the outfall varied depending on the taxonomic grouping. There were no consistent, statistically significant patterns of reductions of either organism abundance or taxa richness of nonmollusks and mollusks near the diffuser in 2002. The macrobenthos was much more similar than dissimilar among the seven sampling stations. Separate cluster analyses of nonmollusk and mollusk data indicated that all stations were similar to one another in terms of taxa composition and relative abundance (similarity >63% for nonmollusks, >66% for mollusks). The dominant mollusk taxa were almost identical at all stations. Only seven taxa are on the list of mollusks that rank among the five most abundant taxa at any one of the seven stations.

The abundance of nonmollusks and mollusks in the study area has increased in recent years. However, there is no consistent spatial pattern in the historic abundance or taxa richness of either nonmollusks or mollusks that indicates an effect of the outfall effluent. The respective numbers of nonmollusk individuals, mollusk individuals, and mollusk taxa collected in 2002 were near the top of their historic range. The number of nonmollusk individuals was less than in all years from 1996 through 2001 and greater than in all years before 1996.

The abundance and taxa richness of crustaceans decreased in 2002 from the high levels recorded in 2001, especially at ZID station HZ and ZID-boundary station HB4. There is a historic pattern of reductions in crustacean abundance and taxa richness at the four ZID-area stations relative to each of the reference stations. This pattern may indicate a trend related to proximity to the diffuser. Relatively low values of crustacean abundance and taxa richness were recorded in 2002 at ZID-area stations HB3, HB4, and HZ. The mean number of crustaceans collected at Station HZ was 5.4 individuals/sample in 2002—an order of magnitude less than the mean of 60.6 individuals/sample recorded at that station in 2001. Fewer crustacean taxa were collected at Station HB4 than at any other station in 2001 (5.0 taxa/sample) and 2002 (1.4 taxa/sample). Only two noncopepod crustacean specimens were collected at Station HB4 in 2002. However, most (14) of the 24 possible comparisons of abundance and taxa richness between ZID-area stations and reference stations were not statistically significant. The presence of pollution-sensitive taxa like amphipods (especially the phoxocephalid *Paraphoxus* sp. A) indicates that the diminished crustacean fauna at the ZID-area stations may be related to a noncontaminant factor.

Despite the crustacean reductions at some stations, the macrobenthos was very abundant and diverse in the ZID area. A combined total of 8,367 nonmollusk and mollusk individuals and 235 taxa were collected in all ZID-area samples, which represent a total sampling area of less than 0.1 m^2.

Taxa diversity (H') and evenness (J) were generally similar among all stations for both total nonmollusks and mollusks. The model of benthic organic enrichment by Pearson and

Rosenberg (1978) proposes that in the transition zone on an enrichment gradient, a few taxa 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 indication of the types of changes in bottom communities predicted by the organic enrichment hypothesis. Maurer et al. (1993) proposed that the Pearson–Rosenberg model may be inappropriate for erosional continental shelf environments. Their study of an outfall on the continental shelf off California found that even with some organic enrichment near the diffuser, there was no evidence of elimination of rare species, even though three species did achieve numerical dominance. The response of the benthic community near the Barbers Point Ocean Outfall does not show the alternate response pattern described by Maurer et al. (1993), presumably because sediment organics there do not show even the moderate enrichment found near the Orange County outfall.

The 2001 regional monitoring survey showed that changes in the macrobenthos of Māmala Bay were associated primarily with water depth, a result that is consistent with the spatial distribution of the macrobenthos at other coastal sites (Swartz et al. 2002; Bergen et al. 2001). Relative to sites of comparable depth, the areas of Māmala Bay in the immediate vicinity of the Barbers Point and Sand Island outfalls were uniquely characterized by the presence of *Ophryotrocha adherens*, a dominant species at Station HB4 in the present survey. The regional survey showed that the abundance and taxa richness of the crustaceans were diminished near the outfalls relative to other areas of Māmala Bay. Reductions in the crustacean assemblage at the Barbers Point ZID-area stations were evident in the present survey. The regional survey also showed that the abundance and richness of both the nonmollusks and mollusks were similar at sites near the outfalls and at sites of comparable depth in Māmala Bay. The high similarity of the nonmollusks and mollusks at reference and ZID-area stations in the present survey is consistent with the results of the regional survey.

In conclusion, there is little evidence of adverse effects of the Barber Point Ocean Outfall on the macrobenthic community in 2002. The primary indication of an effect lies in the crustacean component: there were quantitatively fewer individuals and taxa at ZID-area stations HB3, HB4, and HZ than at all of the reference stations. The presence of nine amphipod species at the ZID-area stations indicates that alterations in the crustacean component may be related to a noncontaminant factor. The analyses of the noncrustacean fauna clearly demonstrate the presence of a diverse and abundant macrobenthos within and near the ZID of the Barbers Point Ocean Outfall.

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TABLE 1. Abundance of Numerically Dominant Nonmollusk Taxa, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2002

Taxon	Number of Individuals							Total
	Station							
	HB1	HB2	HB3	HB4	HZ	HB6	HB7	
Aspidosiphon muelleri	88*	84*	235*	51*	159*	124*	92*	833
Pionosyllis heterocirrata	41*	23*	51*	97*	22	52*	76*	362
Synelmis acuminata	51*	34*	39*	9	23*	44*	144*	344
Euchone sp. B	7	139*		4	7	110*		267
Ophiodromus angustifrons	11	12	29	24	16	26*	24*	142
Myriochele oculata	14	3	42*	35	33*	12	2	141
Prionospio cirrifera	23*	22*	10	4	4	22	27*	112
Myriochele sp. A	2	4	55*	4	33*	11	1	110
Augeneriella dubia	3	3	28	36*	13	3	9	95
Prionospio cirrobranchiata	26*	9	24	4	11	7	12	93
Fabricia sp. A	4	8	19	16	23*	14	4	88
Leptochelia dubia	23*	3	6		2	2	24*	60
Ophryotrocha adherens			2	56*	1			59
Pionosyllis spinisetosa	2	3		39*				44

*Ranked among the five most abundant nonmollusk taxa at individual stations.

TABLE 2. Abundance of Numerically Dominant Mollusk Taxa, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2002

Taxon	Number of Individuals							Total
	Station							
	HB1	HB2	HB3	HB4	HZ	HB6	HB7	
Diala scopulorum	446*	360*	284*	282*	226*	166*	134*	1,898
Cerithidium perparvulum	40	250*	78*	223*	90*	227*	404*	1,312
Diala semistriata	454*	51*	59*	157*	66*	134*	256*	1,177
Finella pupoides	1	37*	185*	289*	327*	262*	3	1,104
Scaliola spp.	447*	202*	41	85	44	39	92*	950
Balcis spp.	194*	25	86*	148*	93*	130*	111*	787
Lophocochlias minutissimus	125*	21	6	7	8	1	20	188

*Ranked among the five most abundant mollusk taxa at individual stations.

TABLE A.1. Position and Depth for Replicate Grab Samples, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2002

Station	Sampling Date	Replicate	Position		Depth (m)
			Latitude	Longitude	
HB1	21 January	1	21°16'50.5"	157°59'13.5"	62.2
		2	21°16'50.6"	157°59'13.6"	61.9
		3	21°16'50.6"	157°59'13.7"	62.5
		4	21°16'50.4"	157°59'13.3"	62.2
		5	21°16'50.6"	157°59'13.4"	62.2
HB2	21 January	1	21°17'00.0"	158°01'20.7"	61.0
		2	21°17'00.0"	158°01'20.6"	61.3
		3	21°17'00.1"	158°01'20.7"	61.3
		4	21°17'00.2"	158°01'20.8"	61.0
		5	21°17'00.1"	158°01'20.8"	60.7
HB3	22 January	1	21°16'53.6"	158°01'28.9"	67.1
		2	21°16'53.6"	158°01'29.0"	66.8
		3	21°16'53.5"	158°01'29.1"	67.1
		4	21°16'53.5"	158°01'29.0"	67.1
		5	21°16'53.6"	158°01'29.0"	66.8
HB4	21 January	1	21°16'47.9"	158°01'38.2"	61.0
		2	21°16'47.8"	158°01'38.1"	61.3
		3	21°16'47.6"	158°01'38.2"	61.0
		4	21°16'47.7"	158°01'38.1"	61.3
		5	21°16'47.7"	158°01'38.3"	61.3
HZ	22 January	1	21°16'53.3"	158°01'30.4"	63.7
		2	21°16'53.5"	158°01'30.5"	64.0
		3	21°16'53.5"	158°01'30.6"	64.0
		4	21°16'53.5"	158°01'30.6"	63.7
		5	21°16'53.6"	158°01'30.6"	63.4
HB6	21 January	1	21°16'32.6"	158°01'46.4"	61.9
		2	21°16'32.4"	158°01'46.5"	61.6
		3	21°16'32.6"	158°01'46.7"	61.3
		4	21°16'32.7"	158°01'46.6"	61.6
		5	21°16'32.6"	158°01'47.0"	61.9
HB7	21 January	1	21°15'33.0"	158°03'14.0"	63.4
		2	21°15'33.1"	158°03'14.0"	63.1
		3	21°15'33.0"	158°03'14.0"	63.4
		4	21°15'33.0"	158°03'14.0"	63.4
		5	21°15'33.0"	158°03'13.8"	63.1

SOURCE: Oceanographic Team, Department of Environmental Services, City and County of Honolulu.

TABLE A.2. Sediment Chemical Characterization of Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January 2002

Station (Replicate)	PD (cm)	ORP (+mV)	O&G (mg/dry kg)	TOC (% dry weight)
HB1 (1)	10.0	30	55	0.27
HB1 (1)(dup)			175	0.29
HB1 (2)	9.0	55	141	0.11
HB1 (3)	8.0	105	189	0.38
HB1 (3)(dup)			226	
HB1 (4)	11.0	55		
HB1 (5)	10.0	100		
HB2 (1)	10.0	110	238	0.36
HB2 (2)	9.0	105	55	0.25
HB2 (3)	8.0	90	63	0.17
HB2 (4)	8.0	130		
HB2 (5)	8.0	85		
HB3 (1)	8.0	180	202	0.19
HB3 (2)	7.0	150		0.35
HB3 (3)	7.5	185	163	0.21
HB3 (4)	7.5	170	290	
HB3 (5)	8.0	175		
HB4 (1)	8.0	115	10	0.07
HB4 (2)	11.0	125	295	0.13
HB4 (2)(dup)				0.10
HB4 (3)	7.0	110		0.17
HB4 (4)	8.0	125	170	
HB4 (5)	9.0	165		
HZ (1)	8.0	120	218	0.07
HZ (2)	8.0	165	81	0.09
HZ (3)	9.0	165	259	0.06
HZ (3)(dup)			176	
HZ (4)	8.0	125		
HZ (5)	7.0	170		
HB6 (1)	6.5	150		0.09
HB6 (2)	8.0	140	45	0.08
HB6 (3)	7.0	165	<5	0.11
HB6 (4)	6.0	115		
HB6 (5)	7.0	135	162	
HB7 (1)	8.0	100	64	0.11
HB7 (2)	8.0	145	100	0.15
HB7 (3)	7.0	155	194	0.09
HB7 (4)	8.0	110		
HB7 (5)	8.0	160		

SOURCE: PD (penetration depth), ORP (oxidation-reduction potential), and O&G (oil and grease) data from Oceanographic Team and Environmental Quality Laboratory, Department of Environmental Services, City and County of Honolulu; TOC (total organic carbon) data from Columbia Analytical Services (Kelso, Washington). The original TOC samples were damaged. The TOC data are for replacement samples collected on 7 and 13 February 2002.

TABLE A.3. Sediment Grain-Size Analysis of Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2002

Station-Replicate	Sample Weight Distribution (%)							
	Phi Size							
	-2	-1	0	1	2	3	4	>4-12
HB1-1	0.86	5.52	13.52	22.27	22.11	21.38	7.74	4.36
HB1-2	0.95	2.62	12.86	24.53	24.90	22.29	6.68	3.61
HB1-3	0.12	2.76	13.59	22.91	23.83	22.86	7.39	4.57
HB2-1	0.12	1.94	5.57	20.40	25.75	22.94	14.45	7.01
HB2-2	0.15	1.86	6.94	22.35	25.47	21.86	13.60	7.11
HB2-3	0.09	1.91	6.15	20.06	24.44	22.56	14.52	7.41
HB3-1	1.66	4.03	6.72	14.99	31.11	31.47	7.04	3.18
HB3-1 (dup)	1.20	3.38	7.57	14.98	31.57	32.69	7.53	3.36
HB3-3	0.44	1.28	4.28	12.40	30.60	37.32	8.68	3.31
HB3-4	0.51	1.20	2.86	11.03	31.50	39.02	9.32	3.71
HB4-1	0.31	1.67	8.11	18.00	27.50	28.72	10.31	3.65
HB4-2	2.84	2.40	9.24	19.97	25.96	25.49	8.32	3.02
HB4-4	3.14	4.09	12.98	20.17	24.55	23.24	8.67	3.48
HZ-1	0.17	0.76	4.08	12.18	28.21	37.45	11.50	3.94
HZ-2	0.31	1.25	4.17	11.57	27.64	36.96	11.67	4.27
HZ-3	0.18	1.97	5.35	13.48	28.33	35.33	10.40	4.06
HZ-3 (dup)	0.83	2.00	5.28	13.27	27.65	34.30	10.46	4.37
HB6-2	0.16	1.64	8.70	15.45	22.32	33.75	10.66	4.76
HB6-3	0.71	2.26	7.34	12.70	21.00	35.19	12.70	5.74
HB6-3 (dup)	0.27	2.44	7.30	12.95	21.55	35.50	12.55	5.56
HB6-5	0.72	2.09	7.33	13.33	22.64	35.77	11.89	5.63
HB7-1	3.98	4.09	8.45	14.61	25.89	31.37	7.03	4.15
HB7-2	3.28	10.74	10.20	14.41	24.89	26.85	4.80	3.77
HB7-3	1.52	4.20	10.59	17.55	26.72	27.92	5.92	4.14

SOURCE: Environmental Quality Laboratory, Department of Environmental Services, City and County of Honolulu.

NOTE: The values listed indicate the fraction percentage of the estimated dry weight of the sediment samples. The coarse fraction (-2 to +4) was analyzed by the sieve method. The fine fraction (greater than +4 to +12) was analyzed by the pipette method.

Table B.1. Basic Statistics for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January 2002
(Sample Size n = 5)

Statistic	Station						
	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	148.40	179.00	220.40	211.20	146.60	194.60	238.20
Standard Deviation	32.51	25.53	77.77	27.39	53.43	50.49	120.54
Standard Error of the Mean	14.54	11.42	34.78	12.25	23.89	22.58	53.91
95% of CI Mean	40.36	31.70	96.55	34.00	66.33	62.68	149.65
Skewness	-0.39	-0.74	1.75	-0.13	0.26	0.84	-0.31
Kurtosis	-2.56	0.32	3.26	1.78	-1.31	-1.25	1.67
Median	157.00	188.00	189.00	213.00	157.00	167.00	254.00
Normality Test (D)	0.204ns	0.238ns	0.292ns	0.245ns	0.218ns	0.308ns	0.228ns

Note: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{0.05} = 0.337$; ns = not significant.

Table B.2. Basic Statistics for Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January 2002
(Sample Size n = 5)

Statistic	Station						
	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	43.40	41.20	37.60	36.20	30.80	41.20	43.00
Standard Deviation	5.86	4.87	6.47	4.32	1.48	6.53	12.59
Standard Error of the Mean	2.62	2.18	2.89	1.93	0.66	2.92	5.63
95% of CI Mean	7.27	6.04	8.03	5.37	1.84	8.11	15.63
Skewness	0.61	1.16	0.30	-0.60	0.55	-0.15	-1.98
Kurtosis	0.00	1.92	1.51	-0.52	0.87	1.05	4.12
Median	44.00	40.00	37.00	37.00	31.00	42.00	47.00
Normality Test (D)	0.192ns	0.235ns	0.214ns	0.173ns	0.246ns	0.192ns	0.363*

Note: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{0.05} = 0.337$; ns = not significant, * = $p < 0.05$.

TABLE B.3. Analysis of Variance for Untransformed Nonmollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2002

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	37,215.2	6	6,202.5	1.53	0.206
Experimental Error	113,762.4	28	4,062.9		
Total	150,977.6	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	43.40	41.20	37.60	36.20	30.80	41.20	43.00
Standard Deviation	5.86	4.87	6.47	4.32	1.48	6.53	12.59

F_{max} test for equal variance: Untransformed data, $F_{max} = 22.29$, not significant at $p > 0.05$.

Conclusion: There are no significant differences in mean nonmollusk abundance among the seven stations.

TABLE B.4. Kruskal–Wallis Nonparametric Comparison of Untransformed Nonmollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2002

Untransformed Data Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	43.40	41.20	37.60	36.20	30.80	41.20	43.00
Standard Deviation	5.86	4.87	6.47	4.32	1.48	6.53	12.59

F_{max} test for equal variance: Untransformed data, $F_{max} = 72.05^{**}$, significant at $p < 0.01$; square root transformed data, $F_{max} = 65.94^{**}$, significant at $p < 0.01$; $\log_{10}$ transformed data, $F_{max} = 62.33^{**}$, significant at $p < 0.01$.

Kruskal–Wallis nonparametric comparison

Kruskal–Wallis statistic: $H = 13.457, p = 0.036^{*}$

Conclusion: Despite the significance of the Kruskal–Wallis statistic, no multiple contrasts among the seven stations were statistically significant.

TABLE B.5. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Crustacean Abundance, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2002

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Among Stations	2,150.74	6	358.46	5.78	0.0005
Experimental Error	1,736.00	28	62.00		
Total	3,886.74	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	20.80	12.20	10.20	10.00	5.40	12.40	30.60
Standard Deviation	6.06	5.89	6.50	7.75	6.35	3.91	14.31

F_{max} test for equal variance: Untransformed data, $F_{max} = 13.39$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean crustacean abundance between the following station pairs, as determined by Student–Newman–Keuls tests:

	HZ	HB4	HB3	HB2	HB6	HB1	HB7
HZ		–	–	–	–	–	*
HB4			–	–	–	–	*
HB3				–	–	–	*
HB2					–	–	*
HB6						–	*
HB1							–

– = not significant; * = $p < 0.05$.

TABLE B.6. Analysis of Variance and A Posteriori Comparison of Means for Square Root Transformed Crustacean Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O'ahu, Hawai'i, January 2002

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	19.59	6	3.26	8.89	0.00002
Experimental Error	10.28	28	0.37		
Total	29.87	34			

Untransformed Data Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	9.80	7.20	5.60	1.40	3.20	6.80	12.00
Standard Deviation	2.17	2.95	1.82	0.55	3.11	2.28	4.69

F_{max} test for equal variance: Untransformed data, $F_{max} = 73.33$*, significant at $p < 0.05$.

Transformed Data Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	3.12	2.63	2.34	1.17	1.51	2.57	3.40
Standard Deviation	0.35	0.58	0.40	0.23	1.07	0.49	0.72

F_{max} test for equal variance: Untransformed data, $F_{max} = 22.19$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean crustacean taxa number between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB4	HZ	HB3	HB6	HB2	HB1	HB7
HB4		–	*	*	*	*	*
HZ			–	*	*	*	*
HB3				–	–	–	–
HB6					–	–	–
HB2						–	–
HB1							–

– = not significant; * = $p < 0.05$.

TABLE C.1. Basic Statistics for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January 2002
(Sample Size n = 5)

Statistic	Station						
	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	476.80	219.80	202.20	286.60	207.60	252.20	314.40
Standard Deviation	32.98	16.57	40.37	52.86	32.85	23.24	18.20
Standard Error of the Mean	14.75	7.41	18.05	23.64	14.69	10.39	8.14
95% of CI Mean	40.94	20.58	50.12	65.63	40.78	28.85	22.60
Skewness	-2.20	-1.66	0.30	0.95	-0.49	0.59	0.13
Kurtosis	4.87	2.50	-2.17	0.87	-0.82	-0.78	0.96
Median	490.00	229.00	199.00	267.00	204.00	242.00	317.00
Normality Test (D)	0.433*	0.311ns	0.228ns	0.245ns	0.230ns	0.270ns	0.222ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{0.05} = 0.337$; ns = not significant; * = $p < 0.05$.

TABLE C.2. Basic Statistics for Untransformed Mollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January 2002
(Sample Size n = 5)

Statistic	Station						
	HB1	HB2	HB3	HB4	HZ	HB6	HB7
Mean	30.20	22.20	28.80	25.60	24.80	33.00	37.00
Standard Deviation	5.07	3.56	3.90	3.58	5.72	4.85	3.67
Standard Error of the Mean	2.27	1.59	1.74	1.60	2.56	2.17	1.64
95% of CI Mean	6.29	4.42	4.84	4.44	7.10	6.02	4.56
Skewness	-0.29	-0.27	0.46	-0.22	0.17	1.38	-0.35
Kurtosis	-2.60	-2.68	-3.12	-1.32	-1.75	2.72	-1.29
Median	31.00	23.00	27.00	27.00	24.00	32.00	37.00
Normality Test (D)	0.228ns	0.215ns	0.278ns	0.252ns	0.169ns	0.300ns	0.193ns

NOTE: CI = confidence interval. Normality was assessed with the Kolmogorov–Smirnov D statistic of goodness of fit to a normal distribution, $D_{0.05} = 0.337$; ns = not significant.

TABLE C.3. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Abundance, Barbers Point Ocean Outfall Sampling Stations, O‘ahu, Hawai‘i, January 2002

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	*p*
Among Stations	278,243.1	6	46,373.85	41.96	<0.0001
Experimental Error	30,946.8	28	1,105.24		
Total	309,189.9	34			

Untransformed Data Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean Abundance	476.80	219.80	202.20	286.60	207.60	252.20	314.40
Standard Deviation	32.98	16.57	40.37	52.86	32.85	23.24	18.20

F_{max} test for equal variance: Untransformed data, $F_{max} = 10.17$, not significant at $p < 0.05$.

Conclusion: There are significant differences in mean mollusk abundance between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB3	HZ	HB2	HB6	HB4	HB7	HB1
HB3		–	–	–	*	*	*
HZ			–	–	*	*	*
HB2				–	*	*	*
HB6					–	*	*
HB4						–	*
HB7							*

– = not significant; * = $p < 0.05$.

TABLE C.4. Analysis of Variance and A Posteriori Comparison of Means for Untransformed Mollusk Taxa Number, Barbers Point Ocean Outfall Sampling Stations, Oʻahu, Hawaiʻi, January 2002

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	p
Among Stations	783.2	6	130.53	6.71	0.0002
Experimental Error	544.4	28	19.44		
Total	1,327.6	34			

Station	HB1	HB2	HB3	HB4	HZ	HB6	HB7
No. of Replicates	5	5	5	5	5	5	5
Mean No. of Taxa	30.20	22.20	28.80	25.60	24.80	33.00	37.00
Standard Deviation	5.07	3.56	3.90	3.58	5.72	4.85	3.67

F_{max} test for equal variance: Untransformed data, $F_{max} = 2.57$, not significant at $p > 0.05$.

Conclusion: There are significant differences in mean number of mollusk taxa between the following station pairs, as determined by Student–Newman–Keuls tests:

	HB2	HZ	HB4	HB3	HB1	HB6	HB7
HB2		–	–	–	–	*	*
HZ			–	–	–	–	*
HB4				–	–	–	*
HB3					–	–	*
HB1						–	–
HB6							–

– = not significant; * = $p < 0.05$.