

**COMMUNITY STRUCTURE OF FISH AND MACROBENTHOS  
AT SELECTED SHALLOW-WATER SITES IN RELATION  
TO THE BARBERS POINT OCEAN OUTFALL, 1996**

Richard E. Brock

PROJECT REPORT PR-97-02

November 1996

**WATER RESOURCES RESEARCH CENTER  
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**Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the view of the Water Resources Research Center.**

## ABSTRACT

This report provides the results of the fifth 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 east and inshore of the outfall terminus; Station BP-2, an experimental station about 1.5 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. The third field survey was completed in March and April 1994, the fourth in June 1995, and the fifth in May 1996; each sampled all four stations. These 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 five 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.



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## INTRODUCTION

### Purpose

The Honouliuli Wastewater Treatment Plant (WWTP), located in 'Ewa, O'ahu, Hawai'i, has been in operation since 1982. Currently, it releases approximately 25.22 mgd (1.11 m<sup>3</sup>/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, beginning 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 fifth survey carried out on 14–15 May 1996.

### 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 and would probably be manifested as a slow decline in the communities so impacted. Gradients of "stress" or "impact" should be evident with distance from the 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 east and inshore (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.

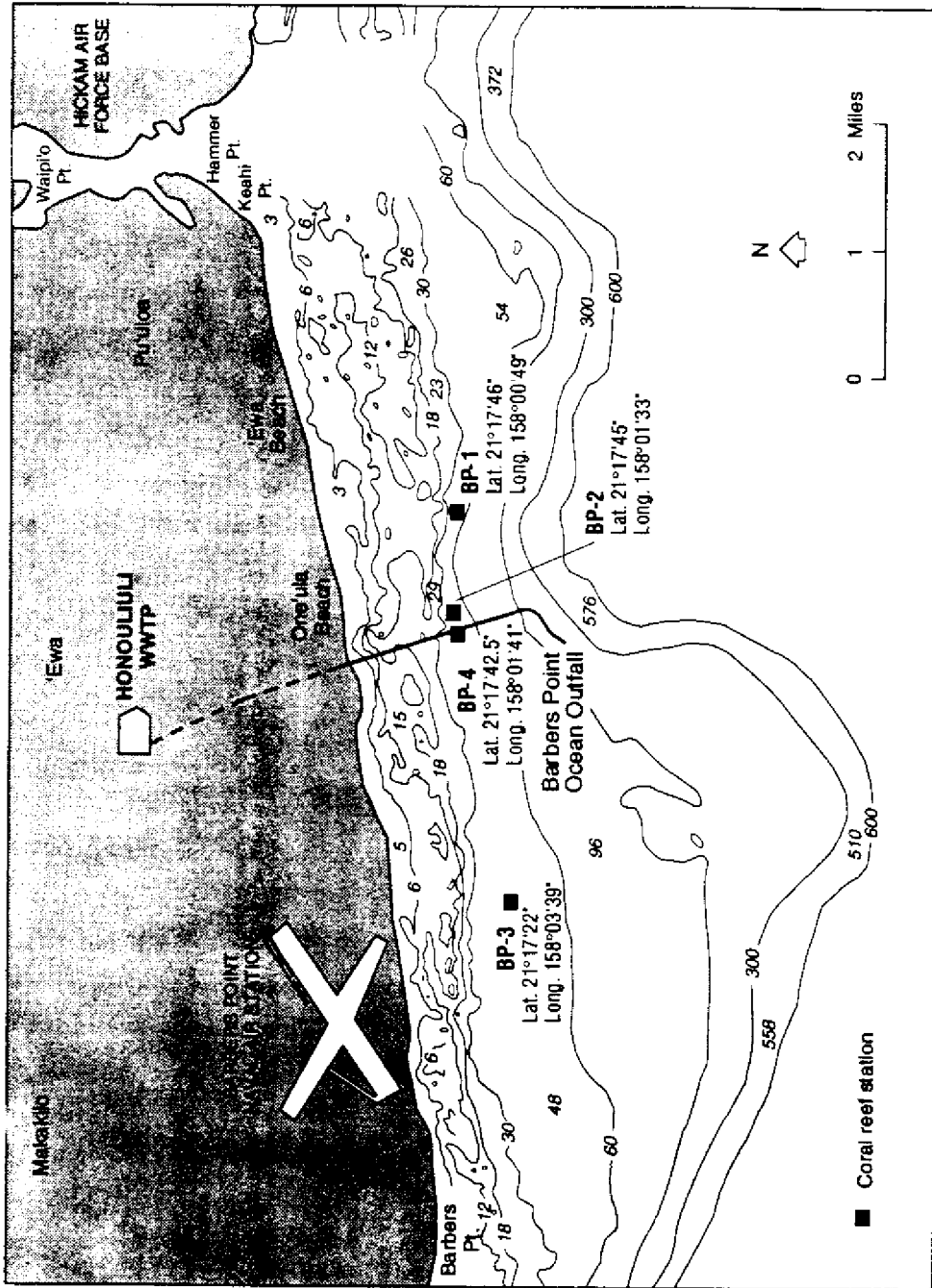


FIGURE 1. General locations of four permanent stations (two transects per station) sampled in the coral reef survey at the Barbers Point Ocean Outfall, O'ahu, Hawai'i. These are the eastern station (BP-1) where the first two transects are located (BP-1-A and BP-2-B), the middle station (BP-2-A and BP-2-B) just east of the sewer discharge pipeline where the second pair of transects (BP-2-A and BP-2-B) are situated, the western station (BP-3) where two transects (BP-3-A and BP-3-B) are established, and a new station (BP-4) established in 1993 where two transects on (BP-4-A) and adjacent to (BP-4-B) the discharge pipe are located.

- Station BP-2 Located about 0.25 km east of the sewage pipeline and approximately 1.5 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 ranging from 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 sewage pipeline and approximately 1.4 km inshore of the discharge terminus in water ranging from 12 to 13 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 × 1 m photographic quadrat was established at each of the marked points, for a total sampling of 3.35 m<sup>2</sup> 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 × 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 are 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 to be adequate for sampling many Hawaiian 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 × 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 cryptic species such as moray eels (family Muraenidae) and nocturnal species such as squirrelfishes (family Holocentridae) and bigeyes or 'āweoweo (family Priacanthidae). This problem is compounded in areas of high relief and coral coverage that affords 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 m<sup>2</sup>). 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 are taken on the species present. Beginning with the 1993 survey, supplementary information on benthic coverage was obtained by using 1 m × 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 × 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.

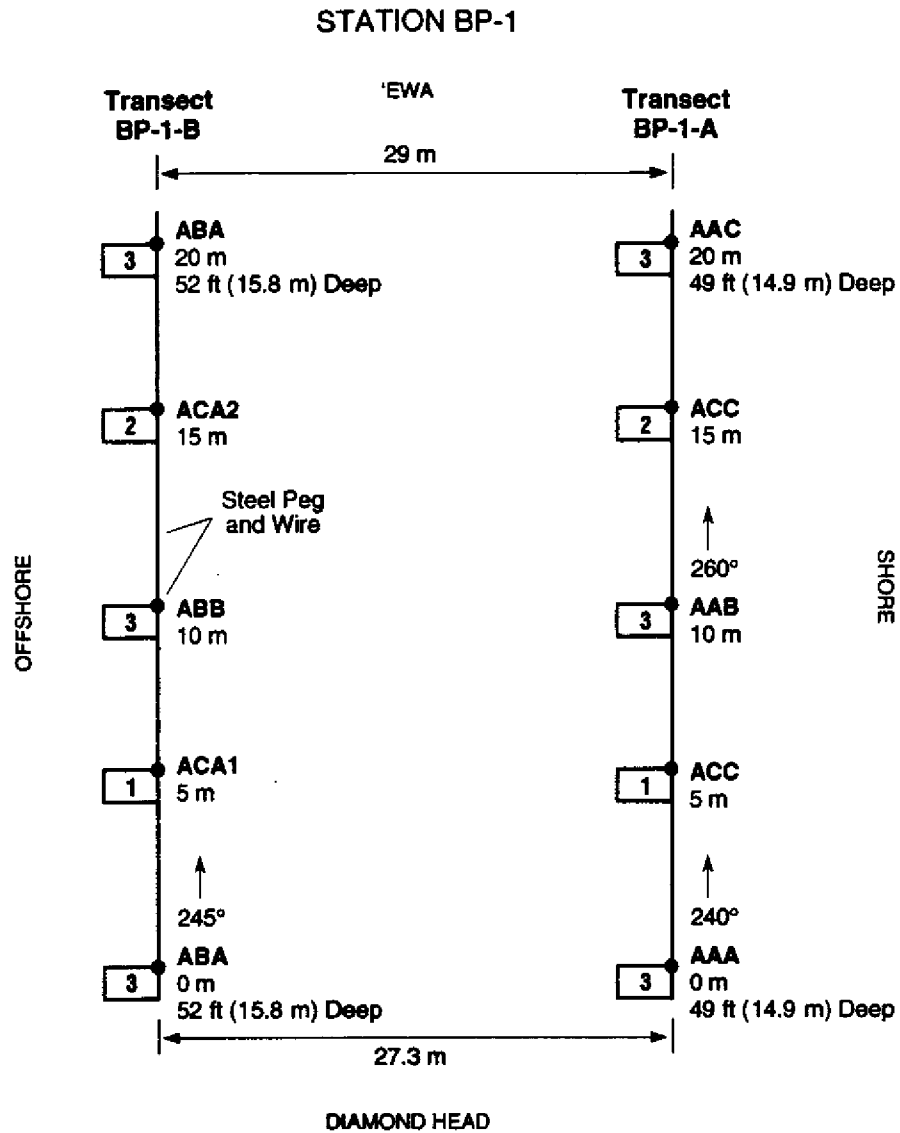
As requested by permit agencies, divers made simple physical measurements at the four stations. Measurements of percent oxygen concentration and temperature were made with a YSI Model 57 Oxygen meter, salinity was taken with a hand-held refractometer, and water clarity was determined using a 12-inch 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 1985). Nonparametric methods were used to avoid meeting requirements of normal distribution and homogeneity of variance in the data. Data were analyzed using the Wilcoxon two-sample test to discern statistically significant differences among ranked means for each transect site and sampling period; this procedure is outlined in Siegel (1956) and Sokal and Rohlf (1995).

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

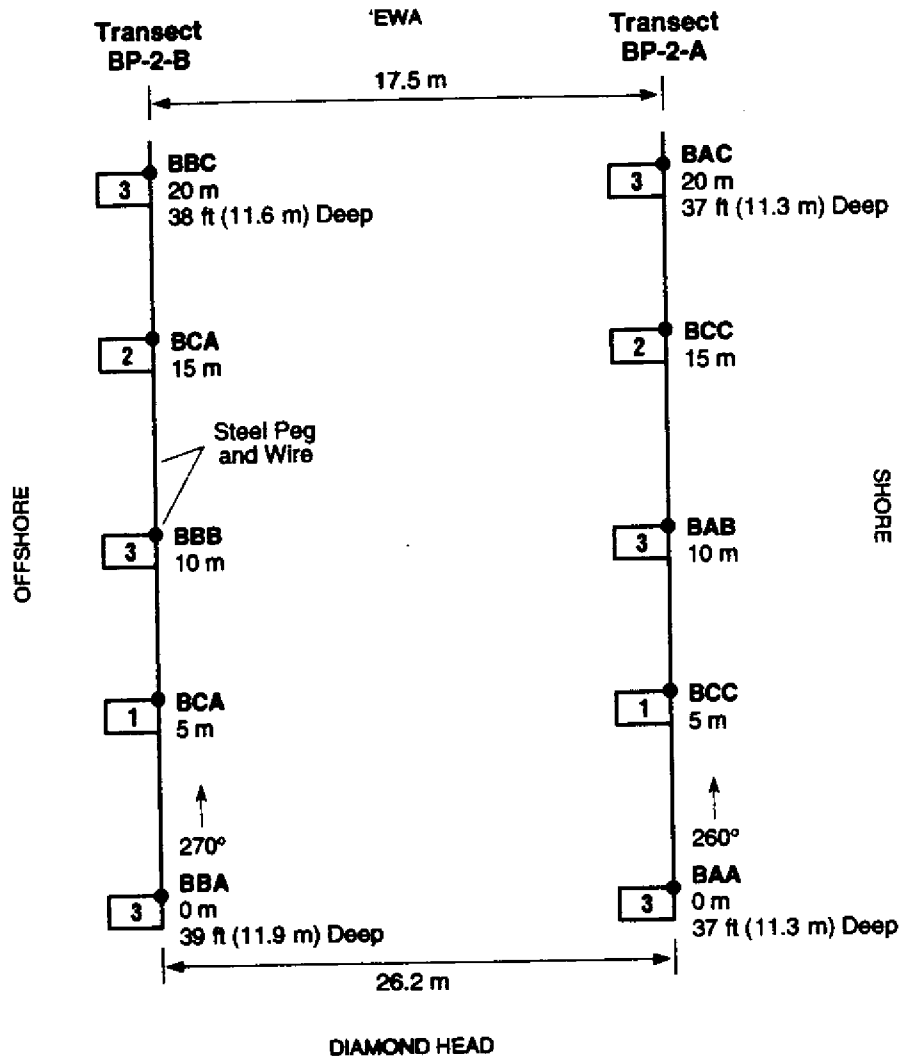
Field sampling was undertaken on 14 and 15 May 1996, and the photographs were taken by members of the Oceanographic Team, Department of Wastewater Management, City and County of Honolulu, on 5, 7, 23, and 29 February 1996. The physical measurements (temperature, salinity, and oxygen) were made on the morning of 20 May 1996. 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.



 Photographic quadrat (0.67 m x 1 m)

FIGURE 2. Locations of the five photographic quadrats each on Transects BP-1-A and BP-1-B located at the eastern station (BP-1) offshore of 'Ewa Beach, O'ahu, Hawai'i

STATION BP-2

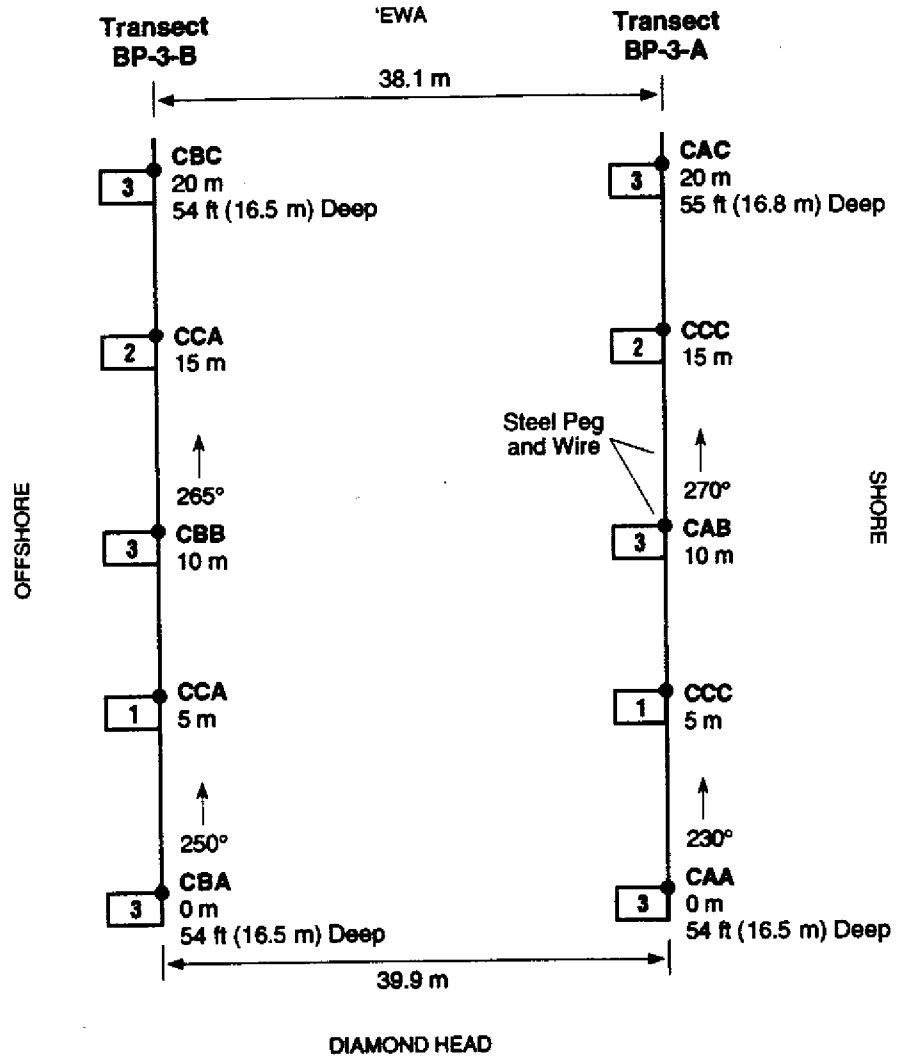


 Photographic quadrat (0.67 m x 1 m)

FIGURE 3. Locations of the five photographic quadrats each on Transects BP-2-A and BP-2-B located at the middle station (BP-2) just east of the Barbers Point Ocean Outfall discharge pipe offshore of 'Ewa Beach, O'ahu, Hawaii'



STATION BP-3



 Photographic quadrat (0.67 m × 1 m)

FIGURE 4. Locations of the five photographic quadrats each on Transects BP-3-A and BP-3-B located at the western station (BP-3) offshore of 'Ewa Beach, O'ahu, Hawai'i

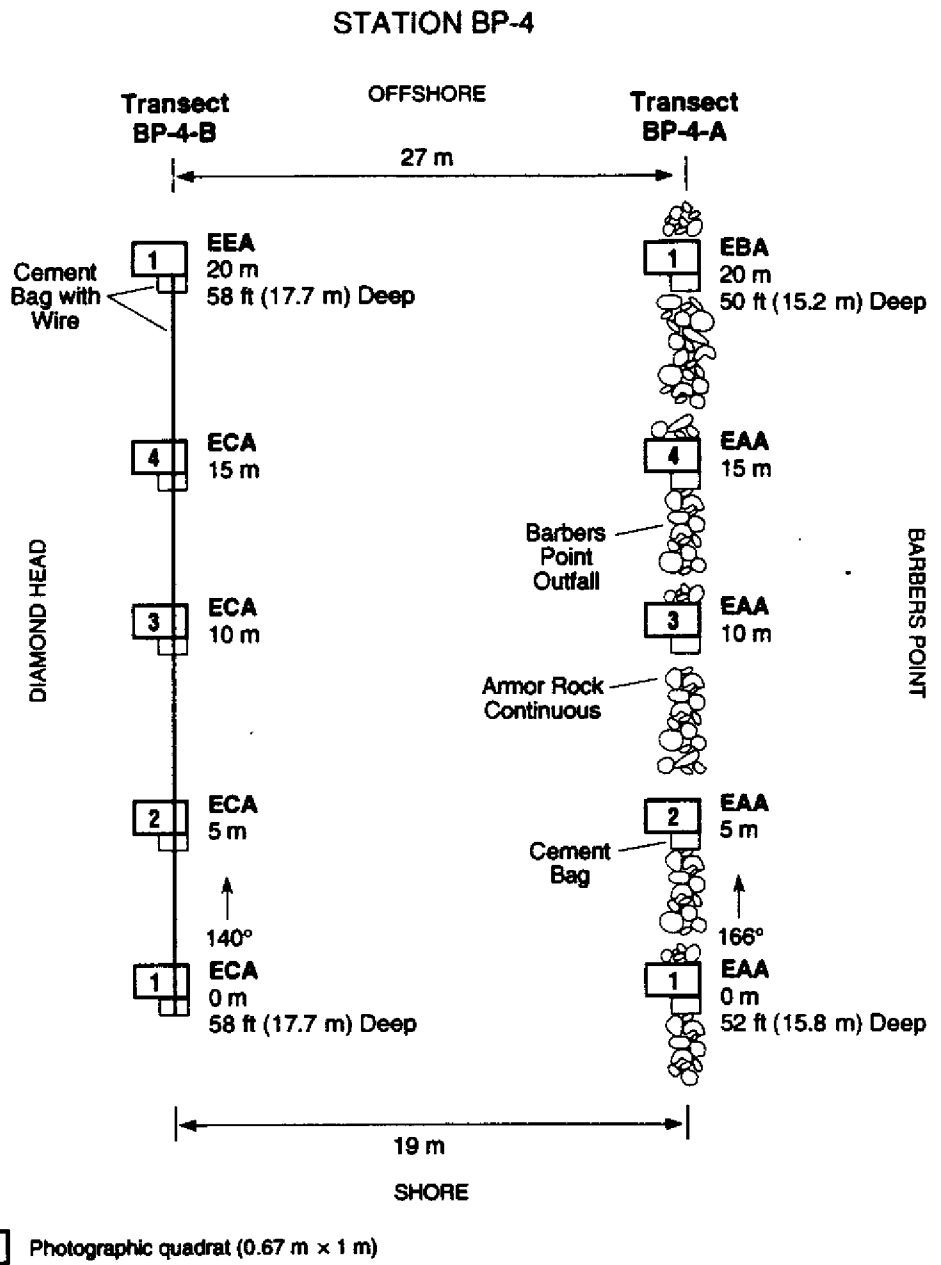


FIGURE 5. Locations of the five photographic quadrats each on Transects BP-4-A and BP-4-B located on and adjacent to the armor rock covering the Barbers Point Ocean Outfall discharge pipe offshore of 'Ewa Beach, O'ahu, Hawaii'

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 situated about 2.2 km east and inshore (northeast) of the deep-ocean outfall terminus. This station 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 at Transect BP-1-A in May 1996 is presented in Table 1. In the visually assessed quadrat survey, one algal species (*Porolithon onkodes*) having a mean coverage of 0.4%, one sponge species (*Chondrosia chucalla*) with a mean coverage of 0.9%, one soft coral species (*Anthelia edmondsoni*) having a mean coverage of 0.1%, and five coral species (*Porites lobata*, *P. compressa*, *Montipora verrucosa*, *Pocillopora meandrina*, and *Pavona varians*) were encountered. *Porites lobata* continues to be the dominant coral at this transect, where mean coral coverage for all species combined was 15.0%. The macroinvertebrate census noted the rock oyster *Spondylus tenebrosus*, the polychaetes *Sabellastarte sanctijosephi* and *Loimia medusa*, the hermit crab *Aniculus strigatus*, and two sea urchin species (*Echinothrix diadema* and *E. calamaris*).

The results of the fish census are presented in the Appendix. Thirty-four species representing 294 individuals were counted on Transect BP-1-A. The most abundant species included the brick soldierfish or menpachi (*Myripristis amaenus*), the damselfish *Dascyllus albisella*, the brown surgeonfish or ma'i'i'i (*Acanthurus nigrofuscus*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fishes was estimated at

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 14 May 1996

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
<i>Porolithon onkodes</i>	2.1				
Sponges					
<i>Chondrosia chucalla</i>			0.3	1.3	2.8
Soft Corals					
<i>Anthelia edmondsoni</i>	0.3				0.1
Corals					
<i>Porites lobata</i>	7.2	34.0	0.5	0.2	22.0
<i>Porites compressa</i>		4.6	0.2	1.1	1.0
<i>Pocillopora meandrina</i>	1.1		0.2		
<i>Pavona varians</i>		0.8			
<i>Montipora verrucosa</i>				0.1	2.1
Sand	1.0		7.0	2.0	4.0
Rubble	29.3	8.0	78.8	95.3	68.0
Hard Substratum	59.0	52.6	13.0		
<hr/>					
II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals				
<hr/>					
Phylum Mollusca					
<i>Spondylus tenebrosus</i>	3				
Phylum Annelida					
<i>Loimia medusa</i>	1				
<i>Sabellastarte sanctijosephi</i>	1				
Phylum Arthropoda					
<i>Aniculus strigatus</i>	1				
Phylum Echinodermata					
<i>Echinothrix calamaris</i>	1				
<i>Echinothrix diadema</i>	4				
<hr/>					
III. Fish Census (4 m × 20 m)					
<hr/>					
34 Species					
294 Individuals					
Estimated Standing Crop = 115 g/m <sup>2</sup>					

NOTE: Results of the 5-m<sup>2</sup> 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 15.0% (visual quadrat method).

115 g/m<sup>2</sup>, with the largest contributors including the emperor fish or mu (*Monotaxis grandoculis*—20% of the total), *Ctenochaetus strigosus* (16% of the total), and *Myripristis amaenus* (11% of the total).

The results of the photo-quadrat survey made at the four stations are presented in Table 2. At Transect BP-1-A, three coral species having a mean coverage of 27.3% were recorded. Also recorded was the algal species *Porolithon onkodes* with a mean coverage of 0.7%. Other benthic organisms present included the sponge *Chondrosia chucalla* and the soft coral *Anthelia edmondsoni*. It should be noted that the photographs used in this study were taken in February and the visual quadrat data were obtained in May 1996.

#### **Transect BP-1-B**

Transect BP-1-B is situated seaward of Transect BP-1-A. The results of the quantitative survey carried out on this transect are presented in Table 3. The quadrat survey noted one algal species (*Porolithon onkodes*) with a mean coverage of 0.3%, one sponge species (*Chondrosia chucalla*) having a mean coverage of 0.2%, and six coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora patula*, *Pavona duerdeni*, and *Fungia scutaria*). The dominant coral species was *Porites lobata*, and mean coral coverage was 23.7%. In the 4 m × 20 m census area, six macroinvertebrate species were seen: the rock oyster *Spondylus tenebrosus*, the leopard cone shell *Conus leopardus*, the boring bivalve *Lithophaga* sp., the Christmas tree worm *Spirobranchus giganteus corniculatus*, the featherduster worm *Sabellastarte sanctijosephi*, and the starfish *Linckia diplax*.

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 27.9% were noted. Also encountered were the alga *Porolithon onkodes* and two encrusting sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*).

The results of the fish census are presented in the Appendix. Forty species representing 370 individuals were censused at Transect BP-1-B, where the most common species present were the brick soldierfish or menpachi (*Myripristis amaenus*), the bluelined snapper or ta'ape (*Lutjanus kasmira*), the brown surgeonfish or ma'i'i'i (*Acanthurus nigrofuscus*), the orangebar surgeonfish or na'ena'e (*Acanthurus olivaceus*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fish was estimated at 290 g/m<sup>2</sup>, with the largest contributors being *Myripristis amaenus* and *Lutjanus kasmira* (each contributing 15% of the total) and *Acanthurus olivaceus* (making up 24% of the total).

TABLE 2. Summary of the Results of the Photographic Quadrat Survey for Stations BP-1 Through BP-4, Barbers Point Ocean Outfall, 'Ewa Beach, O'ahu, Hawai'i, 1996

Transect BP-1-A	Percent Cover				
	Photographic Quadrat				
	AAA3 (0 m)	ACC1 (5 m)	AAB3 (10 m)	ACC2 (15 m)	AAC3 (20 m)
Algae					
<i>Porolithon onkodes</i>		2.9			0.6
Sponges					
<i>Chondrosia chucalla</i>			0.3	0.6	2.0
Soft Corals					
<i>Anthelia edmondsoni</i>					0.3
Corals					
<i>Porites lobata</i>	60.0	52.3			22.4
<i>Porites compressa</i>	0.5	1.1			
<i>Pocillopora meandrina</i>				0.3	
Sand			8.7	3.4	28.7
Rubble			20.1		
Hard Substratum	39.5	43.7	70.9	95.7	46.0
Mean Coral Coverage = 27.3%					

Transect BP-1-B	Percent Cover				
	Photographic Quadrat				
	ABA3 (0 m)	ACA1 (5 m)	ABB3 (10 m)	ACA2 (15 m)	ABC3 (20 m)
Algae					
<i>Porolithon onkodes</i>	19.0	0.8		0.8	1.1
Sponges					
<i>Spirastrella coccinea</i>	0.3				
<i>Chondrosia chucalla</i>	0.3	0.3	0.8	0.1	
Corals					
<i>Porites lobata</i>	36.1	7.6	8.4	16.5	57.7
<i>Porites compressa</i>	2.8	4.2	0.6	1.1	2.2
<i>Pocillopora meandrina</i>	0.3	0.6			1.1
<i>Montipora patula</i>		0.3			
Sand			4.7	0.6	
Rubble		9.0	8.1	14.3	
Hard Substratum	55.2	77.2	77.4	66.6	37.9
Mean Coral Coverage = 27.9%					

TABLE 2—Continued

Transect BP-2-A	Percent Cover				
	Photographic Quadrat				
	BAA3 (0 m)	BCC1 (5 m)	BAB3 (10 m)	BCC2 (15 m)	BAC3 (20 m)
Algae					
<i>Asparagopsis taxiformis</i>			0.3		
Sponges					
<i>Spirastrella coccinea</i>			0.4	0.6	
<i>Chondrosia chucalla</i>	0.3			0.8	0.1
<i>Plakortis simplex</i>				0.3	
Corals					
<i>Porites lobata</i>	0.4			1.7	0.6
<i>Pocillopora meandrina</i>			0.1		0.1
Sand	1.4	14.8	22.4	1.7	12.9
Hard Substratum	97.9	85.2	76.8	95.0	86.3
Mean Coral Coverage = 0.6%					

Transect BP-2-B	Percent Cover				
	Photographic Quadrat				
	BBA3 (0 m)	BCA1 (5 m)	BBB3 (10 m)	BCA2 (15 m)	BBC3 (20 m)
Sponges					
<i>Spirastrella coccinea</i>	0.1	0.3			
<i>Chondrosia chucalla</i>	0.1	0.3		0.8	0.3
Unidentified orange sponge	0.1				0.1
Corals					
<i>Porites lobata</i>	0.4	3.4	0.3		0.3
<i>Pocillopora meandrina</i>	0.3	0.6	0.3		
Sand	36.7	1.7	7.0	1.7	1.7
Hard Substratum	62.2	93.8	92.4	98.3	97.6
Mean Coral Coverage = 1.1%					

TABLE 2—Continued

Transect BP-3-A	Percent Cover				
	Photographic Quadrat				
	CAA3 (0 m)	CCC1 (5 m)	CAB3 (10 m)	CCC2 (15 m)	CAC3 (20 m)
Algae					
<i>Porolithon onkodes</i>		1.4			
Sponges					
<i>Spirastrella coccinea</i>		0.3		0.3	
<i>Chondrosia chucalla</i>	0.1			8.4	0.1
Corals					
<i>Porites lobata</i>		0.1		2.2	
<i>Porites compressa</i>				0.3	
<i>Pocillopora meandrina</i>				2.0	
Sand	1.1		0.8		3.4
Rubble	68.2	46.5	99.2	51.5	62.3
Hard Substratum	30.5	51.7		35.3	34.2
Mean Coral Coverage = 0.9%					

Transect BP-3-B	Percent Cover				
	Photographic Quadrat				
	CBA3 (0 m)	CCA1 (5 m)	CBB3 (10 m)	CCA2 (15 m)	CBC3 (20 m)
Algae					
<i>Porolithon onkodes</i>	0.6	1.7		0.6	
Sponges					
<i>Spirastrella coccinea</i>	0.6	1.4		3.4	0.6
<i>Chondrosia chucalla</i>		0.6			
Corals					
<i>Porites lobata</i>	1.1	2.0		16.5	0.3
<i>Porites compressa</i>				3.1	
<i>Pocillopora meandrina</i>				0.6	0.1
<i>Montipora patula</i>				0.3	
Sand					0.8
Rubble	25.8	47.6	0.8	13.4	56.4
Hard Substratum	61.9	46.8	99.2	62.2	41.7
Mean Coral Coverage = 4.8%					



TABLE 2—Continued

Transect BP-4-A	Percent Cover				
	Photographic Quadrat				
	EAA1 (0 m)	EAA2 (5 m)	EAA3 (10 m)	EAA4 (15 m)	EBA1 (20 m)
Algae					
<i>Porolithon onkodes</i>			2.0		2.2
Sponges					
<i>Spirastrella coccinea</i>	1.4		0.8	0.1	0.6
Corals					
<i>Porites lobata</i>	4.8	20.7	19.3	24.6	17.9
Rubble	33.3	5.3	11.8		6.4
Hard Substratum	60.5	74.0	66.1	75.3	72.9
Mean Coral Coverage = 17.5%					

Transect BP-4-B	Percent Cover				
	Photographic Quadrat				
	ECA1 (0 m)	ECA2 (5 m)	ECA3 (10 m)	EAC4 (15 m)	EEA1 (20 m)
Sponges					
<i>Spirastrella coccinea</i>					0.1
<i>Chondrosia chucalla</i>		0.1		0.8	1.1
<i>Plakortis simplex</i>			0.3		
Soft Corals					
<i>Anthelia edmondsoni</i>				0.3	
Corals					
<i>Porites lobata</i>	0.6		2.0	2.8	0.6
<i>Pocillopora meandrina</i>	14.0		2.8		0.3
Sand	0.8	3.4	0.8	0.8	0.8
Hard Substratum	84.6	96.8	94.1	95.2	97.0
Mean Coral Coverage = 4.6%					

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-m<sup>2</sup> 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 14 May 1996

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
<i>Porolithon onkodes</i>			1.5		
Sponges					
<i>Chondrosia chucalla</i>	0.3		0.2	0.4	
Corals					
<i>Porites lobata</i>	6.8	2.3	14.0	2.1	82.0
<i>Porites compressa</i>	1.4			2.8	4.0
<i>Pocillopora meandrina</i>		0.4	0.2	0.1	
<i>Montipora patula</i>			0.8	1.0	
<i>Pavona duerdeni</i>			0.3		
<i>Fungia scutaria</i>				0.1	
Sand	3.0	6.0	6.0	1.0	
Rubble	70.5	86.3	60.0	73.5	
Hard Substratum	18.0	5.0	17.0	19.0	14.0
<hr/>					
II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals				
<hr/>					
Phylum Mollusca					
<i>Spondylus tenebrosus</i>			1		
<i>Conus leopardus</i>			1		
<i>Lithophaga</i> sp.			2		
Phylum Annelida					
<i>Spirobranchus giganteus corniculatus</i>			5		
<i>Sabellastarte sanctijosephi</i>			1		
Phylum Echinodermata					
<i>Linckia diplax</i>			1		
<hr/>					
III. Fish Census (4 m × 20 m)					
<hr/>					
40 Species					
370 Individuals					
Estimated Standing Crop = 290 g/m <sup>2</sup>					
<hr/>					

NOTE: Results of the 5-m<sup>2</sup> 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 23.7% (visual quadrat method).

### **Station Observations**

In the vicinity of Station BP-1 were seen the corals *Pavona duerdeni* and *Montipora flabellata*, as well as the tableboss or 'a'awa (*Bodianus bilunulatus*) and the bigeye or 'āweoweo (*Priacanthus cruentatus*).

### **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 seen include *Pocillopora meandrina* and *Porites lobata*; other species seen include *Montipora patula*. Two of the common algal species in the area were limu kohu or *Asparagopsis taxiformis* and the recently introduced *Avrainvillea amadelpha*.

The two permanently marked transect lines at this station have an orientation that approximately parallels 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 noted six algal species (*Asparagopsis taxiformis*, *Avrainvillea amadelpha*, *Amansia glomerata*, *Padina japonica*, *Sphacelaria furcigera*, and *Dotyella hawaiiensis*) having a mean coverage of 0.6%, three sponge species (*Chondrosia chucalla*, *Spirastrella coccinea*, and *Terpios zeteki*) with a mean coverage of 0.6%, one soft coral species (*Anthelia edmondsoni*) with a mean coverage of less than 0.1%, and two coral species (*Porites lobata* and *Pocillopora meandrina*). Mean coral coverage at this transect was estimated at 1.0%. The macroinvertebrate census carried out over the 4 m × 20 m area noted five species: the cone shells *Conus quercinus* and *C. lividus*, the polychaete *Spirobranchus giganteus corniculatus*, the rock boring sea urchin *Echinostrephus aciculatum*, and the banded urchin *Echinothrix calamaris*.

The photo-quadrat survey noted one algal species or limu kohu (*Asparagopsis taxiformis*), three sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and *Plakortis simplex*), and two coral species (*Porites lobata* and *Pocillopora meandrina*). Mean coral coverage was estimated at 0.6%.

The results of the fish census are presented in the Appendix. In total seven fish species representing 11 individuals were censused at Transect BP-2-A. The biomass of fishes on this transect was estimated at 9 g/m<sup>2</sup>, with the largest contributors being a bridled triggerfish or humuhumu mimi (*Sufflamen fraenatus*—67% of the total).

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 14 May 1996

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
<b>Algae</b>					
<i>Avrainvillea amadelpha</i>	0.1				
<i>Asparagopsis taxiformis</i>	0.6				0.4
<i>Amansia glomerata</i>				0.9	
<i>Padina japonica</i>				0.1	0.1
<i>Sphacelaria furcigera</i>	0.3	0.2			0.2
<i>Dotyella hawaiiensis</i>			0.1		
<b>Sponges</b>					
<i>Chondrosia chucalla</i>	0.4	0.1	0.3	1.1	0.7
<i>Spirastrella coccinea</i>				0.3	
<i>Terpios zeteki</i>	0.1				
<b>Soft Corals</b>					
<i>Anthelia edmondsoni</i>				0.1	
<b>Corals</b>					
<i>Porites lobata</i>	2.3		0.7	1.4	
<i>Pocillopora meandrina</i>					0.7
<b>Sand</b>		3.0	2.0	2.0	3.0
<b>Hard Substratum</b>	96.2	96.7	97.0	94.1	94.9
<hr/>					
II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals				
<hr/>					
<b>Phylum Mollusca</b>					
<i>Conus lividus</i>	2				
<i>Conus quercinus</i>	1				
<b>Phylum Annelida</b>					
<i>Spirobranchus giganteus corniculatus</i>	11				
<b>Phylum Echinodermata</b>					
<i>Echinostrephus aciculatum</i>	2				
<i>Echinothrix calamaris</i>	3				
<hr/>					
<b>III. Fish Census (4 m × 20 m)</b>					
<hr/>					
7 Species					
11 Individuals					
Estimated Standing Crop = 9 g/m <sup>2</sup>					

NOTE: Results of the 5-m<sup>2</sup> 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 11.3 m; mean coral coverage is 1.0% (visual quadrat method).

### **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 carried out at Transect BP-2-B. Six algal species (*Sphacelaria furcigera*, *Avrainvillea amadelpa*, *Amansia glomerata*, *Asparagopsis taxiformis*, *Dotyella hawaiiensis*, and *Polysiphonia* sp.) with a mean coverage of 0.6%, two encrusting sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) and one boring sponge (*Cliona vastifica*) having a mean coverage of 0.3%, one soft coral (*Anthelia edmondsoni*) with a mean coverage of less than 0.1%, and two coral species (*Porites lobata* and *Pocillopora meandrina*) were noted. Mean coral coverage was estimated at 0.5%. Noncolonial macroinvertebrates censused in the 4 m × 20 m transect include the cone shells *Conus leopardus* and *Conus lividus*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, the burrowing shrimp *Callinassa variabilis*, and three sea urchin species (the rock boring urchin *Echinostrephus aciculatum*, the banded urchin *Echinothrix calamaris*, and the black urchin *Tripneustes gratilla*).

The results of the photo-quadrat survey for Transect BP-2-B are given in Table 2. Three sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and an unidentified orange sponge) provided a mean coverage of 0.4%, and two coral species (*Porites lobata* and *Pocillopora meandrina*) contributed 1.1%.

The fish census noted 12 species of fishes representing 43 individuals (Appendix). The most common species on this transect were the black damselfish or 'ālo'ilo'i (*Dascyllus albisella*) and the brick soldierfish or menpachi (*Myripristis amaenus*). Fish standing crop was estimated at 56 g/m<sup>2</sup>, with a single yellowmargin moray eel or puhi paka (*Gymnothorax flavimarginatus*) contributing 75% and two bridled triggerfishes (*Sufflamen fraenatus*) adding 15%.

### **Station Observations**

The 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. Similarly, the relatively higher abundance of noncolonial macroinvertebrates is probably related to the lack of shelter, which makes their detection easier.

In the vicinity of Station BP-2 were seen the coral *Pavona varians*, the reef crab *Thalamita edwardsi*, the goby *Gnatholepis anjerensis*, and a juvenile shortnose wrasse (*Macropharyngodon geoffroy*).

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 14 May 1996

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
<b>Algae</b>					
<i>Sphacelaria furcigera</i>	0.2	0.4	0.2	0.5	0.1
<i>Polysiphonia</i> sp.		0.3			
<i>Avrainvillea amadelpa</i>			0.4		
<i>Amansia glomerata</i>			0.2		
<i>Asparagopsis taxiformis</i>			0.3	0.1	
<i>Dotyella hawaiiensis</i>			0.1		
<b>Sponges</b>					
<i>Chondrosia chucalla</i>	0.2	0.1	0.3	0.2	0.4
<i>Spirastrella coccinea</i>		0.2		0.1	
<i>Cliona vastifica</i>	0.2				
<b>Soft Corals</b>					
<i>Anthelia edmondsoni</i>			0.1		
<b>Corals</b>					
<i>Porites lobata</i>	0.5	0.4	0.1		0.3
<i>Pocillopora meandrina</i>			1.0	0.2	
Sand	4.0	2.0	1.0		2.0
Hard Substratum	94.9	96.6	96.3	98.9	97.2
<hr/>					
II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals				
<hr/>					
<b>Phylum Mollusca</b>					
<i>Conus leopardus</i>	1				
<i>Conus lividus</i>	1				
<b>Phylum Annelida</b>					
<i>Spirobranchus giganteus corniculatus</i>	5				
<b>Phylum Arthropoda</b>					
<i>Callinassa variabilis</i>	1				
<b>Phylum Echinodermata</b>					
<i>Tripneustes gratilla</i>	1				
<i>Echinothrix calamaris</i>	1				
<i>Echinostrephus aciculatum</i>	4				
<hr/>					
<b>III. Fish Census (4 m × 20 m)</b>					
<hr/>					
12 Species					
43 Individuals					
Estimated Standing Crop = 56 g/m <sup>2</sup>					
<hr/>					

NOTE: Results of the 5-m<sup>2</sup> 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 0.5% (visual quadrat method).

### 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 may occur in depressions 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 three encrusting sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and *Plakortis simplex*) having a mean coverage of 1.7% and four coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, and *Montipora verrucosa*). Mean coral coverage at this location was estimated at 5.2% (visual quadrat method), and the dominant species was *Porites lobata*. Eight macroinvertebrate species were censused, including the rock oyster *Spondylus tenebrosus*, the polychaete *Spirobranchus giganteus corniculatus*, and six sea urchin species (*Echinostrephus aciculatum*, *Tripneustes gratilla*, *Heterocentrotus mammillatus*, *Echinometra mathaei*, *Echinothrix diadema*, and *E. calamaris*).

The results of the photo-quadrat analyses for Transect BP-3-A are presented in Table 2. Noted were one coralline algal species (*Porolithon onkodes*) having a mean coverage of 0.3%, two sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) with a mean coverage of 1.8%, and three coral species (*Porites lobata*, *P. compressa*, and *Pocillopora meandrina*) having a mean coverage of 0.9%.

The results of the fish census at Transect BP-3-A are presented in the Appendix. Twenty-six fish species representing 320 individuals were censused. The most abundant fish species were the manybar goatfish or moano (*Parupeneus multifasciatus*), the damselfish or 'ālo'ilo'i (*Dascyllus albisella*), the saddleback wrasse (*Thalassoma duperrey*), the brown surgeonfish or ma'i'i'i (*Acanthurus nigrofuscus*), as well as the orangebar surgeonfish or na'ena'e (*Acanthurus olivaceus*). The standing crop was estimated at 176 g/m<sup>2</sup>, with a single grey

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 May 1996

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
<b>Sponges</b>					
<i>Chondrosia chucalla</i>	0.3	0.6	0.1	1.0	0.1
<i>Spirastrella coccinea</i>		4.3		1.8	0.4
<i>Plakortis simplex</i>					0.1
<b>Corals</b>					
<i>Porites lobata</i>		1.5		14.5	
<i>Porites compressa</i>				4.0	
<i>Pocillopora meandrina</i>	0.1			5.5	0.1
<i>Montipora verrucosa</i>		0.3			
Sand	2.0		6.0		9.0
Rubble	85.6	71.3	86.9	35.2	84.3
Hard Substratum	12.0	22.0	7.0	38.0	6.0
<hr/>					
II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals				
<b>Phylum Mollusca</b>					
<i>Spondylus tenebrosus</i>	2				
<b>Phylum Annelida</b>					
<i>Spirobranchus giganteus corniculatus</i>	4				
<b>Phylum Echinodermata</b>					
<i>Echinostrephus aciculatum</i>	1				
<i>Tripneustes gratilla</i>	4				
<i>Heterocentrotus mammillatus</i>	4				
<i>Echinometra mathaei</i>	2				
<i>Echinothrix diadema</i>	10				
<i>Echinothrix calamaris</i>	1				
<hr/>					
<b>III. Fish Census (4 m × 20 m)</b>					
26 Species					
320 Individuals					
Estimated Standing Crop = 176 g/m <sup>2</sup>					

NOTE: Results of the 5-m<sup>2</sup> 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 5.2% (visual quadrat method).



snapper or uku (*Aprion virescens*) contributing 13% and *Acanthurus olivaceus* making up 40%.

#### **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 carried out at this transect. Three sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and *Plakortis simplex*) having a mean coverage of 1.2% and five coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora verrucosa*, and *M. patula*) were noted. Coral coverage at this transect was estimated at 2.6% (visual quadrat method). Seven species of macroinvertebrates were censused in the 4 m × 20 m area, including the rock oyster *Spondylus tenebrosus*, the boring bivalve *Lithophaga* sp., and five sea urchin species (*Echinometra mathaei*, *Tripneustes gratilla*, *Heterocentrotus mammillatus*, *Echinothrix diadema*, and *E. calamaris*).

Table 2 presents the results of the photo-quadrat survey carried out at Transect BP-3-B. Noted were one coralline algal species (*Porolithon onkodes*) having a mean coverage of 0.6%, two sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) with a mean coverage of 1.3%, and four coral species (*Montipora patula*, *Pocillopora meandrina*, *Porites compressa*, and *P. lobata*) having a mean coverage of 4.8%.

The results of the fish census carried out at Transect BP-3-B are presented in the Appendix. In total 27 species representing 393 individuals were counted, with the most abundant fishes including the manybar goatfish or moano (*Parupeneus multifasciatus*), the saddleback wrasse or hīnālea lauwiki (*Thalassoma duperrey*), the smalltail wrasse *Pseudojuloides cerasinus*, and the orangebar surgeonfish or na'ena'e (*Acanthurus olivaceus*). The standing crop of fishes was estimated at 282 g/m<sup>2</sup>, and the species contributing most heavily included the tableboss or 'a'awa (*Bodianus bilunulatus*—12% of the total), *Acanthurus olivaceus* (41% of the total), and *Naso hexacanthus* (24% of the total).

#### **Station Observations**

In the vicinity of Station BP-3 were seen the coral *Porites rus*, as well as the undulate moray eel or puhi laumilo (*Gymnothorax undulatus*), the octopus or he'e (*Octopus cyanea*), the reticulated cowry *Cypraea reticulata*, and a small blue trevally or 'ōmilu (*Caranx melampygus*).

#### **Station BP-4**

Station BP-4 was established on 10 September 1993 with two transects placed on and adjacent to the basalt caprock shield that covers and protects the discharge pipe. It is located approximately 250 m west of Station BP-2 in 12.2 to 13.4 m of water and approximately

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 May 1996

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Sponges					
<i>Spirastrrella coccinea</i>	0.3	1.2		1.1	1.7
<i>Chondrosia chucalla</i>	0.4			0.2	0.5
<i>Plakortis simplex</i>				0.8	
Corals					
<i>Porites lobata</i>	4.0		0.1	4.2	0.9
<i>Porites compressa</i>	0.8	0.1		0.3	
<i>Pocillopora meandrina</i>		0.1		0.3	0.3
<i>Montipora verrucosa</i>		1.0			
<i>Montipora patula</i>		0.3		0.7	
Sand		1.0	2.0	2.0	
Rubble	81.5	79.3	94.9	64.4	84.6
Hard Substratum	13.0	17.0	3.0	26.0	12.0
<hr/>					
II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals				
<hr/>					
Phylum Mollusca					
<i>Spondylus tenebrosus</i>		3			
<i>Lithophaga</i> sp.		2			
Phylum Echinodermata					
<i>Echinometra mathaei</i>		4			
<i>Tripneustes gratilla</i>		1			
<i>Heterocentrotus mammillatus</i>		3			
<i>Echinothrix diadema</i>		4			
<i>Echinothrix calamaris</i>		6			
<hr/>					
III. Fish Census (4 m × 20 m)					
<hr/>					
27 Species					
393 Individuals					
Estimated Standing Crop = 282 g/m <sup>2</sup>					

NOTE: Results of the 5-m<sup>2</sup> 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 m; mean coral coverage is 2.6% (visual quadrat method).

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 approximately 19 to 27 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 dimension and are spaced from overlapping contact with one another to about 2 m apart. The open areas between the capstones are 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 noted one algal species (*Porolithon onkodes*) with a mean coverage of 1.2%, one sponge species (*Spirastrella coccinea* having a mean coverage of 0.3%), and two coral species (*Porites lobata* and *Pocillopora meandrina*) having a mean coverage of 27.8%. The census of macroinvertebrates noted seven species: the rock oyster *Spondylus tenebrosus*, the nudibranch *Pteraeolidia ianthina*, two polychaete species (*Sabellastarte sanctijosephi* and *Spirobranchus giganteus corniculatus*), and three sea urchin species (*Echinothrix diadema*, *E. calamaris*, and *Tripneustes gratilla*).

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 0.8%, the encrusting sponge *Spirastrella coccinea* had a mean coverage of 0.6%, and one coral species (*Porites lobata*) had an estimated coverage of 17.5%.

The results of the fish census carried out at Transect BP-4-A are presented in the Appendix. Fifty-two fish species representing 1,247 individuals having an estimated biomass of 685 g/m<sup>2</sup> were censused. The most abundant fish species included the manybar goatfish or moano (*Parupeneus multifasciatus*), the black damselfish or 'ālo'ilo'i (*Dascyllus albisella*), the milletseed butterfly fish or lauwiwili (*Chaetodon miliaris*), the palenose parrotfish or uhu (*Scarus psittacus*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). Species contributing most to the estimated standing crop included *Parupeneus multifasciatus* (24% of the total), the yellowfin goatfish or weke'ula (*Mulloidichthys vanicolensis*—11% of the total), and the orangebar surgeonfish or na'ena'e (*Acanthurus olivaceus*—10% of the total).

#### ***Transect BP-4-B***

Transect BP-4-B was established approximately 15 m to the east of Transect BP-4-A in 13.1 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

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 14 May 1996

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	1.0	3.0
Sponges					
<i>Spirastrella coccinea</i>				1.5	
Corals					
<i>Porites lobata</i>	27.0	42.0	21.0	29.0	19.0
<i>Pocillopora meandrina</i>		0.8		0.3	
Rubble	8.0	8.0	16.0	6.0	3.0
Hard Substratum	65.0	49.2	61.0	62.2	75.0

II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals
Phylum Mollusca	
<i>Spondylus tenebrosus</i>	13
<i>Pteraeolidia ianthina</i>	4
Phylum Annelida	
<i>Sabellastarte sanctijosephi</i>	1
<i>Spirobranchus giganteus corniculatus</i>	36
Phylum Echinodermata	
<i>Echinothrix diadema</i>	107
<i>Echinothrix calamaris</i>	3
<i>Tripneustes gratilla</i>	3

III. Fish Census (4 m × 20 m)
52 Species
1,247 Individuals
Estimated Standing Crop = 685 g/m <sup>2</sup>

NOTE: Results of the 5-m<sup>2</sup> 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 27.8% (visual quadrat method).

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 m<sup>2</sup>. 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 noted two algal species (*Asparagopsis taxiformis* and *Sphacelaria furcigera*) having a mean coverage of less than 0.1% and four coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa*, and *M. patula*) with a mean coverage of 6.2%. The macroinvertebrate census noted the cone shell *Conus leopardus*, the polychaetes *Spirobranchus giganteus corniculatus* and *Loimia medusa*, and the rock boring sea urchin *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 (*Spirastrella coccinea*, *Chondrosia chucalla*, and *Plakortis simplex*) had a mean coverage of 0.5%, one soft coral species (*Anthelia edmondsoni*) had a mean coverage of less than 0.1%, and two coral species (*Pocillopora meandrina* and *Porites lobata*) had a mean coverage of 4.6%.

The results of the fish census carried out at Transect BP-4-B are presented in the Appendix. Twelve species of fishes representing 67 individuals having an estimated standing crop of 27 g/m<sup>2</sup> were encountered. The most abundant fish species at this transect were the smalltail wrasse *Pseudojuloides cerasinus*, and the saddleback wrasse or hīnālea lauwiki (*Thalassoma duperrey*). The bridled triggerfish or humuhumu mimi (*Sufflamen fraenatus*) contributed 28% and *Thalassoma duperrey* made up 18% of the estimated biomass at Transect BP-4-B.

### Physical Measurements and Biological Parameters

Physical measurements made in the morning on 20 May 1996 are presented in Table 10. Little variation was noted in temperature (24.9° to 25.4°C), oxygen saturation (101% to 103%), and salinity (all 34‰) despite the fact that measurements for oxygen and temperature were made at both 1 m below the water 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 from the surface 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 1996 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

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 14 May 1996

I. Quadrat Survey	Percent Cover				
	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
<b>Algae</b>					
<i>Asparagopsis taxiformis</i>				0.1	
<i>Sphacelaria furcigera</i>	0.2				
<b>Sponges</b>					
<i>Plakortis simplex</i>	0.2				0.1
<i>Spirastrella coccinea</i>		0.1		0.1	0.2
<i>Chondrosia chuchalla</i>	0.5	0.1		1.0	0.5
<b>Corals</b>					
<i>Porites lobata</i>	1.3	0.4	1.8	2.4	2.2
<i>Pocillopora meandrina</i>	11.0		0.9	4.0	
<i>Montipora verrucosa</i>				0.1	
<i>Montipora patula</i>	7.0			-	
Sand		1.0	1.0		
Hard Substratum	79.8	98.4	96.3	92.3	97.0
<hr/>					
II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals				
<hr/>					
<b>Phylum Mollusca</b>					
<i>Conus leopardus</i>	1				
<b>Phylum Annelida</b>					
<i>Spirobranchus giganteus corniculatus</i>	2				
<i>Loimia medusa</i>	1				
<b>Phylum Echinodermata</b>					
<i>Echinostrephus aciculatum</i>	5				
<hr/>					
<b>III. Fish Census (4 m × 20 m)</b>					
<hr/>					
12 Species					
67 Individuals					
Estimated Standing Crop = 27 g/m <sup>2</sup>					

NOTE: Results of the 5-m<sup>2</sup> 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 6.2% (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, and 20 May 1996

Location and Time	Oxygen (% of Saturation)		Salinity (‰)	Temperature (°C)		Depth to Secchi Extinction (m)
	Top	Bottom		Top	Bottom	
<b>2 OCTOBER 1991</b>						
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
<b>16 SEPTEMBER 1993</b>						
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
<b>28 APRIL 1994</b>						
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
<b>22 JUNE 1995</b>						
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
<b>20 MAY 1996</b>						
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

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 11. Summary of the Biological Parameters Measured at Stations Sampled in August 1991, May and September 1993, April 1994, June 1995, and May 1996

Transect	% Algal Cover					% Coral Cover					No. of Coral Species				
	1991	1993	1994	1995	1996	1991	1993	1994	1995	1996	1991	1993	1994	1995	1996
BP-1-A	4.2	0.5	1.3	0.7	0.4	23.3	15.5	17.4	17.0	15.0	3	5	5	6	5
BP-1-B	6.1	0.4	0.3	0.6	0.3	29.4	7.1	22.0	25.3	23.7	3	4	5	6	6
BP-2-A	0.5	0.9	0.1	0.9	0.6	3.6	2.2	0.9	1.0	1.0	3	2	1	2	2
BP-2-B	0.3	0.9	0.3	1.3	0.6	2.7	1.1	0.9	0.6	0.5	3	3	4	2	2
BP-3-A	3.0	0	0	0	0	8.0	4.6	8.1	6.5	5.2	4	5	4	5	4
BP-3-B	0.3	0	0	0	0	11.6	3.2	3.3	2.4	2.6	5	4	5	4	5
BP-4-A		0	3.5	2.0	1.2		19.7	26.9	28.1	27.8		4	3	1	2
BP-4-B		0.7	0	0	0.1		0.1	3.7	4.3	6.2		2	3	3	4
Mean	2.4	0.4	0.7	0.7	0.4	13.1	6.7	10.4	10.7	10.3	4	4	4	4	4

Transect	No. of Invert. Species					No. of Fish Species					No. of Fish Individuals				
	1991	1993	1994	1995	1996	1991	1993	1994	1995	1996	1991	1993	1994	1995	1996
BP-1-A	4	4	8	7	6	47	41	39	38	34	745	375	387	355	294
BP-1-B	2	4	4	6	6	42	44	42	38	40	453	488	371	410	370
BP-2-A	6	7	3	6	5	10	6	5	9	7	21	6	7	22	11
BP-2-B	4	4	6	7	7	6	12	11	15	12	12	21	36	68	43
BP-3-A	8	9	6	6	8	38	28	26	35	26	367	82	191	189	320
BP-3-B	6	6	8	6	7	30	17	18	29	27	187	161	109	156	393
BP-4-A		6	7	9	7		49	51	48	52		537	1,563	943	1,247
BP-4-B		2	2	4	4		2	10	10	12		3	15	96	67
Mean	5	5	6	6	6	29	25	25	28	26	298	209	335	280	343

Transect	Biomass (g/m <sup>2</sup> )				
	1991	1993	1994	1995	1996
BP-1-A	406	249	222	108	115
BP-1-B	374	490	202	109	290
BP-2-A	7	9	2	11	9
BP-2-B	2	11	25	26	56
BP-3-A	343	70	255	157	176
BP-3-B	121	311	445	128	282
BP-4-A		374	1,305	440	685
BP-4-B		1	12	16	27
Mean	209	189	309	124	205

NOTE: Coral and algal percent cover as well as the number of coral species are from the photo-quadrats in the 1991 dataset and other data from the 4 m x 20 m area visually assessed at each transect site. Transects BP-4-A and BP-4-B were first sampled in September 1993.



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 since the storm. Fish biomass means are greater in 1996 than in 1995. These changes could be related to the chance encounters with large (heavy) roving predators or large schools of certain species during the most recent census period; lower mean standing crop in 1995 may be related to greater fishing pressure at that time. 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 ( $p > 0.38$ , not significant), the mean percent cover by coral ( $p > 0.75$ , not significant), the mean number of coral species ( $p > 0.99$ , not significant), the mean number of macroinvertebrate species ( $p > 0.58$ , not significant), the mean number of fish species ( $p > 0.99$ , not significant), the mean number of individual fish ( $p > 0.96$ , not significant), and the mean standing crop of fish expressed in grams per square meter ( $p > 0.96$ , not significant).

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 transects.

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 amaneus*), bigeye or 'āweoweo (*Priacanthus cruentatus*), grey snapper or uku (*Aprion virescens*), emperor fish or mu (*Monotaxis grandoculis*), yellowfin goatfish or weke'ula (*Mulloidichthys vanicolensis*), yellowstripe goatfish or weke (*Mulloidichthys flavolineatus*), sidespot goatfish or malu (*Parupeneus pleurostigma*), manybar goatfish or moano (*Parupeneus multifasciatus*), blue goatfish or moano kea (*Parupeneus cyclostomus*), spiny lobster or 'ula (*Panulirus penicillatus*), and the octopus or he'e (*Octopus cyanea*).

### Green Sea Turtle Observations

Seven green sea turtles (*Chelonia mydas*) were encountered during the 1996 field survey. All of these were seen in the vicinity of Station BP-1. One turtle was resting on the transect line and the other six were in the vicinity. The resting turtle had an estimated straight line carapace length of 75 cm, and it had no visible tumors or tags. The remaining individuals were not approached, so no data were collected as to their size or condition; however, as these individuals surfaced for air, they all appeared to be close to adult size (i.e., approaching 80 cm

in straight line carapace length, which is the minimum size of adults). 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, Lāna'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 the 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 Hawaiian coral communities (Dollar 1982). Because Hawaiian 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 m<sup>2</sup> to over 30 m<sup>2</sup>. 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 Hawaiian corals are relatively slow-growing, it will be years before the impact of Hurricane Iniki is no longer evident in the benthic communities at the study sites.

The results from the five 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. 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 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 ( $3 \text{ m}^3/\text{s}$ ) 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, and 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 statistical changes among the 1991, 1993, 1994, 1995, and 1996 sampling periods, 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 found on most coral reefs; the maximum fish standing crop encountered on natural coral reefs is about  $200 \text{ g}/\text{m}^2$  (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 Hawaiian reefs, estimated the standing crop of fishes to range from 4 g/m<sup>2</sup> on sand flats to 186 g/m<sup>2</sup> 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 Hawaiian waters may serve to increase fish standing crops to more than 1 kg/m<sup>2</sup> (Brock and Norris 1989).

Chance encounters with large roving predators (such as emperor fish or mu [*Monotaxis grandoculis*] and grey snappers or uku [*Aprion virescens*]) or schools of planktivorous fishes (such as the mackerel scad or 'ōpelu [*Decapterus macarellus*], the sleek unicornfish or kala holo [*Naso hexacanthus*], the milletseed butterfly fish or lauwiliwili [*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 results in higher biomass estimates.

Schooling species, such as the emperor fish or mu (*Monotaxis grandoculis*) and the orangebar surgeonfish or na'ena'e (*Acanthurus olivaceus*), all contributed substantially to the standing crop at several transects. *Monotaxis grandoculis* contributed 20% to the biomass of fishes present at Transect BP-1-A; and *Acanthurus olivaceus* contributed 24% at Transect BP-2-B, 40% at Transect BP-3-A, and 41% at Transect BP-3-B. Relatively large solitary predators often contributed to the estimated standing crop at a location; a single moray eel or puhi paka (*Gymnothorax flavimarginatus*) made up 75% of the biomass at Transect BP-2-B, and a solitary grey snapper or uku (*Aprion virescens*) accounted for 13% of the standing crop at Transect BP-3-A.

## 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 shore and the annual quantitative survey of the marine communities at these stations should allow a delineation of changes that may be caused by the effluent. In the five annual surveys (1991 through 1996) 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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## APPENDIX



Results of Quantitative Visual Fish Censuses Conducted on Two Transects Each at Four Stations Offshore of 'Ewa Beach, O'ahu, Hawai'i, 14-15 May 1996

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
<b>MURAENIDAE</b>								
<i>Gymnothorax eurostus</i>		1						
<i>Gymnothorax flavimarginatus</i>				1				
<b>SYNODONTIDAE</b>								
<i>Saurida variegatus</i>	1	1						
<b>AULOSTOMIDAE</b>								
<i>Aulostomus chinensis</i>	1					1		2
<b>HOLOCENTRIDAE</b>								
<i>Myripristis amaenus</i>	16	33		7				
<i>Adioryx xantherythrus</i>	9							3
<b>SCORPAENIDAE</b>								
<i>Scorpaenopsis cacopsis</i>								1
<b>FISTULARIIDAE</b>								
<i>Fistularia commersoni</i>		8						
<b>APOGONIDAE</b>								
<i>Apogon kallopterus</i>	13							9
<b>PRIACANTHIDAE</b>								
<i>Priacanthus cruentatus</i>								1
<b>LUTJANIDAE</b>								
<i>Lutjanus kasmira</i>		31						50
<i>Alphareus furcatus</i>		2						
<i>Aprion virescens</i>		1			1	1		
<b>CARANGIDAE</b>								
<i>Decapterus macarellus</i>		3						
<b>SPARIDAE</b>								
<i>Monotaxis grandoculis</i>	6	2						
<b>MULLIDAE</b>								
<i>Parupeneus pleurostigma</i>	1	1	1		4			8
<i>Parupeneus multifasciatus</i>	7	5		1	41	12		132
<i>Parupeneus cyclostomus</i>		1						
<i>Parupeneus bifasciatus</i>								1
<i>Mulloidichthys vanicolensis</i>								26
<b>CHAETODONTIDAE</b>								
<i>Forcipiger flavissimus</i>	1							3
<i>Chaetodon kleinii</i>	2					2		7
<i>Chaetodon ornatissimus</i>	1				2			2
<i>Chaetodon miliaris</i>	1	5			2			146
<i>Chaetodon multicinctus</i>		6				2		4
<i>Chaetodon quadrimaculatus</i>				1	1			1
<i>Chaetodon auriga</i>					1			
<i>Chaetodon fremblii</i>					1			1
<i>Chaetodon unimaculatus</i>						1		
<i>Heniochus diphreutes</i>								24

Results—Continued

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
<b>POMACANTHIDAE</b>								
<i>Centropyge potteri</i>	3	6			1		9	
<b>POMACENTRIDAE</b>								
<i>Dascyllus albisella</i>	58	19		14	33	12	195	
<i>Plectroglyphidodon johnstonianus</i>		2					1	
<i>Chromis hanui</i>	10	13						
<i>Chromis ovalis</i>							13	
<i>Chromis vanderbilti</i>								2
<i>Stegastes fasciolatus</i>	3	1					24	
<i>Abudefduf abdominalis</i>							75	
<b>CIRRHITIDAE</b>								
<i>Paracirrhites arcatus</i>	1	1	1	3				6
<i>Cirrhitops fasciatus</i>					1	1	2	
<b>LABRIDAE</b>								
<i>Bodianus bilunulatus</i>					1	2	4	
<i>Pseudocheilinus octotaenia</i>	1				1			
<i>Pseudocheilinus tetrataenia</i>							1	
<i>Thalassoma duperrey</i>	11	14	2	6	30	5	12	16
<i>Thalassoma ballieui</i>		1						
<i>Gomphosus varius</i>	1	1					1	
<i>Stethojulis balteata</i>	2	2		2	1	2		
<i>Coris gaimard</i>					1		1	
<i>Coris flavovittata</i>							1	
<i>Pseudojuloides cerasinus</i>						4		28
<i>Labroides phthirophagus</i>						1		
<i>Anampses chrysocephalus</i>							2	
<i>Macropharyngodon geoffroy</i>							1	
<i>Halichoeres ornatissimus</i>							1	
<b>MALACANTHIDAE</b>								
<i>Malacanthus brevirostris</i>			2					
<b>SCARIDAE</b>								
<i>Calotomus carolinus</i>					1	1		
<i>Scarus sordidus</i>	3	4				1	30	
<i>Scarus psittacus</i>	12	5			18	25	97	
<i>Scarus rubroviolaceus</i>		1						
<b>BLENNIIDAE</b>								
<i>Exallia brevis</i>	1							
<b>ACANTHURIDAE</b>								
<i>Acanthurus nigrofuscus</i>	34	40		1	46	58	44	1
<i>Acanthurus triostegus</i>	1						9	
<i>Acanthurus nigroris</i>	3	6			13	4	8	
<i>Acanthurus olivaceus</i>		58			101	94	39	
<i>Acanthurus dussumieri</i>							1	
<i>Ctenochaetus strigosus</i>	78	53			9		173	
<i>Zebrasoma flavescens</i>	3	3					1	
<i>Naso lituratus</i>		1			1	2	1	
<i>Naso hexacanthus</i>		20				140	68	1
<i>Naso brevirostris</i>		5				13	5	1

Results—Continued

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
<b>ZANCLIDAE</b>								
<i>Zanclus cornutus</i>		1					1	
<b>BALISTIDAE</b>								
<i>Melichthys niger</i>	4	5						
<i>Melichthys vidua</i>		1			1	2	2	1
<i>Sufflamen bursa</i>	3	3	2	2	3	1	1	4
<i>Sufflamen fraenatus</i>			1	2		1	1	2
<i>Xanthichthys mento</i>								4
<b>MONACANTHIDAE</b>								
<i>Pervagor melanocephalus</i>	1						1	
<i>Cantherhines sandwichiensis</i>						1		
<b>OSTRACIONTIDAE</b>								
<i>Ostracion whitleyi</i>	1							
<b>TETRAODONTIDAE</b>								
<i>Canthigaster jactator</i>	1	4	2	3	5	4	1	
<i>Canthigaster coronata</i>								1
Total No. of Species	34	40	7	12	26	27	52	12
Total No. of Individuals	294	370	11	43	320	393	1,247	67
Estimated Standing Crop (g/m <sup>2</sup> )	115	290	9	56	176	282	685	27

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 (g/m<sup>2</sup>) of fishes present at each location. All censuses were carried out by the author.

