

**COMMUNITY STRUCTURE OF FISH AND MACROBENTHOS
AT SELECTED SHALLOW-WATER SITES IN
RELATION TO THE BARBERS POINT OCEAN OUTFALL, 1999**

Richard E. Brock

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Principal Investigator: James E.T. Moncur

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

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ABSTRACT

This report provides the results of the eighth year of an annual quantitative monitoring of shallow marine communities inshore of the Barbers Point Ocean Outfall located in 61 m of water offshore of 'Ewa Beach, O'ahu, Hawai'i. The monitoring effort focuses on benthic and fish community structure and is designed to detect changes in these communities. Field sampling was first carried out in August 1991 when three study stations were established: Station BP-1, a control station 2.2 km inshore and east of the outfall terminus; Station BP-2, an experimental station about 1.6 km inshore of the terminus; and Station BP-3, an experimental station about 2.9 km west and inshore of the terminus. The second field effort, completed in May and September 1993, resurveyed the above stations as well as established a fourth station (BP-4) on and adjacent to the basalt armor caprock protecting the discharge pipe in 13 m of water and directly inshore of the outfall terminus. Subsequent field surveys were completed in March and April 1994, in June 1995, in May 1996, in February and April 1997, in January and March 1998, and the most recent in January 1999. These permanently marked stations are sited to capitalize on presumed gradients of impact that may be created by the discharge and movement of treated sewage effluent toward the shore and the coral reef communities. Data from the first survey suggested that marine communities offshore of 'Ewa Beach receive disturbance from a number of possible sources, with the largest perturbation probably coming from natural disturbance caused by occasional wave impact. This was most evident at the station directly inshore of the outfall. Data from Station BP-4 showed that benthic communities situated on armor rock which rises above the flat limestone substratum are not subjected to the same sand scour as those situated on the limestone; thus the coral communities on the elevated caprock are better developed on this substrate.

A comparison of the data from the eight annual surveys indicated that no statistically significant change has occurred in the measured biological parameters at these permanent stations, despite the imposition of a major hurricane on these marine communities in September 1992. Thus the data to date support the contention that the operation of the Barbers Point deep-ocean outfall is not having a quantifiable impact on the coral reef resources situated inshore of the outfall terminus.

INTRODUCTION

Purpose

The Honouliuli Wastewater Treatment Plant (WWTP) located in 'Ewa, O'ahu, Hawai'i, has been in operation since 1982. It releases approximately 22 mgd (0.96 m³/s) of primary treated sewage through a 2,670-m pipe at a depth of 61 m offshore of 'Ewa Beach, O'ahu. In recent years controversy has arisen regarding the impact that sewage effluent from the Honouliuli WWTP may have on inshore coral reef species. Accordingly, commencing in 1991 this study was undertaken in an attempt to quantitatively ascertain the impacts that may be occurring. This document presents the results of the eighth survey carried out on 11 and 15 January 1999 and the underwater photography being completed between 13 and 22 January 1999.

Strategy

Marine environmental surveys are usually performed to evaluate the feasibility of, and ecosystem response to, specific proposed activities. Appropriate survey methodologies reflect the nature of the proposed action(s). An action that may have an acute impact (such as channel dredging) requires a survey designed to determine the route of least harm and the projected rate and degree of ecosystem recovery. Impacts that are more chronic or progressive require different strategies for measurement. Management of chronic stress to a marine ecosystem requires identification of system perturbations that exceed boundaries of natural fluctuations. Thus a thorough understanding of normal ecosystem variability is required in order to separate the impact signal from background "noise."

The impacts confronting the marine ecosystem offshore of 'Ewa Beach are most probably those associated with chronic or progressive stresses. Because of the proximity of the population center and industry to the east, marine communities fronting 'Ewa Beach are probably subjected to a wide array of impacts. Thus a sampling strategy must attempt to separate impacts due to wastewater treatment plant effluent on coral reef communities located at some distance shoreward from a host of other possible perturbations originating in the Honolulu and Pearl Harbor areas.

The waters fronting 'Ewa Beach, into which the deep-ocean outfall discharges, can be considered in terms of gradients. There are numerous "gradients" due to point-source and nonpoint-source (such as storm drains and streams) inputs that are occurring to the east. Because many of these inputs have probably been occurring for a considerable period of time, the species composition and functional relationships of the benthic and fish

communities at any given location in the waters offshore of 'Ewa Beach are those that have evolved under the influence of these ongoing perturbations.

As noted above, if impacts are occurring in the shallow marine communities off 'Ewa Beach because of effluent discharged from the deep-ocean outfall, they are probably chronic in nature which would probably manifest themselves as a slow decline in the communities so impacted. Gradients of "stress" or "impact" should be evident with distance from impact source(s). Thus, to quantitatively define these impacts, one should monitor these communities through time in areas suspected of being impacted, as well as in similar communities at varying distances away from the suspected source(s). This rationale has been used in developing the sampling strategy for this study.

MATERIALS AND METHODS

The quantitative sampling of macrofauna of marine communities presents a number of problems, many of which are related to the scale on which one wishes to quantitatively enumerate organism abundance. Marine communities in the waters offshore of 'Ewa Beach may be spatially defined in a range of a few hundred square centimeters (such as the community residing in a *Pocillopora meandrina* coral head) to many hectares (such as areas which are covered by major biotopes). Because considerable interest focuses on visually dominant corals, diurnally exposed macroinvertebrates, and fishes, we designed a sampling program to delineate changes that may be occurring in communities at this scale.

Four permanently marked stations were selected for the monitoring of benthic and fish community response to possible sewage impacts. The approximate locations of these stations are shown in Figure 1. The first three stations (BP-1, BP-2, and BP-3) were established in 1991 and the fourth (BP-4) in 1993. The stations and the rationale for their selection are given below:

Station BP-1: Located about 2.2 km inshore and to the east (northeast) of the deep ocean outfall terminus. This station, which is utilized as a control site, is located in water ranging from 14.9 to 15.8 m in depth (Figure 1). Although complex, prevailing currents move in an inshore and westerly direction approximately parallel to the shoreline (figure 34 in Laevastu et al. 1964). Thus this station is probably outside (to the east) of any shoreward-moving sewage plume. The substratum at this station is primarily limestone, with corals having a "patchy" distribution across it. Coral coverage may locally exceed 70%. Occasionally shallow sand areas located in depressions are found.

Station BP-2: Located about 0.25 km east of the sewer line and approximately 1.6 km inshore and slightly east (northeast) of the discharge terminus in water ranging from 11.3 to 11.9 m in depth. The substratum at this experimental site is a relatively featureless limestone flat with few corals present.

Station BP-3: Located about 2.9 km west and inshore (northwest) of the terminus of the sewage diffuser in water 16.5 to 16.8 m in depth. The substratum at this experimental site is a mix of rubble/sand and emergent limestone with corals. Coral coverage, which is about 25%, is greater at this station than at Station BP-2.

Station BP-4 Located on the sewer line and approximately 1.4 km inshore of the discharge terminus in water ranging from 12.2 to 13.4 m in depth. The substratum varies from basalt caprock overlying the discharge pipe to relatively flat and featureless limestone adjacent to the discharge pipe. This station was established in 1993 to demonstrate the effect that the elevated basalt caprock substratum has on benthic and fish community development in an area that otherwise is flat and featureless and subjected to occasional sand scour.

At each station two transect lines were permanently established using metal stakes and plastic-coated no. 14 copper wire. The transects are 20 m in length and have an orientation that is parallel to shore. Two transects were established at each location to provide some replication. On each transect are five permanently marked locations (0 m, 5 m, 10 m, 15 m, and 20 m) for the taking of photographs of the benthic communities. A single 0.67 m \times 1 m photographic quadrat was established at each of the marked points, for a total sampling of 3.35 m² of substratum on each transect line.

Because of a lawsuit initiated by Hawaii's Thousand Friends and the Sierra Legal Defense Fund regarding the Barbers Point discharge in 1992–93, additional field sampling was carried out beginning in 1993. The coverage by photo-quadrats was increased from three to five sites, and a visual assessment of benthic communities using a 1 m \times 1 m quadrat was made at each of the photo-quadrat sites (i.e., at the 0 m, 5 m, 10 m, 15 m, and 20 m points on each transect) to provide additional information regarding smaller organisms not readily seen with the photo-quadrat method, such as recently recruited benthic species. These changes have made both the photo- and visual quadrat assessment methods the same as those used to survey the Sand Island deep-ocean outfall stations offshore of Honolulu.

Fish abundance and diversity is often related to small-scale topographical relief over short linear distances. A long transect may bisect a number of topographical features (e.g., coral mounds, sand flats, and algal beds), thus sampling more than one community and obscuring distinctive features of individual communities. To alleviate this problem, a short transect (20 m in length), which has proven adequate for sampling many Hawai'i benthic communities (see Brock 1982; Brock and Norris 1989), was used.

Information is collected at each transect location using methods including a visual assessment of fishes, benthic photo-quadrats and quadrats for field appraisals of cover estimates by sessile forms (e.g., algae, corals, and colonial invertebrates), and counting of diurnally exposed motile macroinvertebrates along the transect line. Fish censuses are conducted over a 4 m \times 20 m corridor (the permanent transect line). All fishes within this area to the water's surface are counted. A single diver equipped with scuba, slate, and pencil enters the water, then counts and records all fishes in the prescribed area (method modified from Brock 1954). Besides counting the individuals of all fishes seen, the length of each is estimated for later use in the determination of fish standing crop using linear regression techniques (Ricker 1975). Species-specific regression coefficients have been developed over the last 30 years by the author and others at the University of Hawai'i, the Naval Undersea Center (see Evans 1974), and the Hawai'i Division of Aquatic Resources from weight and body measurements of captured fishes; for many species, the coefficients have been developed using sample sizes in excess of a hundred individuals. The same individual (the author) performs all fish censuses to keep any bias relatively constant between counts and stations.

Besides divers frightening wary fishes, other problems with the visual census technique include underestimating the size of cryptic species such as moray eels (family Muraenidae) and nocturnal species such as squirrelfishes (family Holocentridae) and bigeyes or 'o(-,a)weoweo (family Priacanthidae). This problem is compounded in areas of high relief and coral coverage that afford numerous shelter sites. Species lists and abundance estimates are more accurate for areas of low relief, although some fishes with cryptic habits or protective coloration, such as scorpionfishes or nohu (family Scorpaenidae) and flatfishes (family Bothidae), might still be missed. Another problem is the reduced effectiveness of the visual census technique in turbid water. This is compounded by the difficulty of counting fishes that move quickly or are very numerous. Additionally, bias related to the experience of the census taker should be considered in making comparisons between surveys. Despite these problems, the visual census technique carried out by divers is probably the most accurate nondestructive assessment method currently available for counting diurnally active fishes (Brock 1982).

A number of methods are utilized to quantitatively assess benthic communities at each station, including the taking of photographs at locations marked for repeated sampling through time (each covering 0.67 m²). Photographs provide a permanent record from which coverage of corals and other sessile forms can be estimated. Cover estimates from photographs are recorded as percent cover. Additionally, to help with later analysis in the laboratory of the coverage recorded in photographs, a visual appraisal of each quadrat is

made in the field, and notes taken on the species present. Beginning with the 1993 survey, supplementary information on benthic coverage was obtained by using 1 m \times 1 m quadrats at the 0 m, 5 m, 10 m, 15 m, and 20 m points on each transect line. In these quadrats a visual assessment of cover was made for each species present. Diurnally exposed motile macroinvertebrates greater than 2 cm in some dimension are censused in the same 4 m \times 20 m corridor used for the fish counts.

If macrothalloid algae were encountered in the quadrats, they were quantitatively recorded as percent cover. Emphasis was placed on those species that are visually dominant, and no attempt was made to quantitatively assess the multitude of microalgal species that constitute the “algal turf” so characteristic of many coral reef habitats.

As requested by regulatory agencies, divers made simple physical measurements at the four stations. Measurements of percent oxygen concentration and temperature were made with a YSI Model 57 Oxygen meter, salinity was taken with a hand-held refractometer, and water clarity was determined using a 12-inch secchi disk. Oxygen measurements were taken approximately 1 m below the water surface and 1 m above the bottom.

Data were subjected to simple nonparametric statistical procedures provided in the SAS Institute statistical package (SAS Institute Inc. 1985). Nonparametric methods were used to avoid meeting requirements of normal distribution and homogeneity of variance in the data. Data were analyzed using the Kruskal–Wallis analysis of variance to discern statistically significant differences among ranked means for each transect site and sampling period; this procedure is outlined by Siegel (1956) and Sokal and Rohlf (1995). The a posteriori Student–Newman–Keuls multiple-range test (SAS Institute Inc. 1985) was also used to elucidate differences between locations.

During fieldwork, an effort was made to note the presence of any green sea turtles (a threatened species) within or near the study sites.

RESULTS

Field sampling was undertaken on 11 and 15 January 1999, and the photographic data were collected by members of the Oceanographic Team, Department of Environmental Services (formerly called the Department of Wastewater Management), City and County of Honolulu in the period between 13 and 22 January 1999. The physical measurements (temperature, salinity, and oxygen) were made on the morning of 27 January 1999. Figure 1 shows the approximate locations of the four stations and Figures 2 through 5 show the orientation of the permanent photographic quadrats on each transect line for the four stations.

The results are presented below by station. All transects other than those at Station BP-4 have an orientation that is parallel to the shoreline. The orientation of the transects at Station BP-4 is approximately perpendicular to the shoreline (parallel to the discharge pipe).

Station BP-1

As noted earlier, Station BP-1 is utilized as a control site. It is situated about 2.2 km inshore and to the east (northeast) of the deep-ocean outfall terminus and is located in water ranging from 14.9 to 15.8 m in depth. The substratum at this station is limestone, with corals overlaying it; coverage may locally exceed 70%, and the dominant species are *Porites lobata* and *P. compressa*. The corals form low ridges (“spurs and grooves”) that have an orientation which is perpendicular to the shoreline. These ridges are 2 to 15 m wide and 4 to 50 m long and are spaced 2 to 20 m apart. In the open areas between the ridges the substratum has a veneer of rubble and sand. The physical damage from Hurricane Iniki, which reduced coral cover at all stations, was greatest at Station BP-3, but Station BP-1 also suffered damage to the coral community, which is evident in the coverage data below.

The two permanently marked transects (BP-1-A and BP-1-B) that sample this station have an orientation that is parallel to the shoreline, are located from 27.3 to 29 m apart, and are out of visual range of one another (see Figure 2). Water clarity at this station usually ranges from 10 to 15 m.

Transect BP-1-A

A summary of the data collected on Transect BP-1-A in January 1999 is presented in Table 1. In the visually assessed quadrat survey (quadrat locations given in Figure 2) two algal species (*Porolithon onkodes* and *Desmia hornemannii*) with a mean coverage of 1.9%, one sponge species (*Chondrosia chucalla*) with a mean coverage of 0.6%, one soft coral species (*Anthelia edmondsoni*) having a mean coverage of 0.1%, and five coral species (*Porites lobata*, *P. compressa*, *Montipora verrucosa*, *M. patula*, and *Pocillopora meandrina*) were encountered. *Porites lobata* continues to be the dominant coral at this station, where mean coral coverage for all species combined was 18.7%. The macroinvertebrate census noted the rock oyster *Spondylus tenebrosus*, the boring bivalve *Lithophaga* sp., the dorid *Chromodoris vibrata*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, and four sea urchin species (*Echinothrix diadema*, *E. calamaris*, *Echinometra mathaei*, and *Heterocentrotus mammillatus*).

The results of the photo-quadrat survey made at the four stations are presented in Table 2. At Transect BP-1-A, four coral species having a mean coverage of 30.7% were recorded. Also recorded was the algal species *Porolithon onkodes* with a mean coverage of 1.6% and

the sponge *Chondrosia chucalla* with a mean coverage of 0.2%. It should be noted that the photographs used in this study were taken close to the time that the visual quadrat data were collected.

The results of the fish census are presented in Appendix Table A.1. Thirty-four species representing 558 individuals were counted in the census on Transect BP-1-A. The most abundant species included the brick soldierfish or menpachi (*Myripristis amaenus*), the black damselfish or 'o(,a)lo'ilo'i (*Dascyllus albisella*), the oval chromis *Chromis ovalis*, the brown surgeonfish or mo(,a)'i'i'i (*Acanthurus nigrofusus*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fishes was estimated at 124 g/m², with the largest contributors including *Ctenochaetus strigosus* (27% of the total), *Myripristis amaenus* (14% of the total), and *Chromis ovalis* (12% of the total).

Transect BP-1-B

Transect number BP-1-B is situated seaward of Transect BP-1- A. The results of the quantitative survey (quadrat locations given in Figure 2) carried out on this transect are presented in Table 3. The quadrat survey noted one algal species (*Porolithon onkodes*) with a mean coverage of 0.7%, one sponge species (*Chondrosia chucalla*) having a mean coverage of 0.2%, one soft coral species (*Anthelia edmondsoni*) with a coverage of 0.4%, and six coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Pavona duerdeni*, *Montipora verrucosa*, and *M. patula*). The dominant coral species was *Porites lobata*, and the mean coral coverage was 13.1%. In the 4 m \times 20 m census area, seven macroinvertebrate species were seen: the rock oyster *Spondylus tenebrosus*, the boring bivalve *Lithophaga* sp., the Christmas tree worm *Spirobranchus giganteus corniculatus*, the featherduster worm *Sabellastarte sanctijosephi*, the black sea urchin *Tripneustes gratilla*, the green sea urchin *Echinometra mathaei*, and the long-spined black sea urchin *Echinothrix diadema*.

The results of the photo-quadrat survey for Transect BP-1-B are given in Table 2. Four coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, and *Montipora patula*) having a mean coverage of 18.8% were noted. Also encountered was the alga *Porolithon onkodes* with a mean coverage of 1.3% .

The results of the fish census are presented in Appendix Table A.1. Forty-one species representing 419 individuals were censused at Transect BP-1-B, where the most common species present were the bluelined snapper or ta'a'pe (*Lutjanus kasmira*), the damselfishes *Dascyllus albisella* and *Chromis ovalis*, the brown surgeonfish or mo(,a)'i'i'i (*Acanthurus nigrofusus*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fish was estimated at 211 g/m², with the largest contributors being *Lutjanus kasmira* (35% of the total) and *Ctenochaetus strigosus* (16% of the total).

Station Observations

In the vicinity of Station BP-1 were seen the corals *Fungia scutaria* and *Montipora flabellata*, as well as the yellowmargin moray eel or puhi paka (*Gymnothorax flavimarginatus*), the undulated moray eel or puhi lau milo (*Gymnothorax undulatus*), and the blue goatfish or moano kea (*Parupeneus cyclostomus*).

Station BP-2

Station BP-2 is located about 1.4 km from shore in water from 11.3 to 11.9 m in depth (Figure 1). The substratum at this location is a relatively flat and featureless limestone with little relief present. Common corals include *Pocillopora meandrina* and *Porites lobata*; other species seen include *Montipora patula*. Three of the common algal species seen in the area were limu kohu or *Asparagopsis taxiformis*, *Sphacelaria furcigera*, and the recently introduced *Avrainvillea amadelpha*.

The two permanently marked transect lines at this station have an orientation that is approximately parallel to the shoreline, with the shoreward transect (BP-2-A) situated at a depth of 11.3 m and the seaward transect (BP-2-B) at a depth of 11.6 to 11.9 m (Figure 3).

Transect BP-2-A

Table 4 presents a summary of the quantitative study made at Transect BP-2-A. The visual quadrat survey (quadrat locations given in Figure 3) noted three sponge species (*Chondrosia chucalla*, *Spirastrella coccinea*, and an unidentified orange sponge) with a mean coverage of 0.7%, one soft coral species (*Anthelia edmondsoni*) with a mean coverage of 0.02%, and five coral species (*Porites lobata*, *Pocillopora meandrina*, *Psammocora stellata*, *Montipora patula*, and *M. verrucosa*). The mean coral coverage at this station was estimated at 1.4%. The macroinvertebrate census carried out over the 4 m \times 20 m area noted five species: the rock oyster *Spondylus tenebrosus*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, the rock boring urchin *Echinostrephus aciculatum*, the long-spined black sea urchin *Echinothrix diadema*, and the banded sea urchin *E. calamaris*.

The results of the photo-quadrat survey for this transect are given in Table 2. Two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) with a mean coverage of 0.4% and two coral species (*Porites lobata* and *Pocillopora meandrina*) having a mean coverage of 1.4% were noted.

The results of the fish census are presented in Appendix Table A.1. In total 6 fish species representing 13 individuals were censused at Transect BP-2-A. The most abundant fish species was the sharpback puffer (*Canthigaster jactator*). The biomass of fishes on this

transect was estimated at 15 g/m², with the largest contributors being two wandering grey snappers or uku (*Aprion virescens*) making up 75% of the total.

Transect BP-2-B

Transect BP-2-B was established at a distance varying from 17.5 to 26.2 m seaward of Transect BP-2-A (Figure 3). Table 5 presents the results of the visual quadrat survey (quadrat locations given in Figure 3) carried out at Transect BP-2-B. Three algal species (*Asparagopsis taxiformis*, *Sphacelaria furcigera*, and *Dotyella hawaiiensis*) with a mean coverage of 0.3%, three encrusting sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and an unidentified orange sponge) having a mean coverage of 0.4%, one soft coral species (*Anthelia edmondsoni*) with a mean coverage of 0.06%, and four coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa*, and *M. patula*) were present in the quadrat survey. Mean coral coverage was estimated at 1.1%. Noncolonial macroinvertebrates censused in the 4 m \times 20 m transect area include the Christmas tree worm *Spirobranchus giganteus corniculatus*, the hermit crab *Aniculus strigatus*, and four sea urchin species (*Echinostrephus aciculatum*, *Tripneustes gratilla*, *Echinothrix diadema*, and *E. calamaris*).

The results of the photo-quadrat survey for Transect BP-2-B are given in Table 2. Two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) provided a mean coverage of 0.2%, and two coral species (*Porites lobata* and *Pocillopora meandrina*) contributed a mean coverage of 0.9% at this transect.

The fish census noted 11 species of fishes representing 33 individuals (Appendix Table A.1). The most common species on this transect was the saddleback wrasse or ho(,i)no(,a)lea lauili (*Thalassoma duperrey*). Fish standing crop was estimated at 31 g/m², with a single yellowmargin moray eel or puhi paka (*Gymnothorax flavimarginatus*) contributing 74% to the total.

Station Observations

The relatively low numbers and standing crop of fishes present at Transects BP-2-A and BP-2-B are probably related to the lack of local topographical relief that affords shelter for fishes. The census of the two wandering *Aprion virescens* at Transect BP-2-A probably represents a chance encounter since this species is not known to have any particular tie to the substratum at this transect. Similarly, the relatively higher abundance of noncolonial macroinvertebrates is also probably related to the lack of shelter, which makes their detection easier. In the vicinity of Station BP-2 were seen the corals *Pavona varians* and *Pocillopora damicornis*, the alga *Avrainvillea amadelpha*, the reef crab *Thalamita edwardsi*, the tunicate

Ascidia nigra, the elegant wrasse *Coris venusta*, and the belted wrasse or ‘o(,o)maka (*Stethojulis balteata*).

Station BP-3

Station BP-3 is located about 2.9 km west and inshore of the Barbers Point terminus (Figure 1). This western station is situated approximately 1.6 km offshore of the Barbers Point Naval Air Station at a depth of 16.5 to 16.8 m. The substratum at this location is a mix of coral and rubble mounds or ridges with sand or flat limestone substratum between them. The ridges, which have an orientation that is approximately perpendicular to the shoreline, are from 2 to 15 m in width, 4 to 40 m in length, and up to 0.75 m in height. The ridges are spaced from 3 to 10 m apart; sand in depressions may occur on a scale from 3 to 10 m in width and up to about 30 m in length. Transect BP-3-A, established in water ranging from 16.5 to 16.8 m in depth, is approximately parallel to the shoreline; Transect BP-3-B is about 38 m seaward of Transect BP-3-A at a depth of 16.5 m (Figure 4). Water clarity during sampling was between 12 and 15 m, which is the usual measurement for this location.

Transect BP-3-A

Table 6 presents the results of the quantitative survey carried out at Transect BP-3-A. The visual quadrat survey (quadrat locations given in Figure 4) noted one coralline alga species (*Porolithon onkodes*) with a mean coverage of 0.4%, two encrusting sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) having a mean coverage of 1.5%, one soft coral species (*Anthelia edmondsoni*) with a mean coverage of 0.1%, and five coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora patula*, and *M. verrucosa*). Mean coral coverage at this location was estimated at 9.2% (visual quadrat method), and the dominant species was *Porites lobata*. Nine macroinvertebrate species were censused, including the rock oyster *Spondylus tenebrosus*, the boring bivalve *Lithophaga* sp., the pearl oyster *Pinctada margaritifera*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, and five sea urchin species (*Echinometra mathaei*, *Echinothrix diadema*, *E. calamaris*, *Tripneustes gratilla*, and *Heterocentrotus mammillatus*).

The results of the photo-quadrat analyses for Transect BP-3-A are presented in Table 2. The photo-quadrat analysis noted one coralline algal species (*Porolithon onkodes*) having a mean coverage of 1.3%, two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) with a mean coverage of 0.7%, and three coral species (*Porites lobata*, *P. compressa*, and *Pocillopora meandrina*) having a mean coverage of 2.5%.

The results of the fish census at Transect BP-3-A are presented in Appendix Table A.1. Twenty-eight fish species representing 192 individuals were censused. The most abundant

fish species were the manybar goatfish or moano (*Parupeneus multifasciatus*), the palenose parrotfish or uhu (*Scarus psittacus*), the black damselfish or ‘o(,a)lo‘ilo‘i (*Dascyllus albisella*), the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*), the goldring surgeonfish or kole (*Ctenochaetus strigosus*), and the brown surgeonfish or mo(,a)‘i‘i‘i (*Acanthurus nigrofusus*). The standing crop was estimated at 358 g/m², with tableboss or ‘a‘awa (*Bodianus bilunulatus*) contributing 10% to the total and *Acanthurus olivaceus* making up 57% of the total.

Transect BP-3-B

Transect BP-3-B is located approximately 38 m seaward of Transect BP-3-A (Figure 4). It has an orientation that is parallel to Transect BP-3-A and is located at a water depth of 16.5 m. Table 7 presents the results of the quantitative survey (quadrat locations given in Figure 4) carried out at this transect. Two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) having a mean coverage of 0.7%, one soft coral species (*Anthelia edmondsoni*) with a mean coverage of 0.02%, and five coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora patula*, and *M. verrucosa*) were noted. Coral coverage at this transect is estimated at 5.2% (visual quadrat method). Eight species of macroinvertebrates were censused in the 4 m \times 20 m area, including the boring bivalve *Lithophaga* sp., the rock oyster *Spondylus tenebrosus*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, the hermit crab *Aniculus strigatus*, and the four sea urchin species (*Echinometra mathaei*, *Echinothrix diadema*, *Echinostrephus aciculatum*, and *Tripneustes gratilla*).

Table 2 presents the results of the photo-quadrat survey carried out at Transect BP-3-B. Noted were the coralline algal species (*Porolithon onkodes* and *Hydrolithon* sp.) having a mean coverage of 0.6%, two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) with a mean coverage of 1.9%, and three coral species (*Porites lobata*, *Montipora patula*, and *Pocillopora meandrina*) having a mean coverage of 10.6%.

The results of the fish census carried out at Transect BP-3-B are presented in Appendix Table A.1. In total 29 species representing 199 individuals were counted, with the most abundant fishes including the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*), the sleek unicornfish or kala holo (*Naso hexacanthus*), the black damselfish or ‘o(,a)lo‘ilo‘i (*Dascyllus albisella*), the brown surgeonfish or mo(,a)‘i‘i‘i (*Acanthurus nigrofusus*), and the spotted unicornfish or kala lolo (*Naso brevirostris*). The standing crop of fishes was estimated at 359 g/m², with the species contributing most heavily including a single redlip parrotfish or palukaluka (*Scarus rubroviolaceus*—6% of the total), *Naso brevirostris* (11% of the total), and *Acanthurus olivaceus* (59% of the total).

Station Observations

In the vicinity of Station BP-3 were seen the corals *Fungia scutaria* and *Pavona duerdeni*, the cardinalfish or 'upo(̄,a)palu (*Apogon kallopterus*), the spiny lobster or ula (*Panulirus marginatus*), the red swimming crab *Charybdis erthyrodactylus*, and the leatherback or lai (*Scromberoides laysan*).

Station BP-4

Station BP-4 was established on 10 September 1993 with two transects (BP-4-A and BP-4-B) placed on and adjacent to the basalt caprock shield that covers and protects the discharge pipe approximately 250 m west of BP-2 in 12.2 to 13.4 m of water. Station BP-4 is located approximately 1.4 km shoreward (northeast) of the outfall terminus (Figure 1). Transect BP-4-A was established on top of the caprock shield, and Transect BP-4-B is located between 19.0 and 27.0 m to the east on the adjacent flat natural limestone substratum.

Transect BP-4-A

Transect BP-4-A was established on the basalt capstones that serve to protect the discharge pipe from storm damage. The capstones at this site range in size from 0.5 m to more than 1 m in dimensions and are spaced from overlapping contact with one another to about 2 m apart. The open areas between the capstones is comprised of sand and loose coral rubble. Water depth to the top of the capstones is 12.2 m. This transect has an orientation that follows the discharge pipe and thus is roughly perpendicular to the shoreline (Figure 5).

The results of the quantitative survey carried out at Transect BP-4-A are given in Table 8. The visual quadrat survey (quadrat locations given in Figure 5) noted one algal species (*Porolithon onkodes*) with a mean coverage of 2.4%, one sponge species (*Spirastrella coccinea*) having a mean coverage of 0.2%, one soft coral species (*Anthelia edmondsoni*) with a mean coverage of 0.04%, and two coral species (*Porites lobata* and *P. compressa*) having a mean coverage of 40.0%. The census of macroinvertebrates noted seven species: the rock oyster *Spondylus tenebrosus*, the nudibranch *Pteraeolidia ianthina*, two polychaete species (*Loimia medusa* and *Spirobranchus giganteus corniculatus*), and three echinoderm species (the wana *Echinothrix diadema*, the black sea urchin *Tripneustes gratilla*, and the green sea urchin *Echinometra mathaei*).

The results of the photo-quadrat survey are given in Table 2. In the photo-quadrat analysis, the coralline alga *Porolithon onkodes* had a mean coverage of 1.9%, the encrusting sponge *Spirastrella coccinea* had a mean coverage of 0.7%, and the coral *Porites lobata* had an estimated coverage of 21.8%.

The results of the fish census carried out at Transect BP-4- A are presented in Appendix Table A.1. Thirty-eight fish species representing 971 individuals having an estimated biomass of 893 g/m² were censused. The most abundant fish species included the brown surgeonfish or mo(̄,a)‘i‘i (Acanthurus nigrofuscus), the sleek unicornfish or kala holo (Naso hexacanthus), the black damselfish or ‘o(̄,a)lo‘ilo‘i (Dascyllus albisella), the sergeant major or mamo (Abudefduf abdominalis), and the goldring surgeonfish or kole (Ctenochaetus strigosus). Species contributing most to the estimated standing crop included the grey snapper or uku (Aprion virescens) and Ctenochaetus strigosus, each contributing 15% to the total, and Naso hexacanthus (16% of the total).

Transect BP-4-B

Transect BP-4-B was established between 19.0 and 27.0 m to the east of Transect BP-4-A in 13.1 m to 13.4 m of water. This transect has an orientation that is parallel to Transect BP-4-A and perpendicular to the shoreline. The substratum at this transect is flat limestone with very little relief. A sand/coral rubble veneer overlies portions of the limestone; this veneer does not usually exceed 2 cm in thickness and may cover up to 50 m². These patches of sand are spaced from 5 to 50 m apart.

The results of the quantitative assessment carried out at Transect BP-4-B are presented in Table 9. The visual quadrat survey (quadrat locations given in Figure 5) noted one algal species (*Desmia hornemannii*) with a mean coverage of 0.1%, two encrusting sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) having a mean coverage of 0.5%, and four coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa*, and *M. patula*) with a mean coverage of 8.0%. The macroinvertebrate census noted the rock oyster *Spondylus tenebrosus*, two cone species (*Conus miles* and *Conus marmoratus*), the Christmas tree worm *Spirobranchus giganteus corniculatus*, the hermit crab *Aniculus strigatus*, and three sea urchin species (*Echinothrix calamaris*, *E. diadema*, and *Echinostrephus aciculatum*).

The results of the photo-quadrat survey carried out at Transect BP-4-B are given in Table 2. In this survey, three sponge species (*Chondrosia chucalla*, *Plakortis simplex*, and *Spirastrella coccinea*) had a mean coverage of 0.3%, and three coral species (*Porites lobata*, *Pocillopora meandrina*, and *Montipora patula*) had a mean coverage of 9.2%.

The results of the fish census carried out at Transect BP-4-B are presented in Appendix Table A.1. Eighteen species of fishes representing 57 individuals having an estimated standing crop of 62 g/m² were encountered. The most abundant fish species at this transect were the gilded triggerfish (*Xanthichthys auromarginatus*) and the twospot wrasse *Cheilinus bimaculatus*. The major contributors to the estimated standing crop included a single

yellowmargin moray eel or puhi paka (*Gymnothorax flavimarginatus*—46% of the total) and the redlip parrotfish or palukaluka (*Scarus rubroviolaceus*—27% of the total).

Station Observations

In the vicinity of Transects BP-4-A and BP-4-B was seen a single galapagos shark or mano(,o) (*Carcharhinus galapagensis*) approximately 2 m in precaudal length. This shark did not cross the transects while censusing was being carried out, but because it was in the vicinity, it served to frighten many fishes, resulting in lower than usual counts and biomass estimates for both transects.

Physical Measurements and Biological Parameters

Physical measurements made in the morning on 27 January 1999 are presented in Table 10. Little variation was noted in temperature (24.4° to 25.1°C), percent oxygen saturation (101% to 102%), or salinity (all 34‰) despite the fact that measurements for oxygen and temperature were made at both 1 m below the surface and about 1 m above the bottom. In all cases the secchi disk measurements did not yield an extinction value; water clarity was such that the disk was still visible on the bottom. Probably a better method of determining water clarity would be to collect water samples and measure turbidity with a nephelometer in the laboratory.

The biological data for the 1991 through 1999 annual surveys are summarized as means for each transect in Table 11. The means of all biological parameters measured in these surveys (i.e., percent algal and coral cover; number of coral, other macroinvertebrate, and fish species; number of individual fish; and biomass of fishes) showed a general decline between the 1991 and 1993 surveys and an increasing or leveling off trend since 1993. The early decreases in means may have been related to impacts created by Hurricane Iniki in September 1992, and the increases since the 1993 survey may be related to the recovery in these communities. The fish biomass mean peaked in 1997, was slightly lower in 1998, and decreased in 1999. These changes are related to the chance encounters with large (heavy) roving predators or large schools of certain species during the high biomass census periods; lower mean standing crop in earlier years may be related to greater fishing pressure. Also as noted above, the presence in 1999 of a galapagos shark served to lower the counts of individual fishes and biomass estimates at Station BP-4, the site which usually yields the highest numbers. The Kruskal–Wallis analysis of variance (ANOVA) applied to the annual mean data (combining all transects during an annual sampling period for each parameter; see Table 11) showed that there have been no statistically significant changes (where significance is given at $p = 0.05$ or less) in the mean percent cover by algae ($p > 0.70$, not

significant), the mean percent cover by coral ($p > 0.96$, not significant), the mean number of coral species ($p > 0.83$, not significant), the mean number of macroinvertebrate species ($p > 0.17$, not significant), the mean number of fish species ($p > 0.99$, not significant), the mean number of individual fish ($p > 0.95$, not significant), and the mean standing crop of fish expressed in grams per square meter ($p > 0.60$, not significant).

From 1993 through the most recent survey year, 5 m² of substratum were visually assessed with a 1 × 1 m quadrat on each transect. In 1991, 8.1 m² (2.7 m² at three locations on each transect) of substratum were surveyed using photography. A summary of the coral cover data collected using these methods is presented in Appendix Table A.2. Has there been any significant change in mean coral cover on each of the individual transects over the period of this study? Mean coral cover as measured at each transect over time has not changed significantly at Transects BP-1-A ($p > 0.99$, not significant), BP-1-B ($p > 0.98$, not significant), BP-2-A ($p > 0.52$, not significant), BP-2-B ($p > 0.16$, not significant), BP-3-A ($p > 0.56$, not significant), BP-3-B ($p > 0.56$, not significant), and BP-4-A ($p > 0.27$, not significant) using the Kruskal–Wallis ANOVA. However, coral cover has changed significantly at Transect BP-4-B ($p > 0.03$, significant), but the application of the Student–Newman–Keuls (SNK) test does not separate mean coral cover for any year at Transect BP-4-B as being significantly different. However, the lowest coral cover at Transect BP-4-B (mean = 0.1%) was recorded in 1993 after the hurricane, and the mean has increased since that time. The increase in mean coral cover through time at Transect BP-4-B (see Appendix Table A.2) supports the contention that the operation of the Barbers Point outfall has had no impact on the coral community inshore of the outfall. The conclusion is that coral cover has varied on each transect and quadrat but has not significantly changed through the course of this study despite the imposition of a hurricane in 1992 and the continuous operation of the outfall.

In general the topographic complexity of the substratum is much greater at Transects BP-1-A and -B, BP-3-A and -B, and BP-4-A than at the other transects (i.e., BP-2-A and -B, and BP-4-B) surveyed in this study. The low diversity of fishes at the latter transects is not surprising in view of the little topographical relief present at those sites.

From a commercial fisheries standpoint, a number of important species have been encountered at several of the transect sites during the different survey years; this group includes the brick soldierfish or menpachi (*Myripristis amaenus*), the bigeye or ‘o(,a)weoweo (*Priacanthus cruentatus*), the grey snapper or uku (*Aprion virescens*), the emperor fish or mu (*Monotaxis grandoculis*), the sidespot goatfish or malu (*Parupeneus pleurostigma*), the manybar goatfish or moano (*Parupeneus multifasciatus*), the blue goatfish

or moano kea (*Parupeneus cyclostomus*), the spiny lobster or ula (*Panulirus penicillatus* and *P. marginatus*), and the octopus or he'e (*Octopus cyanea*).

Green Sea Turtle Observations

Three green sea turtles (*Chelonia mydas*) were encountered during the 1999 field survey. Two of these were seen in the vicinity of Station BP-1. One turtle was seen resting on the transect line for Transect BP-1-A on 11 January; the second turtle was seen swimming adjacent to Transect BP-1-B. The resting turtle had an estimated straight line carapace length of 75 cm; it had no visible tumors or tags. The second turtle was approximately 45 cm in straight line carapace length; it also showed no evidence of tags or tumors. The third turtle was encountered on 15 January in the vicinity of Transect BP-3-B. This turtle, which was about 55 cm in straight line carapace length, also showed no evidence of tumors or tags. In general, individual turtles are commonly seen surfacing for air while transiting from Honolulu Harbor to 'Ewa Beach. Most of the individuals seen appear to be subadults.

DISCUSSION

On 11 September 1992 the Hawaiian islands were struck by Hurricane Iniki. The hurricane passed directly over Kaua'i, with sustained winds of 144 mph and gusts to 172 mph causing considerable damage to improvements and forests of that island and the west (leeward) coast of O'ahu. To a lesser extent, high surf caused damage to marine communities along the southern, eastern, and western shores of O'ahu, Kaua'i, Maui, Lo(,)ana'i, and Hawai'i; this damage was primarily to coral communities. In many areas a large amount of sand and other loose material was moved and/or advected out of shallow areas (i.e., depths of less than 27 m) into deeper waters. On O'ahu, storm waves emanating from the southeast were estimated to exceed 7 m in height and were breaking in water at least 20 m deep (personal observations).

Storm damage to benthic and fish communities is frequently patchy, resulting in a mosaic of destruction (personal observations; Connell 1978; Walsh 1983), and the occasional storm event generating high surf is one of the most important parameters that determine the structure of Hawai'i coral communities (Dollar 1982). Because Hawai'i corals are relatively slow growing, storm events need only to occur infrequently (ca. every 20 to 50 years) to be a major structuring force (Grigg 1983). Corals may provide the topographical relief and shelter necessary for fish community development. Numerous studies have shown that storm-generated surf may keep coral reefs in a nonequilibrium or subclimactic state (Grigg and

Maragos 1974; Connell 1978; Woodley et al. 1981; Grigg 1983). The large expanses of near-featureless lava or limestone substratum present around much of the Hawaiian islands at less than 30 m depths attest to the force and frequency of these events (Brock and Norris 1989). These wave forces also impinge upon and impact fish communities (Walsh 1983).

Hurricane Iniki caused damage to coral communities at all four study sites. The greatest impact occurred to the benthic communities at Station BP-3, where many coral colonies completely disappeared or were reduced to rubble. Other sites were entirely covered with coral rubble at scales from 10 m² to over 30 m². In some cases a “blanket” up to 0.5 m of rubble buried coral colonies or killed the lower portions of larger colonies. The hurricane broke many coral colonies into pieces; some of these have survived where they have been lodged into the substratum. These live fragments are responsible for local increases in the diversity of species, and this fragmentation serves as a viable means of reproduction and dispersal for some coral species (Highsmith 1982). Coral rubble and live fragments fill in depressions and holes that otherwise serve as shelter for cryptic fish and invertebrates, thus reducing the complexity of the habitat. This usually results in a decrease in the diversity of species present and may explain some of the declines seen between the 1991 and 1993 surveys. Despite the large changes that occurred in the coral communities of the Barbers Point region, many of the benthic components survived and the communities are well into the process of recovery, as evidenced by the new coral recruits seen at all stations. However, since Hawai‘i corals are relatively slow growing, it will be years before the impact of Hurricane Iniki will no longer be evident in the benthic communities of the study sites.

The results from the eight annual surveys showed that the coral and fish communities are better developed at the eastern (BP-1) and western (BP-3) stations relative to the middle station (BP-2). The relatively scoured appearance of the substratum and poor coral development at Station BP-2 suggests that this area receives occasional wave impact, which curtails the development of the coral community. The poor coral development results in a lack of topographical complexity. This lack of appropriate shelter translates into poor development of the fish community at that location. From the shoreline to a depth of about 20 m, the Barbers Point discharge pipe is buried in a trench and covered with armor rock. This armor stone cover is very incomplete from the shoreline to a depth of about 12 m; from that point seaward, it forms low mounds (up to 1.5 m above the surrounding substratum) that overlie the buried pipe. If the movement of sand over the relatively flat and featureless limestone substratum is causing sand scour that retards the development of the coral community, it follows that corals should be common on the armor rock that rises above the substratum. In this setting, benthic species (such as corals) settling on this rock would be elevated above and out of the influence of the abrasion and scour that otherwise occurs on the

surrounding substratum. Similarly, if sewage effluent continues to play a role in eliminating corals from the limestone and armor rock, then corals should be rare or absent from both locations.

To test these hypotheses Station BP-4 was established in 1993, with Transect BP-4-A on the basalt armor rock of the discharge alignment and Transect BP-4-B approximately 15 m to the east on the flat limestone substratum. As noted in the Results section, the survey data show that the benthic and fish communities are well developed on the elevated armor rock and poorly developed on the adjacent limestone flat that is subjected to periodic scouring. Also apparent is the fact that the corals at Transect BP-4-A show a considerable range in size on the armor rock; the largest corals are no older than the time of outfall construction when the armor rock was placed, and the smaller corals represent more recent recruitment events. Thus the range in sizes of corals shows that their recruitment has continued despite the operation of the outfall.

The working hypothesis is that all four study sites, being situated in relatively shallow water, are outside of the zone of influence of the present Barbers Point deep-water outfall. However, if impacts from the present outfall are occurring to the shallow-water coral reef areas shoreward of the outfall, our monitoring should be able to quantitatively discern these impacts. Because of bottom time constraints, potential dangers with deep diving, and the fact that coral community development is usually greatest in water less than 30 m deep, the placement of biological monitoring stations was restricted to waters less than 20 m deep in this study.

Much of the geographical area of concern in this study has probably been impacted by both point and nonpoint sources of pollution for years. In general, the nearshore currents parallel the shoreline and have a net westerly movement along the coastline (Laevastu et al. 1964); thus stream and industrial inputs from Honolulu Harbor, Ke‘ehi Lagoon, and Pearl Harbor situated to the east would be carried in a westerly direction toward the area offshore of ‘Ewa Beach. Also, from 1955 to 1977 the old Honolulu sewer outfall (located 15 km to the east of the present study area) released 62 mgd (3 m³/s) of raw sewage in 10 m of water offshore of Sand Island. This material was undoubtedly diluted and was probably advected primarily in a west-southwest direction.

Presumably the present Barbers Point outfall releases sewage well offshore at a 61 m depth, and little interaction occurs with the inshore biota. However, if the material was carried into inshore waters, impacts would probably occur to shallow marine communities situated primarily to the west of the outfall—if the information on nearshore currents is correct (see Laevastu et al. 1964; Bathen 1978; Hamilton et al. 1995). Thus the eastern station (BP-1) is viewed as a control site, whereas the station inshore and adjacent to the

discharge pipe (BP-2), the station to the west (BP-3), and the station inshore and on the pipe (BP-4) serve as experimental sites. The spatial separation of the stations precludes direct comparison of data among stations. Comparison of the biological data for each station showed that there were no significant changes between any sampling period, suggesting that the operation of the outfall has not resulted in measurable negative impacts.

Relative to many other locations in Hawai‘i, the fish communities are well developed at the eastern (BP-1), western (BP-3), and pipe-armor rock (BP-4-A) stations. The high standing crop estimates at these stations are much greater than those for most coral reefs; the maximum fish standing crop encountered on natural coral reefs is about 200 g/m² (Goldman and Talbot 1975; Brock et al. 1979). Two explanations for the high biomass of fishes censused at the study stations are (1) the shelter created by the natural topographical relief serves to attract many fishes, thus locally enhancing the fish community, and (2) chance encounters with roving predators or planktivorous schooling species during censuses serve to increase the biomass estimates.

Space and cover are important agents governing the distribution of coral reef fishes (Risk 1972; Sale 1977; Gladfelter and Gladfelter 1978; Brock et al. 1979; Ogden and Ebersole 1981; Anderson et al. 1981; Shulman et al. 1983; Shulman 1984; Eckert 1985; Walsh 1985; Alevizon et al. 1985). Similarly, the standing crop of fishes on a reef is correlated with the degree of vertical relief of the substratum. Thus Brock (1954), using visual techniques on Hawai‘i reefs, estimated the standing crop of fishes to range from 4 g/m² on sand flats to 186 g/m² in an area of considerable vertical relief. If structural complexity or topographical relief is important to coral reef fish communities, then the addition of materials to increase this relief in otherwise barren areas may serve to locally enhance the biomass of fish. Such manipulations are well known and usually take the form of artificial reefs. Artificial reefs in Hawai‘i waters may serve to increase fish standing crops to more than 1 kg/m² (Brock and Norris 1989).

Chance encounters with large roving predators (such as emperor fish or mu [*Monotaxis grandoculis*] and the grey snapper or uku [*Aprion virescens*]) or schools of planktivorous fishes (such as the mackerel scad or ‘o(,o)pelu [*Decapterus macarellus*], the sleek unicornfish or kala holo [*Naso hexacanthus*], the milletseed butterflyfish or lauwiwili [*Chaetodon miliaris*], and the sergeant major or mamo [*Abudefduf abdominalis*]) may greatly increase the counts and biomass on a particular transect. The presence of the natural topographical relief in the vicinity of Stations BP-1 and BP-3 as well as Transect BP-4-A serves to focus numerous predators and planktivorous fishes near these locations. Many of these species have home ranges that are considerably larger than the area covered by our

transects, making encounters during a census a haphazard event. The inclusion of these fishes in a census will result in higher biomass estimates.

Schooling species, such as *Monotaxis grandoculis* and the orangebar surgeonfish or na'ena'e (*Acanthurus olivaceus*), contributed substantially to the standing crop on several transects. *A. olivaceus* was an important contributor to the standing crop at Transects BP-3-A (57% of the total) and BP-3-B (59% of the total) in the 1999 survey. *Decapterus macarellus*, a highly migratory coastal schooling species, contributed substantially to the biomass in several survey years but not in 1999. Similarly, the schooling yellowfin goatfish or weke'ula (*Mulloides vanicolensis*) and the bluelined snapper or ta'ape (*Lutjanus kasmira*) contributed to the biomass estimates. For example, in 1998 *L. kasmira* made up 36% and *M. vanicolensis* 9% of the biomass on Transect BP-4-A. In 1999 *L. kasmira* contributed 35% to the biomass on this same transect.

CONCLUSION

The siting of the permanent stations near the Barbers Point Ocean Outfall to capitalize on presumed gradient(s) of impact that may be created by the discharge and movement of treated sewage effluent toward the shore and the annual quantitative survey of these stations should allow a delineation of changes that may be caused by the effluent. In the eight annual surveys (1991, 1993 through 1999) no statistically significant change was detected in the measured biological parameters at the permanent survey stations, despite the imposition of a major hurricane on the marine communities in September 1992. Thus the data to date support the contention that the operation of the Barbers Point deep-ocean outfall is not having a quantifiable impact on the coral reef resources situated inshore of the outfall terminus.

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TABLE 1. Summary of Biological Observations Made at Transect BP-1-A, 2.2 km Northeast and Inshore of Barbers Point Ocean Outfall Terminus, on 11 January 1999

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
<i>Porolithon onkodes</i>	8.0	1.0			
<i>Desmia hornemannii</i>				0.3	
Sponges					
<i>Chondrosia chucalla</i>		1.1	0.5	1.1	0.1
Soft Corals					
<i>Anthelia edmondsoni</i>	0.4		0.1	0.1	0.1
Corals					
<i>Porites lobata</i>	2.0	46.0	1.0		3.0
<i>Porites compressa</i>		2.4		1.0	2.0
<i>Pocillopora meandrina</i>			1.3	2.9	
<i>Montipora verrucosa</i>				0.3	
<i>Montipora patula</i>			1.0	0.4	1.4
Sand	1.5		23.0	3.0	
Rubble	41.1	34.5	64.1	90.9	52.4
Hard Substratum	47.0	15.0	9.0		12.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					

<i>Spondylus tenebrosus</i>	4
<i>Lithophaga</i> sp.	4
<i>Chromodoris vibrata</i>	1
Phylum Annelida	
<i>Spirobranchus giganteus corniculatus</i>	27
Phylum Echinodermata	
<i>Echinothrix diadema</i>	5
<i>Echinothrix calamaris</i>	1
<i>Echinometra mathaei</i>	2
<i>Heterocentrotus mammillatus</i>	1

III. Fish Census (4 m ∞ 20 m)					
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34 Species					
558 Individuals					
Estimated Standing Crop = 124 g/m ²					

NOTE: Results of the 5-m² quadrat sampling (visual appraisal) of the benthic community are presented in Part I, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is presented in Part III. Water depth ranges from 14.9 m to 15.8 m; mean coral coverage is 18.7% (visual quadrat method).

TABLE 2. Summary of the Results of the Photographic Quadrat Survey for Transects at Stations BP-1 Through BP-4, Barbers Point Ocean Outfall, 'Ewa Beach, O'ahu, Hawai'i, 1999

		Percent Cover				
		Photographic Quadrat				
Transect BP-1-A		AAA3	ACC1	AAB3	ACC2	AAC3
		(0 m)	(5 m)	(10 m)	(15 m)	(20 m)
Algae						
<i>Porolithon onkodes</i>	6.0	2.0				
Sponges						
<i>Chondrosia chucalla</i>					1.0	
Corals						
<i>Porites lobata</i>	74.0	55.0		0.3	20.0	
<i>Porites compressa</i>		1.0			1.0	
<i>Pocillopora meandrina</i>			1.0	1.0		
<i>Montipora patula</i>				0.1		
Sand			5.0	5.0		
Rubble			11.0	9.0	20.0	
Hard Substratum	20.0	42.0	83.0	83.6	59.0	
Mean Coral Coverage = 30.7%						

		Percent Cover				
		Photographic Quadrat				
Transect BP-1-B		ABA3	ACA1	ABB3	ACA2	ABC3
		(0 m)	(5 m)	(10 m)	(15 m)	(20 m)
Algae						
<i>Porolithon onkodes</i>	1.1	0.8	0.6	2.8	1.1	
Corals						
<i>Porites lobata</i>	18.2	9.8	12.9	9.8	24.9	
<i>Porites compressa</i>	2.5	5.3	0.8	1.4	1.1	
<i>Pocillopora meandrina</i>	1.1	0.6	0.3		1.1	
<i>Montipora patula</i>		2.5	0.6	1.1		
Sand			1.4	4.2		
Rubble			7.3	2.5		
Hard Substratum	77.1	81.0	76.1	78.2	71.8	

Mean Coral Coverage = 18.8%					
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TABLE 2—*Continued*

Transect BP-2-A		Percent Cover				
		Photographic Quadrat				
		BAA3	BCC1	BAB3	BCC2	BAC3
		(0 m)	(5 m)	(10 m)	(15 m)	(20 m)

Sponges						
<i>Spirastrella coccinea</i>	0.8		0.3			
<i>Chondrosia chucalla</i>	0.4			0.3	0.3	
Corals						
<i>Porites lobata</i>	0.1	0.1	0.3	2.8	1.0	
<i>Pocillopora meandrina</i>	0.1		1.1	1.1	0.3	
Sand	0.8	1.4	0.8	0.8	0.8	
Hard Substratum	97.8	98.5	97.5	95.0	97.6	
Mean Coral Coverage = 1.4%						

Transect BP-2-B		Percent Cover				
		Photographic Quadrat				
		BBA3	BCA1	BBB3	BCA2	BBC3
		(0 m)	(5 m)	(10 m)	(15 m)	(20 m)

Sponges						
<i>Spirastrella coccinea</i>		0.1				0.1
<i>Chondrosia chucalla</i>	0.1	0.3		0.3	0.3	
Corals						
<i>Porites lobata</i>	0.8	1.1	0.3	0.1		
<i>Pocillopora meandrina</i>	1.1	0.6				0.6
Sand	0.8	0.6	0.6	0.8	0.6	
Hard Substratum	97.2	97.3	99.1	98.8	98.4	
Mean Coral Coverage = 0.9%						

TABLE 2—Continued

Transect BP-3-A		Percent Cover				
		Photographic Quadrat				
		CAA3	CCC1	CAB3	CCC2	CAC3
		(0 m)	(5 m)	(10 m)	(15 m)	(20 m)

Algae						
<i>Porolithon onkodes</i>		3.9		2.8		
Sponges						
<i>Spirastrella coccinea</i>						0.6
<i>Chondrosia chucalla</i>	0.8	1.0	0.3			0.8
Corals						
<i>Porites lobata</i>		1.3		5.9		0.3
<i>Porites compressa</i>		0.8				
<i>Pocillopora meandrina</i>				4.2		
Sand	0.6		0.3			1.7
Rubble	69.5	22.7	99.4	28.3		37.2
Hard Substratum	29.1	70.3		58.8		59.4
Mean Coral Coverage = 2.5%						

Transect BP-3-B		Percent Cover				
		Photographic Quadrat				
		CBA3	CCA1	CBB3	CCA2	CBC3
		(0 m)	(5 m)	(10 m)	(15 m)	(20 m)

Algae						
<i>Porolithon onkodes</i>	1.7	1.1				
<i>Hydrolithon</i> sp.				0.3		
Sponges						
<i>Spirastrella coccinea</i>	1.4	4.5		3.1		0.6
<i>Chondrosia chucalla</i>		0.1				
Corals						
<i>Porites lobata</i>	16.0	1.7		25.5		1.1
<i>Pocillopora meandrina</i>		2.0		4.2		0.6

<i>Montipora patula</i>	0.3	1.1	0.1		0.6
Sand		0.3	0.3		1.4
Rubble	9.8	40.3	99.6	20.2	42.0
Hard Substratum	70.8	48.9		46.7	53.7
Mean Coral Coverage = 10.6%					

TABLE 2—Continued

Transect BP 4-A		Percent Cover				
		Photographic Quadrat				
		EAA1	EAA2	EAA3	EAA4	EBA1
		(0 m)	(5 m)	(10 m)	(15 m)	(20 m)

Algae						
<i>Porolithon onkodes</i>		0.8	3.1	2.0	3.4	
Sponges						
<i>Spirastrella coccinea</i>	1.4	0.7	1.1	0.1	0.3	
Corals						
<i>Porites lobata</i>	6.4	26.6	29.7	23.5	23.0	
Rubble	14.0		10.6			
Hard Substratum	78.2	71.9	55.5	74.4	73.3	
Mean Coral Coverage = 21.8%						

Transect BP 4-B		Percent Cover				
		Photographic Quadrat				
		ECA1	ECA2	ECA3	EAC4	EEA1
		(0 m)	(5 m)	(10 m)	(15 m)	(20 m)

Sponges						
<i>Chondrosia chucalla</i>		0.4	0.3	0.1	0.3	
<i>Plakortis simplex</i>		0.1	0.3			
<i>Spirastrella coccinea</i>	0.1					
Corals						
<i>Porites lobata</i>	0.8	0.1	4.5	6.7	1.4	
<i>Pocillopora meandrina</i>	17.9					
<i>Montipora patula</i>	14.6					
Sand		0.8				0.3
Hard Substratum	66.6	98.6	94.9	93.2	98.0	
Mean Coral Coverage = 9.2%						

NOTE: Presented in the body of the table are the percent cover of species and substrate types for each transect. Data for all

stations are based on one 0.67-m² photo-quadrat at each 5-m stop (i.e., at the 0 m, 5 m, 10 m, 15 m, and 20 m points along the transect).

TABLE 3. Summary of Biological Observations Made at Transect BP-1-B, 2.2 km Inshore and Northeast of Barbers Point Ocean Outfall Terminus, on 11 January 1999

I. Quadrat Survey		Percent Cover				
		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Algae						
<i>Porolithon onkodes</i>	0.7					3.0
Sponges						
<i>Chondrosia chucalla</i>		0.3	0.7	0.1		
Soft Corals						
<i>Anthelia edmondsoni</i>		0.3	0.4	1.2		
Corals						
<i>Porites lobata</i>	12.0	5.5	2.0	3.4	27.0	
<i>Porites compressa</i>	1.5	1.2		0.8	2.5	
<i>Pocillopora meandrina</i>	0.6	0.2	0.1	1.1	2.7	
<i>Montipora patula</i>			1.9	2.3		
<i>Montipora verrucosa</i>			0.1			
<i>Pavona duerdeni</i>			0.5			
Sand	2.0	9.0	14.0	4.0		
Rubble	37.2	69.5	65.3	48.1	7.0	
Hard Substratum	46.0	14.0	15.0	39.0	57.8	

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
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Phylum Mollusca	
<i>Spondylus tenebrosus</i>	1
<i>Lithophaga</i> sp.	4
Phylum Annelida	
<i>Spirobranchus giganteus corniculatus</i>	39
<i>Sabellastarte sanctijosephi</i>	1
Phylum Echinodermata	
<i>Echinothrix diadema</i>	3
<i>Tripneustes gratilla</i>	1
<i>Echinometra mathaei</i>	1

III. Fish Census (4 m ∞ 20 m)					
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41 Species				
419 Individuals				
Estimated Standing Crop = 211 g/m ²				

NOTE: Results of the 5-m² quadrat sampling (visual appraisal) of the benthic community are presented in Part I, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is presented in Part III. Water depth ranges from 14.9 to 15.8 m; mean coral coverage is 13.1% (visual quadrat method).

TABLE 4. Summary of Biological Observations Made at Transect BP-2-A, 0.25 km East of the Discharge Pipe and 1.5 km Inshore and Northeast of Barbers Point Ocean Outfall Terminus, on 11 January 1999

I. Quadrat Survey		Percent Cover				
		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Sponges						
<i>Chondrosia chucalla</i>	0.3		0.1	0.9	0.2	
<i>Spirastrella coccinea</i>				0.2	1.7	
Unidentified orange sponge	0.1					
Soft Corals						
<i>Anthelia edmondsoni</i>					0.1	
Corals						
<i>Porites lobata</i>	1.0	0.2	0.7	1.0	0.4	
<i>Pocillopora meandrina</i>		0.2		1.3	1.3	
<i>Montipora verrucosa</i>				0.1	0.1	
<i>Montipora patula</i>	0.2		0.3	0.2		
<i>Psammocora stellata</i>		0.2				
Sand	2.0	4.0	3.0	1.0	3.0	
Hard Substratum	96.4	95.4	95.9	95.3	93.2	

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
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Phylum Mollusca	
<i>Spondylus tenebrosus</i>	1
Phylum Annelida	
<i>Spirobranchus giganteus corniculatus</i>	3
Phylum Echinodermata	
<i>Echinostrephus aciculatum</i>	1
<i>Echinothrix diadema</i>	11
<i>Echinothrix calamaris</i>	2

III. Fish Census (4 m ∞ 20 m)					
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6 Species					
13 Individuals					

Estimated Standing Crop = 15 g/m ²					
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NOTE: Results of the 5-m² quadrat sampling (visual appraisal) of the benthic community are presented in Part I, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is presented in Part III. Water depth ranges from 11.3 to 11.9 m; mean coral coverage is 1.4% (visual quadrat method).

TABLE 5. Summary of Biological Observations Made at Transect BP-2-B, 0.25 km East of the Discharge Pipe and 1.5 km Inshore and Northeast of Barbers Point Ocean Outfall Terminus, on 11 January 1999

I. Quadrat Survey		Percent Cover				
		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Algae						
<i>Asparagopsis taxiformis</i>				1.0		
<i>Sphacelaria furcigera</i>	0.3					
<i>Dotyella hawaiiensis</i>						0.3
Sponges						
<i>Chondrosia chucalla</i>	0.5	0.1	0.2	0.4	0.3	
<i>Spirastrella coccinea</i>						0.1
Unidentified orange sponge	0.2					
Soft Corals						
<i>Anthelia edmondsoni</i>					0.3	
Corals						
<i>Porites lobata</i>	0.9	0.3	0.6	0.2	0.1	
<i>Pocillopora meandrina</i>	0.1	0.3	0.9	1.0	0.3	
<i>Montipora patula</i>		0.4	0.5			
<i>Montipora verrucosa</i>		0.1				
Sand	4.0	2.0	2.0	14.0	1.0	
Hard Substratum	94.0	96.8	94.8	15.9	97.9	

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
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Phylum Annelida	
<i>Spirobranchus giganteus corniculatus</i>	1
Phylum Arthropoda	
<i>Aniculus strigatus</i>	1
Phylum Echinodermata	
<i>Echinothrix calamaris</i>	1
<i>Echinothrix diadema</i>	5
<i>Echinostrephus aciculatum</i>	1
<i>Tripneustes gratilla</i>	2

III. Fish Census (4 m ∞ 20 m)					
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11 Species				
33 Individuals				
Estimated Standing Crop = 31 g/m ²				

NOTE: Results of the 5-m² quadrat sampling (visual appraisal) of the benthic community are presented in Part I, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is presented in Part III. Water depth ranges from 11.3 to 11.9 m; mean coral coverage is 1.1% (visual quadrat method).

TABLE 6. Summary of Biological Observations Made at Transect BP-3-A, 3.3 km West and Inshore of Barbers Point Ocean Outfall Terminus, on 15 January 1999

I. Quadrat Survey		Percent Cover				
		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Algae						
<i>Porolithon onkodes</i>					2.0	
Sponges						
<i>Chondrosia chucalla</i>	0.4			0.8		1.1
<i>Spirastrella coccinea</i>			4.5			0.6
Soft Corals						
<i>Anthelia edmondsoni</i>			0.5			0.2
Corals						
<i>Porites lobata</i>	0.1		4.8	0.1	23.0	0.5
<i>Porites compressa</i>			1.2		6.5	
<i>Pocillopora meandrina</i>			1.2		8.0	0.4
<i>Montipora verrucosa</i>	0.1					
<i>Montipora patula</i>	0.3					
Sand	3.0		6.0	9.0		16.0
Rubble	92.1		40.8	90.1	19.0	81.2
Hard Substratum	4.0		41.0		41.5	

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
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Phylum Mollusca	
<i>Spondylus tenebrosus</i>	1
<i>Lithophaga</i> sp.	7
<i>Pinctada margaritifera</i>	1
Phylum Annelida	
<i>Spirobranchus giganteus corniculatus</i>	7
Phylum Echinodermata	
<i>Echinometra mathaei</i>	4
<i>Echinothrix diadema</i>	8
<i>Echinothrix calamaris</i>	1
<i>Tripneustes gratilla</i>	1
<i>Heterocentrotus mammillatus</i>	4

III. Fish Census (4 m ∞ 20 m)					
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28 Species					
192 Individuals					
Estimated Standing Crop = 358 g/m ²					

NOTE: Results of the 5-m² quadrat sampling (visual appraisal) of the benthic community are presented in Part I, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is presented in Part III. Water depth ranges from 16.5 to 16.8 m; mean coral coverage is 9.2% (visual quadrat method).

TABLE 7. Summary of Biological Observations Made at Transect BP-3-B, 3.3 km West and Inshore of Barbers Point Ocean Outfall Terminus, on 15 January 1999

I. Quadrat Survey		Percent Cover				
		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Sponges						
<i>Spirastrella coccinea</i>			1.5			0.8
<i>Chondrosia chucalla</i>					0.6	0.7
Soft Corals						
<i>Anthelia edmondsoni</i>			0.1			
Corals						
<i>Porites lobata</i>	5.0	1.1			5.0	0.9
<i>Porites compressa</i>	1.0	0.5			1.0	0.4
<i>Pocillopora meandrina</i>	0.6	0.5	0.2		2.8	1.1
<i>Montipora patula</i>	0.3	3.0			1.9	0.3
<i>Montipora verrucosa</i>		0.2	0.1			0.1
Sand	1.0	0.5	2.0		4.0	2.0
Rubble	81.8	73.6	97.7		65.7	70.7
Hard Substratum	11.0	19.0			19.0	23.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals					
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Phylum Mollusca	
<i>Spondylus tenebrosus</i>	1
<i>Lithophaga</i> sp.	4
Phylum Annelida	
<i>Spirobranchus giganteus corniculatus</i>	18
Phylum Arthropoda	
<i>Aniculus strigatus</i>	1
Phylum Echinodermata	
<i>Echinometra mathaei</i>	6
<i>Echinothrix diadema</i>	7
<i>Echinostrephus aciculatum</i>	2
<i>Tripneustes gratilla</i>	1

III. Fish Census (4 m ∞ 20 m)						
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29 Species					
199 Individuals					
Estimated Standing Crop = 359 g/m ²					

NOTE: Results of the 5-m² quadrat sampling (visual appraisal) of the benthic community are presented in Part I, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is presented in Part III. Water depth is 16.5 to 16.8 m; mean coral coverage is 5.2% (visual quadrat method).

TABLE 8. Summary of Biological Observations Made at Transect BP-4-A, Situated on the Basalt Caprock of the Barbers Point Discharge Pipe, Approximately 1.4 km Inshore (North) of Barbers Point Ocean Outfall Terminus, on 11 January 1999

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
<i>Porolithon onkodes</i>		2.0	3.0		7.0
Sponges					
<i>Spirastrella coccinea</i>					1.2
Soft Corals					
<i>Anthelia edmondsoni</i>	0.2				
Corals					
<i>Porites lobata</i>	39.0	47.0	31.0	22.0	56.0
<i>Porites compressa</i>	2.7			2.3	
Rubble	14.0	3.0	9.0	27.0	3.0
Hard Substratum	44.1	48.0	57.0	48.7	32.8

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
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Phylum Mollusca	
<i>Spondylus tenebrosus</i>	6
<i>Pteraeolidia ianthina</i>	2
Phylum Annelida	
<i>Spirobranchus giganteus corniculatus</i>	127
<i>Loimia medusa</i>	1
Phylum Echinodermata	
<i>Echinothrix diadema</i>	206
<i>Tripneustes gratilla</i>	2
<i>Echinometra mathaei</i>	1

III. Fish Census (4 m ∞ 20 m)					
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38 Species					
971 Individuals					
Estimated Standing Crop = 893 g/m ²					

NOTE: Results of the 5-m² quadrat sampling (visual appraisal) of the benthic community are presented in Part I, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is presented in Part III. Water depth is 12.2 m; mean coral coverage is 40.0% (visual quadrat method).

TABLE 9. Summary of Biological Observations Made at Transect BP-4-B, Situated on Smooth Limestone Substratum 15 m East of the Basalt Caprock of the Barbers Point Discharge Pipe, Approximately 1.4 km Inshore (North) of Barbers Point Ocean Outfall Terminus, on 11 January 1999

I. Quadrat Survey		Percent Cover				
		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Algae						
<i>Desmia hornemannii</i>		0.6				
Sponges						
<i>Chondrosia chucalla</i>		0.2				
<i>Spirastrella coccinea</i>	1.5		0.9			
Corals						
<i>Porites lobata</i>	0.6	0.4	0.9	2.3	3.3	
<i>Pocillopora meandrina</i>	9.0	0.4	1.0	1.1	0.2	
<i>Montipora patula</i>	19.0			1.7		
<i>Montipora verrucosa</i>					0.1	
Hard Substratum	69.9	98.4	97.2	94.9	96.4	
II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals					
Phylum Mollusca						
<i>Conus marmoratus</i>	1					
<i>Conus miles</i>	1					
<i>Spondylus tenebrosus</i>	1					
Phylum Annelida						
<i>Spirobranchus giganteus corniculatus</i>	22					
Phylum Arthropoda						
<i>Aniculus strigatus</i>	1					
Phylum Echinodermata						
<i>Echinostrephus aciculatum</i>	3					
<i>Echinothrix diadema</i>	41					
<i>Echinothrix calamaris</i>	16					
III. Fish Census (4 m ∞ 20 m)						
18 Species						

57 Individuals					
Estimated Standing Crop = 62 g/m ²					

NOTE: Results of the 5-m² quadrat sampling (visual appraisal) of the benthic community are presented in Part I, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is presented in Part III. Water depth ranges from 13.1 to 13.4 m; mean coral coverage is 8.0% (visual quadrat method).

TABLE 10. Summary of Physical Measurements Made at Each Station in the Vicinity of Transect Pairs, 2 October 1991, 16 September 1993, 28 April 1994, 22 June 1995, 20 May 1996, 27 February 1997, 5 February 1998, and 27 January 1999

Location and Time	Oxygen (% of Saturation)		Salinity (‰)	Temperature (°C)		Depth to Secchi Extinction (m)
	Top	Bottom		Top	Bottom	
2 OCTOBER 1991						
Station BP-1						
1000 hr	103	102	34	25.3	25.1	>15.0
Station BP-2						
1025 hr	101	101	34	25.0	24.9	>11.0
Station BP-3						
1110 hr	102	102	34	25.4	25.2	>16.5
16 SEPTEMBER 1993						
Station BP-1						
0945 hr	102	101	34	25.4	25.1	>15.0
Station BP-2						
1020 hr	103	102	34	25.5	25.2	>11.0
Station BP-3						
1100 hr	103	100	34	25.7	25.4	>16.5
Station BP-4						
1040 hr	102	102	34	25.5	25.4	>13.0
28 APRIL 1994						
Station BP-1						
0930 hr	103	102	34	23.1	23.0	>15.0
Station BP-2						
1010 hr	102	101	34	22.7	23.0	>11.0
Station BP-3						
1100 hr	101	101	34	23.0	23.0	>16.5
Station BP-4						
1040 hr	103	103	34	23.1	23.0	>13.0
22 JUNE 1995						
Station BP-1						
0930 hr	102	102	34	25.5	25.3	>15.0
Station BP-2						
1015 hr	104	103	34	25.6	25.5	>11.0

Station BP-3								
1110 hr	102	103		34	25.0	25.0		>16.5
Station BP-4								
1050 hr	102	102		34	25.3	25.4		>13.0
20 MAY 1996								
Station BP-1								
0945 hr	102	101		34	25.1	24.9		>15.0
Station BP-2								
1030 hr	102	102		34	25.3	25.2		>11.0
Station BP-3								
1115 hr	102	103		34	25.2	25.2		>16.5
Station BP-4								
1215 hr	101	102		34	25.4	25.2		>13.0

TABLE 10—*Continued*

Location and Time	Oxygen (% of Saturation)		Salinity (‰)	Temperature (°C)		Depth to Secchi Extinction (m)
	Top	Bottom		Top	Bottom	
27 FEBRUARY 1997						
Station BP-1						
1000 hr	103	103	34	25.4	25.0	>15.0
Station BP-2						
1030 hr	102	103	34	25.5	25.3	>11.0
Station BP-3						
1215 hr	103	101	34	25.3	25.2	>16.5
Station BP-4						
1100 hr	103	102	34	25.4	25.1	>13.0
5 FEBRUARY 1998						
Station BP-1						
0930 hr	101	102	34	24.4	24.4	>15.0
Station BP-2						
1000 hr	102	103	34	24.2	24.1	>11.0
Station BP-3						
1100 hr	103	102	34	24.5	24.3	>16.5
Station BP-4						
1030 hr	101	102	34	24.1	24.2	>13.0
27 JANUARY 1999						
Station BP-1						
0810 hr	100	100	34	25.1	24.8	>15.0
Station BP-2						
0840 hr	102	100	34	24.6	24.5	>11.0
Station BP-3						
0925 hr	100	102	34	24.9	24.8	>16.5
Station BP-4						
1010 hr	101	101	34	24.8	24.4	>13.0

NOTE: Oxygen and temperature measurements were made approximately 1 m below the surface and 1 m above the bottom; water clarity at all stations was greater than the depth, thus extinction could not be directly measured.

TABLE A.1. Results of Quantitative Visual Fish Censuses Conducted on Two Transects Each at Four Stations Offshore of 'Ewa Beach, O'ahu, Hawai'i, 11 and 15 January 1999

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
MURAENIDAE								
<i>Gymnothorax flavimarginatus</i>				1			1	1
<i>Gymnothorax steindachneri</i>		1						
HOLOCENTRIDAE								
<i>Myripristis amaenus</i>	34	8					18	
<i>Flammeo sammara</i>		1						
AULOSTOMIDAE								
<i>Aulostomus chinensis</i>	1	1					3	
FISTULARIIDAE								
<i>Fistularia commersonii</i>	2					1		
SCORPAENIDAE								
<i>Scorpaenopsis diabolus</i>		1						
SERRANIDAE								
<i>Cephalopholis argus</i>						1	2	
APOGONIDAE								
<i>Apogon kallopterus</i>		5			5			
MALACANTHIDAE								
<i>Malacanthus brevirostris</i>				2				
LUTJANIDAE								
<i>Lutjanus kasmira</i>		31					14	
<i>Alphareus furcatus</i>		1					1	
<i>Aprion virescens</i>			2		1	1	9	
CARANGIDAE								
<i>Decapterus macarellus</i>							2	
<i>Alectis ciliaris</i>					3			
<i>Seriola dumerili</i>							3	
LETHRINIDAE								
<i>Monotaxis grandoculis</i>	1	15						

MULLIDAE								
<i>Parupeneus pleurostigma</i>					1			2
<i>Parupeneus multifasciatus</i>	4	8			17	7	28	1
CHAETODONTIDAE								
<i>Forcipiger flavissimus</i>		4			2	2	3	
<i>Chaetodon kleinii</i>	3				3	2	30	
<i>Chaetodon miliaris</i>							40	
<i>Chaetodon multicinctus</i>	6	6			4			2
<i>Chaetodon quadrimaculatus</i>					1			
<i>Chaetodon ornatissimus</i>	2							
<i>Chaetodon lunula</i>					2			
<i>Heniochus diphreutes</i>							7	
<i>Hemitaurichthys polylepis</i>							15	

TABLE A.1—Continued

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
POMACANTHIDAE								
<i>Centropyge potteri</i>	8	8						
POMACENTRIDAE								
<i>Dascyllus albisella</i>	76	24		5	17	15	132	
<i>Plectroglyphidodon johnstonianus</i>		4			1			
<i>Chromis hanui</i>	8	10						
<i>Chromis ovalis</i>	200	37					42	
<i>Chromis vanderbilti</i>								4
<i>Chromis agilis</i>		6						
<i>Stegastes fasciolatus</i>	3					2	6	
<i>Abudefduf abdominalis</i>							55	
CIRRHITIDAE								
<i>Paracirrhites arcatus</i>		1	3	4		3		3
<i>Paracirrhites forsteri</i>	2						1	
<i>Cirrhitops fasciatus</i>					1	1		
LABRIDAE								
<i>Bodianus bilunulatus</i>					2		2	
<i>Pseudocheilinus octotaenia</i>	2	3			1		8	
<i>Pseudocheilinus tetrataenia</i>		1						
<i>Thalassoma duperrey</i>	9	10		11	4	9	12	7
<i>Thalassoma ballieui</i>		1					1	
<i>Stethojulis balteata</i>	1					1		
<i>Coris gaimard</i>					3			
<i>Coris venusta</i>						1		
<i>Pseudojuloides cerasinus</i>	2	7				2		3
<i>Cheilinus bimaculatus</i>			1	4				10
<i>Macropharyngodon geoffroy</i>	1	2				1		2
SCARIDAE								
<i>Calotomus carolinus</i>						1		
<i>Scarus sordidus</i>	3	9					24	
<i>Scarus psittacus</i>	1	7			16	12	36	
<i>Scarus rubroviolaceus</i>						1		2
BLENNIIDAE								
<i>Exallia brevis</i>		1					1	

ACANTHURIDAE								
<i>Acanthurus nigrofusus</i>	61	60		2	24	24	51	
<i>Acanthurus triostegus</i>							7	1
<i>Acanthurus nigroris</i>	16	14			4	4		
<i>Acanthurus olivaceus</i>	1	5			37	50	39	2
<i>Acanthurus dussumieri</i>						1		
<i>Acanthurus thompsoni</i>	12						12	
<i>Ctenochaetus strigosus</i>	78	104			21	9	279	
<i>Zebrasoma flavescens</i>	3	9						
<i>Naso lituratus</i>	2	2			10	1	6	
<i>Naso hexacanthus</i>	7	1				24	68	
<i>Naso brevirostris</i>					3	20		
<i>Zanclus cornutus</i>		1			3		4	

TABLE A.1—*Continued*

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
BALISTIDAE								
<i>Melichthys vidua</i>		2		1	1	1	3	
<i>Sufflamen bursa</i>	5	2	1	1	2	1	3	4
<i>Xanthichthys auromarginatus</i>								8
MONACANTHIDAE								
<i>Cantherhines dumerili</i>	1		2	1				1
<i>Pervagor spilosoma</i>	1							
<i>Pervagor melanocephalus</i>		1						
OSTRACIIDAE								
<i>Lactoria fornasini</i>		1						
TETRAODONTIDAE								
<i>Canthigaster jactator</i>	1	4	4	1	3	1	3	2
<i>Canthigaster coronata</i>	1							2
Total No. of Species	34	41	6	11	28	29	38	18
Total No. of Individuals	558	419	13	33	192	199	971	57
Estimated Standing Crop (g/m ²)	124	211	15	31	358	359	893	62

NOTE: Each entry in the body of the table represents the total number of individuals of each species seen; totals are presented at the foot of the table along with an estimate of the standing crop of fishes present at each location. All censuses were carried out by the author.

TABLE A.2. Summary of Coral Cover Data for Each Visually Assessed Quadrat on Each Transect for 1991 and 1993 Through 1999

Site	Quadrat	Coral Cover (%)							
	Location	1991	1993	1994	1995	1996	1997	1998	1999
Transect BP-1-A	0 m	40.7	19.0	19.0	19.0	8.3	7.3	10.6	2.0
	5 m		32.5	52.4	41.9	39.4	30.7	4.5	48.4
	10 m	17.1	0.6	1.8	1.4	0.9	1.5	1.9	3.3
	15 m		2.2	1.6	0.6	1.4	1.6	41.2	4.6
	20 m	12.3	23.0	12.1	21.7	25.1	32.0	20.5	35.4
	Mean	23.4	15.5	17.4	16.9	15.0	14.6	15.7	18.7
Transect BP-1-B	0 m	37.9	7.5	8.5	16.0	8.2	8.7	8.2	14.1
	5 m		8.1	7.3	4.6	2.7	4.2	37.3	6.9
	10 m	1.8	1.0	2.1	6.4	15.3	3.9	0.9	4.6
	15 m		6.9	4.5	9.4	6.1	7.2	2.1	7.6
	20 m	48.5	12.1	87.4	90.0	86.0	44.2	33.9	32.2
	Mean	29.4	7.1	22.0	25.3	23.7	13.6	16.5	13.1
Transect BP-2-A	0 m	3.6	4.5	2.4	2.6	2.3	2.1	0.5	1.2
	5 m		0.1	0	0.8	0	0.1	0.2	0.6
	10 m	2.4	0.5	0.6	0.6	0.7	0.9	1.8	1.0
	15 m		5.0	1.0	0.7	1.4	0.6	1.0	2.6
	20 m	4.9	0.9	1.3	1.0	0.7	1.3	0.2	1.8
	Mean	3.6	2.2	1.1	1.1	1.0	1.0	0.7	1.4
Transect BP-2-B	0 m	0.8	0.1	0	0.4	0.5	0.6	1.4	1.0
	5 m		3.0	1.3	1.1	0.4	0.5	0.3	1.1
	10 m	5.6	1.9	2.7	0.7	1.1	0.9	1.2	2.0
	15 m		0.3	0.1	0.5	0.2	0.5	1.1	1.2
	20 m	1.9	0.2	0.6	0	0.3	0.5	2.3	0.4
	Mean	2.8	1.1	0.9	0.5	0.5	0.6	1.3	1.1

Transect BP-3-A	0 m	7.2	0.7	0.7	0	0.1	0	4.2	0.5
	5 m		1.5	1.3	1.6	1.8	1.7	6.4	7.2
	10 m	1.0	0.6	0.9	0	0	0.4	0.1	0.1
	15 m		19.8	37.5	31.2	24.0	17.5	13.0	37.5
	20 m	15.8	0.2	0	0.1	0.1	0.4	2.2	0.9
	Mean	8.0	4.6	8.1	6.6	5.2	4.0	5.2	9.2

TABLE A.2—*Continued*

Site	Quadrat	Coral Cover (%)							
	Location	1991	1993	1994	1995	1996	1997	1998	1999
Transect BP-3-B	0 m	22.4	4.4	0.4	3.4	4.8	5.2	0.6	6.9
	5 m		2.7	6.6	3.1	1.5	7.9	2.3	5.3
	10 m	9.2	0.3	0.1	0.6	0.1	0.2	0.2	0.3
	15 m		6.0	7.9	4.6	5.5	20.1	31.4	10.7
	20 m	3.5	2.7	1.6	0.1	1.2	2.3	0.4	2.8
	Mean	11.7	3.2	3.3	2.4	2.6	7.1	7.0	5.2
Transect BP-4-A	0 m		6.0	13.1	19.0	27.0	9.2	21.0	41.7
	5 m		13.8	52.0	46.0	42.8	40.0	29.1	47.0
	10 m		56.1	19.6	26.0	21.0	31.3	26.0	31.0
	15 m		15.2	31.0	27.0	29.3	28.0	11.1	24.3
	20 m		7.6	19.0	22.0	19.0	28.0	21.0	56.0
	Mean		19.7	26.9	28.0	27.8	27.3	21.6	40.0
Transect BP-4-B	0 m		0.1	10.5	11.7	19.3	17.6	13.4	28.6
	5 m		0.2	0.2	0.3	0.4	3.9	1.1	0.8
	10 m		0.2	1.5	2.3	2.7	0.4	3.7	1.9
	15 m		0.1	5.7	5.8	6.5	2.6	7.5	5.1
	20 m		0.1	0.8	1.6	2.2	4.6	2.6	3.6
	Mean		0.1	3.7	4.3	6.2	5.8	5.7	8.0

NOTE: Only three locations on each transect were sampled in 1991, and the transects at Station BP-4 were not established until 1993. Data for the years preceding 1999 are from earlier reports by the author.