COMMUNITY STRUCTURE OF FISH AND MACROBENTHOS AT SELECTED SHALLOW-WATER SITES IN RELATION TO THE BARBERS POINT OCEAN OUTFALL, 1993

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ABSTRACT

This report provides the results of the second 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. 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 limestone; thus the coral communities on the elevated caprock are better developed on this substrate. A comparison of the data from the two surveys (1991 and 1993) indicated that no statistically significant change has taken place 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 m^3/s) of primary treated sewage through a 2670-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 report presents the results of the second survey carried out on 25–26 May and 10 September 1993.

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 occurring to 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 (such as storm drains and streams) and nonpoint source 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 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 250 m east of the sewer line and approximately 1500 m 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 caprock of the discharge pipe and 15 m to the east on flat limestone substratum in 12 m of water. Coral coverage on the elevated basalt caprock is about 15% and on the limestone less than 1%.

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 parallel to shore. Two transects were established at each location to provide some replication. Both “sample” approximately the same benthic communities. On each transect are three permanently marked locations (0 m, 10 m, and 20 m) for the taking of photographs of the benthic communities. Four photographic quadrats (each 0.67 m ∞ 1 m) were established at each of the marked points, for a total sampling of 8.04 m^2 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 in 1993. For the 1993 survey two additional photo-quadrat sites were established at the 5 m and 15 m points on each transect line, bringing the total area sampled using the photo-quadrat technique to 9.38 m^2 per transect. In addition, a visual assessment of benthic coverage using a 1 m ∞ 1 m quadrat was made 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 using the photo-quadrat method, such as recently recruited benthic species.

Also established in 1993 were two additional transects. Both were established at Station BP-4, where they were placed on and adjacent to the basalt caprock shield that covers and protects the discharge pipe. The two transects are located approximately 250 m west of Station BP-2 in 12 m of water. One transect was established on top of the caprock shield (BP-4-A) and the second 15 m to the east on the flat natural limestone substratum (BP-4-B). The same survey methods used at the other transects were used at these transects. The purpose for adding the two new transects is 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.

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 proved 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 20 m ∞ 4 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 estimation 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 Hawaii 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 frightening wary fishes, other problems with the visual census technique include the underestimation 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 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^2). 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 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 were 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 three 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 sample period; this procedure is outlined in Siegel (1956) and Sokal and Rohlf (1981).

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 at Stations BP-1, BP-2, and BP-3 on 25–26 May 1993. The two new transects located on and directly adjacent to the discharge pipe at Station BP-4 were sampled on 10 September 1993. Figure 1 shows the approximate locations of the four stations. Figures 2, 3, and 4 show the orientation of the permanent photographic quadrats on each transect line for the first three stations. The photographic data were collected by members of the Oceanographic Team, Department of Wastewater Management, City and County of Honolulu.

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 inshore and to the east (northeast) of the deep ocean outfall terminus (Figure 1). 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 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 1993 is presented in Table 1. In the quadrat survey one coralline algal species (*Porolithon onkodes*), one soft coral species (*Anthelia edmondsoni*), and five coral species (*Porites lobata*, *P. compressa*, *Montipora verrucosa*, *M. patula,* and *Pocillopora meandrina*) were encountered. *Porites lobata* was the dominant coral at this transect, where mean coral coverage for all species combined was 15.5%. In the macroinvertebrate census the rock oyster *Spondylus tenebrosus*, the terebellid polychaete *Loimia medusa*, and two sea urchin species (*Heterocentrotus mammillatus* and *Echinometra mathaei*) were noted.

The results of the fish census are presented in the Appendix. Forty-one fish species representing 375 individuals were seen at Transect BP-1-A. The most abundant species included the brick soldierfish or mempachi (*Myripristes amaenus*), two damselfish species (*Chromis ovalis* and *Dascyllus albisella*), the brown surgeonfish or ma'i'i'i (*Acanthurus *nigrofuscus*), the goldring surgeonfish or kole (*Ctenochaetus strigosus*), and the sleek unicornfish or kala holo (*Naso hexacanthus*). The standing crop of fishes was estimated at 249 g/m^2, with the largest contributors including *Naso hexacanthus* (31% of the total), the emperor or mu (*Monotaxis grandoculis*—22% of the total), and a single grey snapper or uku (*Aprion virescens*—7% of the total).

The results of the photo-quadrat survey conducted at Transect BP-1-A are presented in Table 2. Five coral species having a mean coverage of 20.9% were recorded. Also recorded were two algal species (*Porolithon onkodes* and *Hydrolithon rienboldii*) having a mean coverage of 6.4%. Other benthic species present included two sponge species and the soft coral *Anthelia edmondsoni*.

Transect BP-1-B

Transect BP-1-B is situated 27 to 29 m 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 two algal species (*Desmia hornemannii* and *Porolithon onkodes*), one sponge species (*Chondrosia chucalla*), and four coral species (*Porites lobata*, *P. compressa*, *Montipora patula*, and *Pavona varians*). The dominant coral species was *Porites lobata*, and mean coral coverage was 7.1%. In the 4 m ∞ 20 m census area four macroinvertebrate species were seen: the rock oyster *Spondylus tenebrosus*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, and two sea urchin species (*Tripneustes gratilla* and *Heterocentrotus mammillatus*).

The results of the photo-quadrat survey for Transect BP-1-B are given in Table 2. Three coral species (*Porites lobata*, *P. compressa*, and *Pocillopora meandrina*) having a mean coverage of 27.2% were noted. Also encountered were two algal species (*Porolithon onkodes* and *Hydrolithon rienboldii*) and two encrusting sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*).

The results of the fish census are presented in the Appendix. Forty-four fish species representing 488 individuals were noted in the census area, with the most common species present being the mackeral scad or opelu (*Decapterus macarellus*), the damselfish *Chromis ovalis*, the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*), the goldring surgeonfish or kole (*Ctenochaetus strigosus*), and the sleek unicornfish or kala holo (*Naso hexacanthus*). The standing crop of fish at Transect BP-1-B was estimated at 490 g/m^2, and the species responsible for much of this were *Decapterus macarellus* (59% of the total), the emperor or mu (*Monotaxis grandoculis*—7% of the total), and *Naso hexacanthus* (11% of the total).

Station observations

In the vicinity of Station BP-1 were seen the corals *Pocillopora meandrina*, *Pavona varians*, *P. duerdeni*, and *Montipora flabellata*, as well as the undulated moray eel or puhi laumilo (*Gymnothorax eurostus*).

Station BP-2

Station BP-2 is located about 1.4 km from shore in water ranging 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. Common corals seen included *Pocillopora meandrina* and *Porites lobata*; other species seen included *Montipora verrilli* and *M. verrucosa*. Two of the common algal species in the area were limu kohu or *Asparagopsis taxiformis* and the alga *Sphacelaria furcigera*.

Two transects were established at Station BP-2 to sample the benthic and fish communities adjacent to the shallow portion of the Barbers Point deep ocean outfall pipe. The two permanently marked transect lines 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 noted three algal species (*Halimeda opuntia*, *Sphacelaria furcigera*, and *Asparagopsis taxiformis*), one sponge species (*Chondrosia chucalla*), and two coral species (*Porites lobata* and *Pocillopora meandrina*). Mean coral coverage at this station was estimated at 2.2%, and the dominant species was *Porites lobata*. The macroinvertebrate census carried out over the 4 m ∞ 20 m area noted seven species: the cone shell species (*Conus lividus*, *C. miles*, and *C. marmoratus*), the Christmas tree worm *Spirobranchus giganteus corniculatus*, the brown hermit crab *Aniculus strigatus*, and two sea urchin species (the rock boring urchin *Echinostrephus aciculatum* and the green urchin *Echinometra mathaei*).

The photo-quadrat survey noted two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*), the soft coral *Anthelia edmondsoni*, and two coral species (*Porites lobata* and *Pocillopora meandrina*). Coral coverage was estimated at 1.8%.

The results of the fish census are presented in the Appendix. In total six fish species representing six individuals were censused at Transect BP-2-A. The biomass of fishes on this transect was estimated at 9 g/m^2, with the largest contributor being a single-barred filefish or ‘O(o,¯)‘ili (*Cantherhines dumerilii*—62% of the total).

Transect BP-2-B

Transect BP-2-B was established at a distance varying from 17.5 to 26 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. One algal species (*Sphacelaria furcigera*), two encrusting sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*), and three coral species (*Porites lobata*, *Pocillopora meandrina*, and *Montipora verrucosa*) were noted. Corals were not an important component of the benthos at this location; mean coverage was estimated at 1.1% (visual quadrat method). Noncolonial macroinvertebrates censused in the 4 m ∞ 20 m transect included the cone shell *Conus lividus*, the brown hermit crab *Aniculus strigatus*, and two sea urchin species (the rock boring urchin *Echinostrephus aciculatum* and the banded urchin *Echinothrix calamaris*).

The results of the photo-quadrat survey for Transect BP-2-B are given in Table 2. Two sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) provided a mean coverage of 0.2%, and two coral species (*Porites lobata* and *Pocillopora meandrina*) contributed a mean coverage of 1.3% at this transect.

The results of the fish census at Transect BP-2-B are presented in the Appendix. Twelve fish species representing 21 individuals were censused. The most common fish seen on this transect was the saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*). Fish standing crop was estimated at 11 g/m^2, with a single barred filefish or ‘O(o,¯)‘ili (*Cantherhines dumerilii*) contributing 34% of the total and *Thalassoma duperrey* 26% of the total.

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. The relatively higher abundance of noncolonial macroinvertebrates is also probably related to the lack of shelter, thus making their detection easier.

In the vicinity of Station BP-2 were seen the coral *Pavona varians*, the abbreviated cone shell *Conus miliaris*, the reef crab *Thalamita edwardsi*, the octopus or he‘e (*Octopus cyanea*), and the belted wrasse or ‘omaka (*Stethojulis balteata*).

Station BP-3

Station BP-3 is located about 2.9 km west and inshore of the Barbers Point outfall 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 have an orientation that is approximately perpendicular to the shoreline and are 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 was established about 38 m seaward of Transect BP-3-A at a depth of 16.5 m (Figure 4). At the time of sampling, water clarity 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 two encrusting sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) and five coral species (*Porites lobata*, *P. compressa*, *P. [Synaraea] convexa*, *Pocillopora meandrina*, and *Montipora patula*). *Porites lobata* was the dominant species seen, and mean coral coverage at this location was estimated at 4.6% (visual quadrat method). Nine macroinvertebrate species were seen, including the rock oyster *Spondylus tenebrosus*, the leopard cone *Conus leopardus*, the top shell *Turbo intercostalis*, the cushion starfish *Culcita novaeguineae*, the banded sea urchin *Echinothrix calamaris*, the rock boring urchin *Echinostrephus aciculatum*, the green sea urchin *Echinometra mathaei*, the black sea urchin *Tripneustes gratilla*, and the slate pencil sea urchin *Heterocentrotus mammillatus*.

The results of the photo-quadrat survey for Transect BP-3-A are presented in Table 2. Noted were one coralline algal species (*Porolithon onkodes*) having a mean coverage of 0.1%, two sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) having a mean coverage of 0.5%, and three coral species (*Porites lobata*, *P. compressa*, and *Pocillopora meandrina*) having a mean coverage of 1.3%.

The results of the fish census at Transect BP-3-A are presented in the Appendix. Twenty-eight fish species representing 82 individuals were censused. The most abundant fish species were the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*) and the damselfish *Chromis vanderbilti*. The standing crop of fishes was estimated at 70 g/m^2, and the species contributing most heavily included a single black triggerfish or humuhumu ele‘ele (*Melichthys niger*—9% of the total), a single barred filefish or ‘O(o,¯)‘ili (*Cantherhines dumerilii*—11% of the total), and three orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*—19% 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 has a water depth of 16.5 m.

Table 7 presents the results of the quantitative survey carried out at this transect. One sponge species (*Spirastrella coccinea*) and four coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, and *Montipora verrucosa*) were noted. Coral coverage at this transect was estimated at 3.2% (visual quadrat method). Six species of macroinvertebrates were censused in the 4 m ∞ 20 m area, including the rock oyster *Spondylus tenebrosus*, the slate pencil sea urchin *Heterocentrotus mammillatus*, the black sea urchin *Tripneustes gratilla*, the banded sea urchin *Echinothrix calamaris*, the long-spined black sea urchin or wana (*Echinothrix diadema*), and the green sea urchin *Echinometra mathaei*. The most abundant macroinvertebrate present was the black sea urchin.

Table 2 presents the results of the photo-quadrat survey carried out at Transect BP-3-B. Noted were two coralline algal species (*Porolithon onkodes* and *Hydrolithon rienboldii*) having a mean coverage of 1.8%, two sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) with a mean coverage of 0.4%, and four coral species (*Montipora verrucosa*, *Pocillopora meandrina*, *Porites compressa*, and *P. lobata*) having a mean coverage of 8.3%.

The results of the fish census carried out at Transect BP-3-B are presented in the Appendix. In total 17 species representing 161 individuals were counted, with the most abundant fishes being the mackeral scad or opelu (*Decapterus macarellus*), the damselfish *Chromis vanderbilti*, and the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*). The standing crop of fish on Transect BP-3-B was estimated at 311 g/m^2, with the largest contributors being *Decapterus macarellus* (58% of the total), *Acanthurus olivaceus* (17% of the total), and a single grey snapper or uku (*Aprion virescens*—5% of the total).

Station observations

In the vicinity of Station BP-3 were seen the corals *Fungia scutaria* and *Pavona varians*, as well as the yellowmargin moray eel or puhi paka (*Gymnothorax flavimarginatus*) and the spiny lobster or ‘ula (*Panulirus marginatus*).

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 Station BP-2 in 12 to 13 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 approximately 15 m to the east on the adjacent flat natural limestone substratum.

Transect BP-4-A

Transect BP-4-A was established on the basalt caprock that serve to protect the discharge pipe from storm damage. The caprock at this site range 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 caprock are comprised of sand and loose coral rubble. Water depth to the top of the caprock is 12.2 m. This transect has an orientation that follows the discharge pipe and thus is roughly perpendicular to the shoreline.

The results of the quantitative survey carried out at Transect BP-4-A are given in Table 8. The visual quadrat survey noted one sponge species (*Spirastrella coccinea*) with a mean coverage of 0.2% and four coral species (*Porites lobata*, *Pocillopora meandrina*, *P. eydouxi*, and *Montipora verrucosa*) having a mean coverage of 19.7%. The census of macroinvertebrates noted six species: the cone shell *Conus miles*, a slipper lobster or ulapapa (*Paribaccus antarcticus*), the black sea cucumber *Holothuria atra*, and three sea urchin species (*Tripneustes gratilla*, *Echinothrix diadema*, and *E. calamaris*).

The results of the photo-quadrat survey are given in Table 2. Noted were one coralline algal species (*Porolithon onkodes*) having a mean coverage of 0.3%, one encrusting sponge species (*Spirastrella coccinea*) having a mean coverage of 0.2%, and three coral species (*Porites lobata*, *Pocillopora meandrina*, and *P. eydouxi*) having a mean coverage of 17.9%.

The results of the fish census carried out at Transect BP-4-A are presented in the Appendix. Forty-nine fish species representing 537 individuals having an estimated biomass of 374 g/m^2 were censused. The most abundant fish species included the cardinalfish or ‘upO(a,¯)palu (*Apogon kallopterus*), the sidespot goatfish or malu (*Parupeneus pleurostigma*), the black damselfish or ‘O(a,¯)lo‘ilo‘i (*Dascyllus albisella*), the saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*), the spectacled parrotfish or uhu ‘ahu‘ula (*Scarus perspicillatus*), the bulletnose parrotfish or uhu (*Scarus sordidus*), and the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*). Species contributing most to the estimated standing crop at Transect BP-4-A included two yellowmargin moray eels or puhi paka (*Gymnothorax flavimarginatus*—21% of the total), the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*—22% of the total), and the orangespine unicornfish or umaumalei (*Naso lituratus*—7% 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 (Figure 4). This transect has an orientation that is parallel to Transect BP-4-A as well as perpendicular to the shoreline. The substratum at this transect is flat limestone with very little relief; over portions of this are areas of a sand/coral rubble veneer overlying the limestone that does not usually exceed 2 cm in thickness and may cover up to 50 m^2. These patches of sand are spaced from 5 to 50 m apart.

Table 9 presents the results of the quantitative assessment carried out at Transect BP-4-B. The visual quadrat survey noted one algal species (*Sphacelaria furcigera*) with a mean coverage of 0.7%, the encrusting red sponge *Spirastrella coccinea* having a mean coverage of 0.2%, the soft coral *Anthelia edmondsoni* having a mean coverage of 0.06%, and two coral species (*Porites lobata* and *Pocillopora meandrina*) having a mean coverage of 0.1%. The macroinvertebrate census noted the presence of the cone shell *Conus miles* and the rock boring urchin *Echinostrephus aciculatum*.

The results of the photo-quadrat survey carried out at Transect BP-4-B are given in Table 2. Noted were the alga *Sphacelaria furcigera* with a mean coverage of 0.7%, the sponge *Spirastrella coccinea* with a mean coverage of 0.06%, and two coral species (*Pocillopora meandrina* and *Porites lobata*) with a mean coverage of 0.2%.

The results of the fish census carried out at Transect BP-4-B are presented in the Appendix. Two fish species representing three individuals having an estimated standing crop of 0.8 g/m^2 were encountered at this transect.

Physical Measurements and Biological Parameters

Physical measurements made on the morning of 16 September 1993 are summarized in Table 10. Little variation was noted in temperature (25.1° to 25.7°C), percent oxygen saturation (100% to 103%), and salinity (all 34‰) despite the fact that measurements for oxygen and temperature were made both at 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 nephalometer in the laboratory.

The biological data for both the 1991 and 1993 surveys are summarized as means for each transect in Table 11. The means of all biological parameters measured in this survey (i.e., percent algal and coral cover; number of coral, other macroinvertebrate, and fish species; number of individual fish; and biomass of fishes) declined (or remained unchanged) from 1991 to 1993. These changes may be related to impacts created by Hurricane Iniki in September 1992 (discussed below). The Wilcoxon two-sample test applied to the annual mean data (combining all transects during an annual sample period for each parameter; see Table 11) showed that there have been no statistically significant changes (where significance is given at $p \leq 0.05$) in the mean percent cover by algae ($p > 0.40$, not significant) and by coral ($p > 0.33$, not significant); in the mean number of coral species ($p > 0.30$, not significant), macroinvertebrate species ($p > 0.89$, not significant), and fish species ($p > 0.80$, not significant); in the mean number of individual fish ($p > 0.61$, not significant); and in the mean standing crop of fish expressed in g/m^2 ($p > 0.90$, 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 transect sites.

From a commercial fisheries standpoint, a number of important species have been encountered at several of the transect sites, including the brick soldierfish or mempachi (*Myripristes amaenus*), the mackeral scad or opelu (*Decapterus macarellus*), the manybar goatfish or moano (*Parupeneus multifasciatus*), the grey snapper or uku (*Aprion virescens*), the emperor or mu (*Monotaxis grandoculis*), the octopus or he‘e (*Octopus cyanea*), and the spiny lobster or ‘ula (*Panulirus marginatus*).

Green Sea Turtle Observations

No green sea turtles (*Chelonia mydas*) were encountered at any of the transect sites; however, individual turtles are commonly seen surfacing for air while transiting from Honolulu Harbor to ‘Ewa Beach. Most individuals seen are juveniles (i.e., they are less than 80 cm in straight line carapace length).

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 resulting in considerable damage to improvements and forests on 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(a,¯)na‘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). The 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^2 to over 30 m^2. 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 have survived and the communities are recovering, 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 will no longer be evident in the benthic communities at the study sites.

The results from the 1991 and 1993 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 suggest 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 rock 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, 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 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, Keehi Lagoon, and Pearl Harbor situated to the east would be carried in a westerly direction toward the area offshore of ʻEwa 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 m^3/s) of raw sewage in 10 m of water offshore of Sand Island. This material was undoubtedly diluted but 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). Thus the eastern station (BP-1) is viewed as a control site, and the station inshore and adjacent to the discharge pipe (BP-2) as well as the station to the west (BP-3) 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 between the 1991 and 1993 sampling periods, suggesting that the operation of the outfall has not resulted in measurable negative impacts.

Relative to many other locations in the Hawaiian islands, 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 are much greater than found on most coral reefs; the maximum fish standing crop encountered on natural coral reefs is about 200 g/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^2 on sand flats to 186 g/m^2 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^2 (Brock and Norris 1989).

Chance encounters with large roving predators (such as the emperor or mu [*Monotaxis grandoculis*] and the grey snapper or uku [*Aprion virescens*]) or schools of planktivorous fishes (such as the mackeral scad or opelu [*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 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 *Naso hexacanthus*, *Monotaxis grandoculis*, *Decapterus macarellus*, and the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*) all contributed substantially to the standing crop at several transects. At Transect BP-1-A *Monotaxis grandoculis* contributed 22% of the biomass and *Naso hexacanthus* accounted for 31%. At Transect BP-1-B *Decapterus macarellus* comprised 59% of the standing crop, at Transect BP-3-A *Acanthurus olivaceus* made up 19%, and at Transect BP-3-B *Decapterus macarellus* contributed 58% owing to a chance encounter with a school. Interestingly, other than two yellowmargin moral eels or puhi paka (*Gymnothorax flavimarginatus*), none of the fish species censused at Transect BP-4-A contributed more than 5% to the estimated biomass present. Relatively large solitary predators often contributed to the estimated standing crop at a location; a single grey snapper or uku (*Aprion virescens*) made up 7% of the biomass at Transect BP-1-A, 32% at Transect BP-3-A, and 5% at Transect BP-3-B.

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 these stations should allow a delineation of the changes that may be caused by the effluent. In the 1991 and 1993 surveys no statistically significant change was detected 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 discharge.

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TABLE 1. Summary of Biological Observations Made at Transect BP-1-A, 2.2 km Inshore and Northeast of Barbers Point Deep Ocean Outfall Terminus (Station BP-1), May 1993

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Porolithon onkodes	2	0.5			
Soft Corals					
Anthelia edmondsoni					1.2
Corals					
Porites lobata	19	27		2	23
P. compressa		4.5	0.5		
Pocillopora meandrina		1		0.1	
Montipora verrucosa				0.1	
M. patula			0.1		
Sand				2	1
Rubble	23	8	40	87.8	12
Hard Substratum	56	59	59.4	8	62.8

II. Macroinvertebrate Census (4 ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Spondylus tenebrosus	2				
Phylum Annelida					
Loimia medusa	1				
Phylum Echinodermata					
Heterocentrotus mammillatus	1				
Echinometra mathaei	2				

III. Fish Census (4 ∞ 20 m)					
41 Species					
375 Individuals					
Estimated Standing Crop = 249 g/m^2					

NOTE: Results of the 5-m^2 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 15.5% (visual quadrat method).

TABLE 2. Summary of Results of the Photographic Quadrat Survey, 1993

Transect BP-1-A	Percent Cover Photographic Quadrat				
	AAA (0 m)	ACC1 (5 m)	AAB (10 m)	ACC2 (15 m)	AAC (20 m)
Algae					
Hydrolithon rienboldii	10.5	10.6			5.3
Porolithon onkodes	1.1	4.2	0.2		0.1
Sponges					
Spirastrella coccinea			0.1		0.1
Chondrosia chucalla					0.1
Soft Corals					
Anthelia edmondsoni	0.1				0.4
Corals					
Porites lobata	38	38.7	0.3	2.8	17.5
P. compressa	1.5	4.8	0.1		
Pocillopora meandrina			0.1		
Montipora verrucosa	0.4				
M. patula	0.3				
Sand			17.1	1.4	3.4
Rubble	2	7	73.3	95.8	39.7
Hard Substratum	46.1	34.7	8.8		33.4
Mean Coral Coverage = 20.9%					

Transect BP-1-B	Percent Cover Photographic Quadrat				
	ABA (0 m)	ACA1 (5 m)	ABB (10 m)	ACA2 (15 m)	ABC (20 m)
Algae					
Hydrolithon rienboldii	6.8			1.4	6.1
Porolithon onkodes		2.5			1.6
Sponges					
Spirastrella coccinea	0.3	0.3	0.2		0.1
Chondrosia chucalla	0.1	0.1	0.1		
Corals					
Porites lobata	13.2	16	10.5	17.9	53.7
P. compressa	4.7	1.7	3.4	10.1	4.5

Pocillopora meandrina					0.4
Sand	1.6	0.6	0.7	1.7	
Rubble	21.4	44	53.2	20.5	
Hard Substratum	51.9	34.8	31.9	48.4	33.6
Mean Coral Coverage = 27.2%					

TABLE 2—*Continued*

Transect BP-2-A	Percent Cover Photographic Quadrat				
	BAA (0 m)	BCC1 (5 m)	BAB (10 m)	BCC2 (15 m)	BAC (20 m)
Sponges					
Spirastrella coccinea	0.1		0.1	0.7	0.1
Chondrosia chucalla	0.3		0.1	0.3	0.2
Soft Corals					
Anthelia edmondsoni	0.1		0.1		
Corals					
Porites lobata	3.1	0.2	0.3	2.5	0.3
Pocillopora meandrina			0.1	2	0.3
Sand	48.3	29.4	49.9	9.2	16.3
Hard Substratum	48	70.4	49.4	85.3	82.8
Mean Coral Coverage = 1.8%					

Transect BP-2-B	Percent Cover Photographic Quadrat				
	BBA (0 m)	BCA1 (5 m)	BBB (10 m)	BCA2 (15 m)	BBC (20 m)
Sponges					
Spirastrella coccinea	0.1		0.1	0.1	
Chondrosia chucalla	0.1			0.6	0.1
Corals					
Porites lobata	0.3	5.3	0.7		0.1
Pocillopora meandrina			0.2		
Sand	71.1	30.5	50.8	11.2	46.4
Hard Substratum	28.4	64.2	48.2	88.1	53.2
Mean Coral Coverage = 1.3%					

TABLE 2—*Continued*

Transect BP-3-A	Percent Cover Photographic Quadrat				
	CCA (0 m)	CCC1 (5 m)	CAB (10 m)	CCC2 (15 m)	CAC (20 m)
Algae					
Porolithon onkodes				0.6	
Sponges					
Spirastrella coccinea	0.1	0.6	0.1	0.3	0.1
Chondrosia chucalla			0.1	1.1	
Corals					
Porites lobata	0.4	0.3	0.7	2.2	0.1
P. compressa			0.1		0.4
Pocillopora meandrina				2.5	
Sand	5.3	1.1	1.4		1.4
Rubble	81.7	28.3	97.6	62.5	98
Hard Substratum	12.5	69.7		30.8	
Mean Coral Coverage = 1.3%					

Transect BP-3-B	Percent Cover Photographic Quadrat				
	CBA (0 m)	CCA1 (5 m)	CBB (10 m)	CCA2 (15 m)	CBC (20 m)
Algae					
Porolithon onkodes	1.2	0.3		1.1	0.4
Hydrolithon rienboldii		5.9			
Sponges					
Spirastrella coccinea	0.6			1.1	0.4
Chondrosia chucalla					0.1
Corals					
Porites lobata	5.4	19.6	0.1	14.3	
P. compressa	0.2		0.2	0.3	0.3
Pocillopora meandrina			0.1	0.3	0.1
Montipora verrucosa				0.3	0.3
Sand	0.7		0.4		0.8
Rubble	65.9	74.2	99.2	51.3	97.6
Hard Substratum	26			31.3	

Mean Coral Coverage = 8.3%					

TABLE 2—*Continued*

Transect BP-4-A	Percent Cover, Photographic Quadrat				
	AAA1 (0 m)	AAA2 (5 m)	AAA3 (10 m)	AAA4 (15 m)	AAB1 (20 m)
Algae					
Porolithon onkodes	0.7		0.3		0.6
Sponges					
Spirastrella coccinea			0.8		0.3
Corals					
Porites lobata	15.4	27.5	18.2	8.1	6.7
Pocillopora meandrina	4.8	0.6		2.5	0.8
P. eydouxi		4.8			
Sand		0.6			
Rubble	21.3	4.2	21	34.5	5
Hard Substratum	57.8	62.3	59.7	54.9	86.6
Mean Coral Coverage = 17.9%					

Transect BP-4-B	Percent Cover, Photographic Quadrat				
	BBB1 (0 m)	BBB2 (5 m)	BBB3 (10 m)	BBB4 (15 m)	BBA1 (20 m)
Algae					
Sphacelaria furcigera	2.8		0.6		0.3
Sponges					
Spirastrella coccinea	0.1	0.1	0.1		
Corals					
Porites lobata	0.3	0.1	0.3	0.3	
Pocillopora meandrina		0.1			
Sand	2.8	2.8	0.8	96.1	93.3
Rubble	0.8	1.7	0.6	3.6	6.4
Hard Substratum	93.2	95.2	97.6		
Mean Coral Coverage = 0.2%					

NOTE: Presented in the body of the table are the percent cover of species and substrate types for each transect. Note that for Stations BP-1, BP-2, and BP-3 the 5 m and 15 m data are based on one 0.67-m^2 photo-quadrat and the 0 m, 10 m, and 20 m data on the mean from four 0.67-m^2 quadrats at each location. Data for Station BP-4 are based on one quadrat at each 5-m stop (i.e., 0 m, 5 m, 10 m, 15 m, and 20 m).

TABLE 3. Summary of Biological Observations Made at Transect BP-1-B, 2.2 km Inshore and Northeast of Barbers Point Deep Ocean Outfall Terminus (Station BP-1), May 1993

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect (m) 0	5	10	15	20
Algae					
Desmia hornemannii	0.5		1		
Porolithon onkodes					0.5
Sponges					
Chondrosia chucalla				0.1	0.1
Corals					
Porites lobata	6	8	0.1	5	3.5
P. compressa	1.5	0.1	0.9	1.8	8
Montipora patula				0.1	0.1
Pavona varians					0.5
Sand	2	3	32		
Rubble	66	88.9	49	85	87.3
Hard Substratum	24		17	8	

II. Macroinvertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Mollusca	
Spondylus tenebrosus	3
Phylum Annelida	
Spirobranchus giganteus corniculatus	8
Phylum Echinodermata	
Heterocentrotus mammillatus	1
Tripneustes gratilla	2

III. Fish Census (4 ∞ 20 m)
44 Species
488 Individuals
Estimated Standing Crop = 490 g/m^2

NOTE: Results of the 5-m^2 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 7.1% (visual quadrat method).

TABLE 4. Summary of Biological Observations Made at Transect BP-2-A, 250 m East of the Discharge Pipe and 1.5 km Inshore and Northeast of Barbers Point Deep Ocean Outfall Terminus (Station BP-2), May 1993

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Halimeda opuntia	0.1				
Sphacelaria furcigera	0.5	3	0.3		
Asparagopsis taxiformis		0.5			
Sponges					
Chondrosia chucalla			0.3	0.1	
Corals					
Porites lobata	4.5	0.1	0.5	4.5	0.1
Pocillopora meandrina				0.5	0.8
Sand		3	2		1
Hard Substratum	94.9	93.4	96.9	94.9	98.1

II. Macroinvertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Mollusca	
Conus lividus	3
C. miles	1
C. marmoratus	1
Phylum Annelida	
Spirobranchus giganteus corniculatus	12
Phylum Arthropoda	
Aniculus strigatus	1
Phylum Echinodermata	
Echinostrephus aciculatum	5
Echinometra mathaei	1

III. Fish Census (4 ∞ 20 m)
6 Species
6 Individuals
Estimated Standing Crop = 9 g/m^2

NOTE: Results of the 5-m^2 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 2.2% (visual quadrat method).

TABLE 5. Summary of Biological Observations Made at Transect BP-2-B, 250 m East of the Discharge Pipe and 1.5 km Inshore and Northeast of Barbers Point Deep Ocean Outfall Terminus (Station BP-2), May 1993

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Sphacelaria furcigera	1	1.5	1		1
Sponges					
Chondrosia chucalla			0.3		0.1
Spirastrella coccinea	0.2				
Soft Corals					
Anthelia edmondsoni	0.1	0.1	0.1		0.1
Corals					
Porites lobata	0.1	3	1.2	0.3	0.2
Pocillopora meandrina			0.5		
Montipora verrucosa			0.2		
Sand	20	2	4	5	
Hard Substratum	78.6	93.4	92.7	94.7	98.6

II. Macroinvertebrate Census (4 ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Conus lividus	1				
Phylum Arthropoda					
Aniculus strigatus	1				
Phylum Echinodermata					
Echinostrephus aciculatum	10				
Echinothrix calamaris	1				

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

NOTE: Results of the 5-m^2 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 Deep Ocean Outfall Terminus (Station BP-3), May 1993

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect (m) 0	5	10	15	20
Sponges					
Spirastrella coccinea			0.2		
Chondrosia chucalla			0.1	0.7	
Corals					
Porites lobata	0.1	1.2	0.5	13	0.1
P. compressa				4	0.1
P. (Synaraea) convexa		0.2			
Pocillopora meandrina	0.3	0.1	0.1	2.8	
Montipora patula	0.3				
Sand	4	3	2		1
Rubble	91.3	85.5	94.1	65.5	88.8
Hard Substratum	4	10	3	14	10

II. Macroinvertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Mollusca	
Spondylus tenebrosus	1
Conus leopardus	1
Turbo intercostalis	1
Phylum Echinodermata	
Tripneustes gratilla	3
Echinometra mathaei	3
Echinostrephus aciculatum	1
Echinothrix calamaris	8
Heterocentrotus mammillatus	4
Culcita novaeguineae	1

III. Fish Census (4 ∞ 20 m)
28 Species
82 Individuals
Estimated Standing Crop = 70 g/m^2

NOTE: Results of the 5-m^2 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 4.6% (visual quadrat method).

TABLE 7. Summary of Biological Observations Made at Transect BP-3-B, 3.3 km West and Inshore of Barbers Point Deep Ocean Outfall Terminus (Station BP-3), May 1993

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Sponges					
Spirastrella coccinea	1.5	0.1			
Corals					
Porites lobata	2.3	1.5		3.5	
P. compressa	0.8				0.7
Pocillopora meandrina	1.3	0.5	0.3	2.5	2
Montipora verrucosa		0.7			
Sand	2	0.5		5	
Rubble	84.1	78.7	99.7	72	76.3
Hard Substratum	8	18		17	21

II. Macroinvertebrate Census (4 ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Spondylus tenebrosus	1				
Phylum Echinodermata					
Tripneustes gratilla	13				
Echinothrix calamaris	11				
E. diadema	3				
Echinometra mathaei	6				
Heterocentrotus mammillatus	1				

III. Fish Census (4 ∞ 20 m)					
17 Species					
161 Individuals					
Estimated Standing Crop = 311 g/m^2					

NOTE: Results of the 5-m^2 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 3.2% (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 Deep Ocean Outfall Terminus (Station BP-4), September 1993

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect (m) 0	5	10	15	20
Sponges					
Spirastrella coccinea	1				
Corals					
Porites lobata	6	13	56	15	6
Pocillopora meandrina		0.8	0.1	0.2	
P. eydouxi					1.5
Montipora verrucosa					0.1
Sand	3	6	2	15	3
Rubble	12	10		6	32
Hard Substratum	78	70.2	41.9	63.8	57.4

II. Macroinvertebrate Census (4 ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Conus miles	1				
Phylum Arthropoda					
Paribaccus antarcticus	1				
Phylum Echinodermata					
Tripneustes gratilla	11				
Echinothrix calamaris	14				
E. diadema	16				
Holothuria atra	2				

III. Fish Census (4 ∞ 20 m)					
49 Species					
537 Individuals					
Estimated Standing Crop = 374 g/m^2					

NOTE: Results of the 5-m^2 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 19.7% (visual quadrat method).

TABLE 9. Summary of Biological Observations Made at Transect BP-4-B, Situated on the Smooth Limestone Substratum 15 m East of the Basalt Caprock of the Honouliuli Discharge Pipe, Approximately 1.4 km Inshore (North) of Barbers Point Deep Ocean Outfall Terminus (Station BP-4), September 1993

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Sphacelaria furcigera	1.5	0.6	0.9		0.5
Sponges					
Spirastrella coccinea	1				
Soft Corals					
Anthelia edmondsoni	0.1	0.1			0.1
Corals					
Porites lobata	0.1	0.1	0.2	0.1	0.1
Pocillopora meandrina		0.1			
Sand	2			97.9	89.3
Hard Substratum	95.3	99.1	98.9	2	10

II. Macroinvertebrate Census (4 ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Conus miles	1				
Phylum Echinodermata					
Echinostrephus aciculatum	5				

III. Fish Census (4 ∞ 20 m)					
2 Species					
3 Individuals					
Estimated Standing Crop = 0.8 g/m^2					

NOTE: Results of the 5-m^2 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 13.1 m to 13.4 m; mean coral coverage is 0.1% (visual quadrat method).

TABLE 10. Summary of Physical Measurements Made at Each Station in the Vicinity of Transect Pairs, 2 October 1991 and 16 September 1993

Location and Time	Oxygen (% of Saturation) Top	Oxygen (% of Saturation) Bottom	Salinity (‰)	Temperature (°C) Top	Temperature (°C) Bottom	Depth to Secchi Extinction (m)
2 OCTOBER 1991						
Station BP-1						
1000 hr	103	102	34	25.3	25.1	>15
Station BP-2						
1025 hr	101	101	34	25.0	24.9	>11
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
Station BP-2						
1020 hr	103	102	34	25.5	25.2	>11
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

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 Station Transects Sampled in August 1991 and May and September 1993

Transect	% Algal Cover	% Coral Cover	No. of Coral Species	No. of Invert. Species	No. of Fish Species	No. of Fish Individuals	Biomass (g/m²)
		1991		1991			

BP-1-A	
BP-2-A	32
BP-2-B	
BP-3-A	
BP-3-B	54
BP-4-A	
BP-4-B	
Mean	

NOTE: Coral and algal percent cover as well as the number of coral species are from the 9.4 m^2 sampled by photo-quadrat techniques at each transect site; other data are from the 20 ∞ 4 m area visually assessed at each transect site. Note that Transects BP-4-A and BP-4-B were first sampled in September 1993.

Results of Quantitative Visual Fish Censuses Conducted on Two Transects Each at Four Stations Offshore of ‘Ewa Beach, O‘ahu, Hawai‘i, 25–26 May and 10 September 1993

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
MURAENIDAE								
Gymnothorax flavimarginatus							2	
HOLOCENTRIDAE								
Myripristes amaenus	20							
Adioryx xantherythrus							14	
A. diadema	13							
AULOSTOMIDAE								
Aulostomus chinensis	1							
FISTULARIIDAE								
Fistularia commersoni	1	1				1		
APOGONIDAE								
Apogon kallopterus							45	
SERRANIDAE								
Cephalopholis argus	1	1						
CARANGIDAE								
Decapterus macarellus		120				75	1	
Caranx melampygus							1	
LUTJANIDAE								
Lutjanus kasmira		21						
Alphareus furcatus	1							
Aprion virescens	1				1	1		
SPARIDAE								
Monotaxis grandoculis	16	7						
MULLIDAE								
Parupeneus pleurostigma				1	1		36	
P. multifasciatus	2	1			7	8	30	
P. bifasciatus								2
CHAETODONTIDAE								

Forcipiger flavissimus	2				1		2	
Chaetodon multicinctus	2	8					4	
C. fremblii	1							
C. kleinii	1	2			1		4	
C. auriga					1			
C. lunula	2	1			2			
C. quadrimaculatus				2			2	
C. miliaris				1	1	1	16	
POMACANTHIDAE								
Centropyge potteri	2	4					2	
POMACENTRIDAE								
Dascyllus albisella	20	26		2	7		39	
Plectroglyphidodon johnstonianus	2	4					6	
Abudefduf abdominalis							10	
Chromis vanderbilti					14	34	27	
C. hanui	12	8					13	
C. verator		4						

Results—*Continued*

FAMILY and Species	Transect (BP-) 1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
C. ovalis	80	85					5	
C. agilis							14	
Stegastes fasciolatus	1	3			2		3	
CIRRHITIDAE								
Paracirrhitus arcatus		2			1		2	
Cirrhitops fasciatus					1		3	
LABRIDAE								
Labroides phthirophagus		1						
Bodianus bilunulatus		1					1	
Cheilinus bimaculatus			1	1				
C. rhodochrous	1							
Pseudocheilinus octotaenia		4			1		3	
Thalassoma duperrey	6	3		7	1	4	37	
T. ballieui	1	3					3	
Coris gaimard	1						1	
C. venusta				1		1	12	
Pseudojuloides cerasinus	5	13		1	2	6		
Stethojulis balteata		2		1	1		1	
Macropharyngodon geoffroy		1					11	
Anampses chrysocephalus							7	
Novaculichthys taeniourus		1						
Gomphosus varius		2						
SCARIDAE								
Calotomus carolinus							2	
Scarus perspicillatus	2	8					42	
S. sordidus	7	1					37	
S. psittacus	2	3						
BOTHIDAE								
Bothus pantherinus			1					
GOBIIDAE								
Gnathelepis anjerensis								1
BLENNIIDAE								
Exallis brevis		1						

ACANTHURIDAE								
Acanthurus nigrofuscus	25	31			16	7	39	
A. nigroris					4		19	
A. olivaceus	1	1			3	13	11	
A. triostegus	2	1					3	
A. achilles		1						
A. mata					1		3	
Ctenochaetus strigosus	28	58			5			
Zebrasoma flavescens	9	4						
Naso lituratus							4	
N. hexacanthus	90	41					4	
N. brevirostris	5							
ZANCLIDAE								
Zanclus cornutus	1				1	2		

Results—*Continued*

FAMILY and Species	Transect (BP-) 1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
BALISTIDAE								
Melichthys niger	4	3			3	3		
M. vidua	1	1	1	1	1	1	2	
Sufflamen bursa	1	2			1	2	3	
S. fraenatus							1	
MONACANTHIDAE								
Pervagor melanocephalus	1							
Cantherhines dumerilii	1	1	1	1	1		1	
OSTRACIONTIDAE								
Ostracion meleagris							5	
CANTHIGASTERIDAE								
Canthigaster jactator		1	1	2	1	1	3	
C. coronata		1	1			1		
DIODONTIDAE								
Diodon holocanthus							1	
Total No. of Species	41	44	6	12	28	17	49	2
Total No. of Individuals	375	488	6	21	82	161	537	3
Estimated Standing Crop (g/m^2)	249	490	9	11	70	311	374	0.8

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^2) of fishes present at each location. All censuses were carried out by the author.