COMMUNITY STRUCTURE OF FISH AND MACROBENTHOS AT SELECTED SHALLOW-WATER SITES IN RELATION TO THE BARBERS POINT OCEAN OUTFALL, 1995

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ABSTRACT

This report provides the results of the fourth 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. The third field survey, completed in March and April 1994, as well as the fourth survey, conducted in June 1995, sampled all of the 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 four surveys (1991, 1993, 1994, and 1995) 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. Currently, it releases approximately 26 mgd (1.14 m^3/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 fourth survey carried out on 19–24 February and 19–22 June 1995.

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

Station BP-2 Located about 0.25 km east of the 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 (north west) 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^2 of substratum on each transect line.

Because of a lawsuit inititated 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 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 ‘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 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 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 on 19 and 20 June 1995, and the photographs were taken by members of the Oceanographic Team, Department of Wastewater Management, City and County of Honolulu, on 19, 21, 22, and 24 February 1995. The physical measurements (temperature, salinity, and oxygen) were made on the morning of 22 June 1995. Figure 1 shows the approximate locations of the four stations, and Figures 2 through 5 show the orientation of the permanent photographic quadrats on each transect line for the four stations.

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

Station BP-1

As noted earlier, Station BP-1 is utilized as a control site situated about 2.2 km inshore and to the east (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 June 1995 is presented in Table 1. In the visually assessed quadrat survey, two algal species (*Porolithon onkodes* and *Halimeda onkodes*) having a mean coverage of 0.7%, two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) with a mean coverage of 0.5%, one soft coral species (*Anthelia edmondsoni*) having a mean coverage of 0.3%, and six coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora verrucosa*, *M. patula*, 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 17.0%. The macroinvertebrate census noted the rock oyster *Spondylus tenebrosus*, two polychaete species (*Loimia medusa* and *Sabellastarte sanctijosephi*), and four echinoderm species (*Linckia multiflora*, *Echinometra mathaei*, *Tripneustes gratilla*, and *Echinothrix calamaris*).

The results of the fish census are presented in the Appendix. Thirty-eight species representing 355 individuals were counted on Transect BP-1-A. The most abundant species included the brick soldierfish or menpachi (*Myripristis amaenus*), the damselfishes *Chromis ovalis* and *Dascyllus albisella*, and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fishes was estimated at 108 g/m^2, with the largest contributors including the emperor fish or mu (*Monotaxis grandoculis*—11% of the total), *Ctenochaetus strigosus* (17% of the total), and *Myripristis amaenus* (17% 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, two coral species having a mean coverage of 25.0% were recorded. Also recorded was the algal species *Porolithon onkodes* with a mean coverage of 1.3%. Other benthic organisms present included the sponge *Chondrosia chucalla* and the soft coral *Anthelia edmondsoni*.

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 0.6%, one sponge species (*Chondrosia chucalla*) having a mean coverage of 0.2%, one soft coral species (*Anthelia edmondsoni*) with a mean coverage of 0.6%, and six coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora patula*, *M. flabellata*, and *M. verrucosa*). The dominant coral species was *Porites lobata*, and mean coral coverage was 25.3%. In the 4 m ∞ 20 m census area, six macroinvertebrate species were seen: the rock oyster *Spondylus tenebrosus*, the octopus *Octopus cyanea*, the boring bivalve *Lithophaga* sp., the Christmas tree worm *Spirobranchus giganteus corniculatus*, the starfish *Linckia diplax*, and the black spiny sea urchin or wana (*Echinothrix diadema*).

The results of the photo-quadrat survey for Transect BP-1-B are given in Table 2. Four coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, and *Montipora patula*) having a mean coverage of 24.6% 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. Thirty-eight species representing 410 individuals were censused at Transect BP-1-B, where the most common species present were the brick soldierfish or menpachi (*Myripristis amaenus*), three damselfish species (*Dascyllus albisella*, *Chromis ovalis*, and *C. hanui*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fish was estimated at 109 g/m^2, with the largest contributors being *Myripristis amaenus* (16% of the total), the saddleback wrasse or ho(¯,i)no(¯,a)lea lauwili (*Thalassoma duperrey*—12% of the total), and *Ctenochaetus strigosus* (17% of the total).

Station Observation

In the vicinity of Station BP-1 were seen the corals *Pavona duerdeni* and *Porites rus*.

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 verrilli* and *M. verrucosa*. 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 five algal species (*Asparagopsis taxiformis*, *Avrainvillea amadelpha*, *Amansia glomerata*, *Padina japonica*, and *Dictyopteris australis*) having a mean coverage of 0.9%, two sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) with a mean coverage of 1.1%, 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 six species: the cone shells *Conus lividus*, *C. quercinus*, and *C. imperialis*; the polychaete *Spirobranchus giganteus corniculatus*; the rock boring sea urchin *Echinostrephus aciculatum*; and the black sea urchin *Tripneustes gratilla*.

The photo-quadrat survey noted one algal species or limu kohu (*Asparagopsis taxiformis*), two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*), and two coral species (*Porites lobata* and *Pocillopora meandrina*). Mean coral coverage was estimated at 0.9%.

The results of the fish census are presented in the Appendix. In total nine fish species representing 22 individuals were censused at Transect BP-2-A. The biomass of fishes on this transect was estimated at 11 g/m^2, with the largest contributors being two barred filefish or ‘o‘ili (*Cantherhines dumerili*—81% of the total).

Transect BP-2-B

Transect BP-2-B was established at a distance varying from 17.5 to 26.2 m seaward of Transect BP-2-A (Figure 3). Table 5 presents the results of the visual quadrat survey carried out at Transect BP-2-B. Six algal species (*Amansia glomerata*, *Asparagopsis taxiformis*, *Avrainvillea amadelpha*, *Dictyopteris australis*, *Halimeda opuntia*, and *Martensia fragilis*) with a mean coverage of 1.3%, two encrusting sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) having a mean coverage of 0.9%, one soft coral (*Anthelia edmondsoni*) with a mean coverage of 0.1%, and two coral species (*Porites lobata* and *Pocillopora meandrina*) were noted. Mean coral coverage was estimated at 0.6%. Noncolonial macroinvertebrates censused in the 4 m ∞ 20 m transect include the cone shell *Conus imperialis*, the pinna *Streptopinna saccata*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, the banded shrimp *Stenopus hispidus*, and three sea urchin species (the rock boring urchin *Echinostrephus aciculatum*, the banded urchin *Echinothrix calamaris*, and the black spiny urchin *Echinothrix diadema*).

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 0.3%, the soft coral *Anthelia edmondsoni* added less than 0.1%, and two coral species (*Porites lobata* and *Pocillopora meandrina*) contributed 0.9%.

The fish census noted 15 species of fishes representing 68 individuals (Appendix). The most common species on this transect were the black damselfish or ‘o(¯,a)lo‘ilo‘i (*Dascyllus albisella*) and the saddleback wrasse or ho(¯,i)no(¯,a)lea lauwili (*Thalassoma duperrey*). Fish standing crop was estimated at 26 g/m^2, with the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*) contributing 22% and a single moral eel or puhi (*Gymnothorax petelli*) adding 53%.

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*, and the belted wrasse or ‘o(¯,o)maka (*Stethojulis balteata*).

Station BP-3

Station BP-3 is located about 2.9 km west and inshore of the Barbers Point terminus (Figure 1). This western station is situated approximately 1.6 km offshore of the Barbers Point Naval Air Station at a depth of 16.5 to 16.8 m. The substratum at this location is a mix of coral and rubble mounds or ridges with sand or flat limestone substratum between them. The ridges, which have an orientation that is approximately perpendicular to the shoreline, are from 2 to 15 m in width, 4 to 40 m in length, and up to 0.75 m in height. The ridges are spaced from 3 to 10 m apart; sand 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 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*) having a mean coverage of 1.5% and five coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora verrucosa*, and *Pavona varians*). Mean coral coverage at this location was estimated at 6.5% (visual quadrat method), and the dominant species was *Porites lobata*. Six macroinvertebrate species were censused, including the rock oyster *Spondylus tenebrosus* and five sea urchin species (*Echinothrix diadema*, *E. calamaris*, *Echinometra mathaei*, *Tripneustes gratilla*, and *Heterocentrotus mammillatus*).

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 0.06%, two sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) with a mean coverage of 1.1%, a soft coral (*Anthelia edmondsoni*) with a mean coverage of less than 0.1%, 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. Thirty-five fish species representing 189 individuals were censused. The most abundant fish species were the manybar goatfish or moano (*Parupeneus multifasciatus*), the damselfishes *Dascyllus albisella* and *Chromis vanderbilti*, as well as the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*). The standing crop was estimated at 157 g/m^2, with the tableboss or ‘a‘awa (*Bodianus bilunulatus*) contributing 13% and *Acanthurus olivaceus* making up 56%.

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. Two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) having a mean coverage of 0.4% and four coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, and *Montipora patula*) were noted. Coral coverage at this transect was estimated at 2.4% (visual quadrat method). Six species of macroinvertebrates were censused in the 4 m ∞ 20 m area, including the rock oyster *Spondylus tenebrosus*, a juvenile hermit crab (*Dardanus* sp.), the slate pencil sea urchin *Heterocentrotus mammillatus*, the black sea urchin *Tripneustes gratilla*, the banded sea urchin *Echinothrix calamaris*, and the green sea urchin *Echinometra mathaei*.

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 0.1%, two sponge species (*Chondrosia chucalla* and *Spirastrella coccinea*) with a mean coverage of 0.6%, and four coral species (*Montipora patula*, *Pocillopora meandrina*, *Porites compressa*, and *P. lobata*) having a mean coverage of 8%.

The results of the fish census carried out at Transect BP-3-B are presented in the Appendix. In total 29 species representing 156 individuals were counted, with the most abundant fishes including the manybar goatfish or moano (*Parupeneus multifasciatus*), the saddleback wrasse or ho(¯,i)no(¯,a)lea lauwili (*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 128 g/m^2, and the species contributing most heavily included the tableboss or ‘a‘awa (*Bodianus bilunulatus*—14% of the total) and *Acanthurus olivaceus* (64% of the total).

Station Observations

In the vicinity of Station BP-3 were seen the coral *Porites rus*, as well as the yellowmargin moray eel or puhi paka (*Gymnothorax flavimarginatus*), the octopus or he‘e (*Octopus cyanea*), and the mackerel scad or ‘o(¯,o)pelu (*Decapterus macarellus*).

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 15.2 to 17.7 m of water and 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 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 0.2%, one sponge species (*Chondrosia chucalla* having a mean coverage of 0.2%), and one coral species (*Porites lobata*) having a mean coverage of 28.0%. The census of macroinvertebrates noted nine species: the rock oyster *Spondylus tenebrosus*, the nudibranch *Pteraeolidia ianthina*, two polychaete species (*Loimia medusa* and *Sabellastarte* *sanctijosephi*), the spiny lobster or ‘ula (*Panulirus penicillatus*), and four sea urchin species (*Tripneustes gratilla*, *Echinothrix diadema*, *E. calamaris*, and *Echinometra mathaei*).

The results of the photo-quadrat survey are given in Table 2. In the photo-quadrat analysis, the coralline alga *Porolithon onkodes* had a mean coverage of 0.4%, the encrusting sponge *Spirastrella coccinea* had a mean coverage of 0.3%, and one coral species (*Porites lobata*) had an estimated coverage of 15.1%.

The results of the fish census carried out at Transect BP-4-A are presented in the Appendix. Forty-eight fish species representing 943 individuals having an estimated biomass of 440 g/m^2 were censused. The most abundant fish species included the brick soldierfish or menpachi (*Myripristis amaenus*), the black damselfish or ‘o(¯,a)lo‘ilo‘i (*Dascyllus albisella*), the sergeant major or mamo (*Abudefduf abdominalis*), the damselfish *Chromis ovalis*, the convict tang or manini (*Acanthurus triostegus*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). Species contributing most to the estimated standing crop included the yellowmargin moray eel or puhi paka (*Gymnothorax flavimarginatus*—14% of the total), the brick soldierfish or menpachi (*Myripristis amaenus*—10% of the total), and the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*—13% of the total).

Transect BP-4-B

Transect BP-4-B was established from 19 to 27 m to the east of Transect BP-4-A in 17.7 m of water. This transect has an orientation that is parallel to Transect BP-4-A and perpendicular to the shoreline. The substratum at this transect is flat limestone with very little relief. A sand/coral rubble veneer overlies portions of the limestone; this veneer does not usually exceed 2 cm in thickness and may cover up to 50 m^2. 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 three encrusting sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and *Plakortis simplex*) having a mean coverage of 0.6%, one soft coral species (*Anthelia edmondsoni*) having a mean coverage of 0.1%, and three coral species (*Porites lobata*, *Pocillopora meandrina*, and *Montipora patula*) with a mean coverage of 4.3%. The macroinvertebrate census noted the cone shell *Conus leopardus*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, the brown hermit crab *Aniculus strigatus*, 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, two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) had a mean coverage of 0.2%, 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 3.9%.

The results of the fish census carried out at Transect BP-4-B are presented in the Appendix. Ten species of fishes representing 96 individuals having an estimated standing crop of 16 g/m^2 were encountered. The most abundant fish species at this transect were the elegant coris *Coris venusta*, the smalltail wrasse *Pseudojuloides cerasinus*, and the sleek unicornfish or kala holo (*Naso hexacanthus*). *Naso hexacanthus* contributed 64% of the estimated biomass at Transect BP-4-B.

Physical Measurements and Biological Parameters

Physical measurements made in the morning on 22 June 1995 are presented in Table 10. Little variation was noted in temperature (25.0° to 25.6°C), oxygen saturation (102% to 104%), 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 nephalometer in the laboratory.

The biological data for the 1991, 1993, 1994, and 1995 annual surveys are summarized as means for each transect in Table 11. The means of all biological parameters measured in these surveys (i.e., percent algal and coral cover; number of coral, other macroinvertebrate, and fish species; number of individual fish; and biomass of fishes) showed a general decline between the 1991 and 1993 surveys and an increasing or leveling off trend since 1993. The early decreases in means may have been related to impacts created by Hurricane Iniki in September 1992, and the increases since the 1993 survey may be related to the recovery in these communities since the storm. Fish biomass means, however, are lower in 1995 than in previous sampling years. These changes could be related to the chance encounters with large (heavy) roving predators or large schools of certain species during a census or due to a decline related to greater fishing pressure. 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 ($p > 0.29$, not significant), the mean percent cover by coral ($p > 0.59$, not significant), the mean number of of coral species ($p > 0.96$, 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 > 0.91, not significant), and the mean standing crop of fish expressed in grams per square meter (p > 0.93, 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 import ant 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 ‘o(¯,a)weoweo (*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

Three green sea turtles (*Chelonia mydas*) were encountered during the 1995 field survey. One of these was seen in the vicinity of Station BP-1 and the other two in the vicinity of Station BP-3. The turtle near Station BP-1 was seen on the surface; it had an estimated straight line carapace length of 75 cm. The two turtles seen adjacent to Station BP-3 were both swimming; one had an estimated straight line carapace length of 45 cm, whereas the second had an estimated length of 70 cm. In general, individual turtles are commonly seen surfacing for air while transiting from Honolulu Harbor to ‘Ewa Beach. Most are juveniles (i.e., their straight line carapace length is less than 80 cm).

DISCUSSION

On 11 September 1992 the Hawaiian islands were struck by Hurricane Iniki. The hurricane passed directly over Kaua‘i, with sustained winds of 144 mph and gusts to 172 mph causing considerable damage to improvements and forests of that island and the west (leeward) coast of O‘ahu. To a lesser extent, high surf caused damage to marine communities along the southern, eastern, and western shores of O‘ahu, Kaua‘i, Maui, Lo(¯,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). 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^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 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 four 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, Keehi 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 m^3/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). 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 among the 1991, 1993, 1994, and 1995 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 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 emperor fish or mu [*Monotaxis grandoculis*] and grey snappers 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 butterflyfish 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 11% to the biomass of fishes present at Transect BP-1-A; and *Acanthurus olivaceus* contributed 22% at Transect BP-2-B, 56% at Transect BP-3-A, and 64% 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 (*Gymnothorax petelli*) made up 53% of the biomass at Transect BP-2-B, and two yellowmargin morays or puhi paka (*G. flavimarginatus*) accounted for 14% of the relatively large standing crop at Transect BP-4-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 four annual surveys (1991, 1993, 1994, and 1995) 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 outfall terminus.

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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 Ocean Outfall Terminus, on 19 June 1995

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Porolithon onkodes	3.0				
Halimeda onkodes	0.5				
Sponges					
Spirastrella coccinea			1.1		
Chondrosia chucalla	0.1	0.2		1.1	1.0
Soft Corals					
Anthelia edmondsoni			0.2		1.1
Corals					
Porites lobata	19.0	36.0	1.0	0.4	19.0
Porites compressa		5.0	0.3		0.7
Pocillopora meandrina		0.2	0.1	0.1	
Montipora verrucosa				0.1	0.9
Montipora patula		0.1			1.1
Pavona varians		0.6			
Sand	0.5		10.0		4.0
Rubble	41.0		73.3	92.3	66.2
Hard Substratum	35.9	57.9	14.0	6.0	6.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Spondylus tenebrosus	2				
Phylum Annelida					
Loimia medusa	2				
Sabellastarte sanctijosephi	1				
Phylum Echinodermata					
Linckia multiflora	1				
Echinometra mathaei	1				
Tripneustes gratilla	3				

Echinothrix calamaris	3				
III. Fish Census (4 m ∞ 20 m)					
38 Species					
355 Individuals					
Estimated Standing Crop = 108 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 14.9 m; mean coral coverage is 17.0% (visual quadrat method).

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, February 1995

Transect BP-1-A	Percent Cover Photographic Quadrat				
	AAA3	ACC1	AAB3	ACC2	AAC3
	(0 m)	(5 m)	(10 m)	(15 m)	(20 m)
Algae					
Porolithon onkodes	2.0	4.2			0.1
Sponges					
Chondrosia chucalla				0.1	0.3
Soft Corals					
Anthelia edmondsoni				0.3	0.6
Corals					
Porites lobata	56.0	43.4		0.1	23.2
Porites compressa	2.0	0.3			
Sand			5.6	1.1	
Rubble			73.1	94.1	35.3
Hard Substratum	40.0	52.1	21.3	4.3	40.5
Mean Coral Coverage = 25.0%					

Transect BP-1-B	Percent Cover Photographic Quadrat				
	ABA3	ACA1	ABB3	ACA2	ABC3
	(0 m)	(5 m)	(10 m)	(15 m)	(20 m)
Algae					
Porolithon onkodes	1.1			1.4	1.4
Sponges					
Spirastrella coccinea			0.1		
Chondrosia chucalla	0.3	0.7	0.1	1.4	
Corals					

Porites lobata	25.5	8.1	8.4	15.7	50.4
Porites compressa	6.7		1.4	2.0	3.4
Pocillopora meandrina		0.3			0.8
Montipora patula		0.3	0.4		
Sand			0.3	0.6	
Rubble	4.5	33.6	7.0	13.7	
Hard Substratum	61.9	57.0	82.2	66.5	44.0
Mean Coral Coverage = 24.6%					

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					
Asparagopsis taxiformis				14.8	
Sponges					
Spirastrella coccinea		0.1	0.3		
Chondrosia chucalla	0.6		0.3	2.0	0.1
Corals					
Porites lobata	0.6			1.4	0.6
Pocillopora meandrina			0.3	1.7	
Sand	3.6	19.0	27.2	5.6	18.5
Hard Substratum	95.2	80.8	72.0	74.5	80.8
Mean Coral Coverage = 0.9%					

Transect BP-2-B	Percent Cover Photographic Quadrat BBA3 (0 m)	BCA1 (5 m)	BBB3 (10 m)	BCA2 (15 m)	BBC3 (20 m)
Sponges					
Spirastrella coccinea	0.1				0.1
Chondrosia chucalla	0.1	0.1		0.6	0.3
Soft Corals					
Anthelia edmondsoni					0.1
Corals					
Porites lobata	0.6	3.1	0.3		0.1
Pocillopora meandrina		0.3			
Sand	53.5	12.0	26.3	12.3	5.8
Hard Substratum	45.6	84.4	73.4	87.1	93.6

Mean Coral Coverage = 0.9%					

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					
Porolithon onkodes	0.3				
Sponges					
Spirastrella coccinea	0.1			0.3	
Chondrosia chucalla	0.3		0.3	4.5	0.1
Soft Corals					
Anthelia edmondsoni	0.1				
Corals					
Porites lobata	0.5			2.8	
Porites compressa				0.3	
Pocillopora meandrina				1.1	
Sand	0.8	5.9	0.8		5.3
Rubble	82.2	46.8	98.9	75.4	59.0
Hard Substratum	16.5	46.8		15.7	35.6
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					
Porolithon onkodes	0.6				
Sponges					
Spirastrella coccinea	0.4	0.3	0.1	0.7	0.8
Chondrosia chucalla	0.1	0.6	0.1		0.1

Corals					
Porites lobata	11.2	7.8	0.1	18.5	
Porites compressa				1.4	
Pocillopora meandrina				0.6	
Montipora patula				0.3	
Sand			0.8		0.6
Rubble	34.5	59.4	98.9	31.4	21.0
Hard Substratum	53.2	31.9		47.2	77.4
Mean Coral Coverage = 8.0%					

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					
Porolithon onkodes			0.6		1.4
Sponges					
Spirastrella coccinea	0.3			0.8	0.3
Corals					
Porites lobata	1.7	27.4	22.4		23.8
Rubble	39.5	11.2	18.8		18.8
Hard Substratum	58.5	61.3	58.3	75.4	79.6
Mean Coral Coverage = 15.1%					

Transect BP-4-B	Percent Cover Photographic Quadrat ECA1 (0 m)	ECA2 (5 m)	ECA3 (10 m)	EAC4 (15 m)	EEA1 (20 m)
Sponges					
Spirastrella coccinea					0.1
Chondrosia chucalla		0.3		0.1	0.6
Soft Corals					
Anthelia edmondsoni		0.1			
Corals					
Porites lobata	0.6	0.1	1.4	1.7	0.6
Pocillopora meandrina	13.7		1.4		
Sand	0.8	3.4	0.8	0.8	1.4
Hard Substratum	84.9	96.1	96.4	97.3	97.3
Mean Coral Coverage = 3.9%					

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^2 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 19 June 1995

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Porolithon onkodes	1.0				2.0
Sponges					
Chondrosia chucalla		0.1		1.1	
Soft Corals					
Anthelia edmondsoni		1.4	1.0	0.4	
Corals					
Porites lobata	12.0	3.8	2.0	4.0	86.0
Porites compressa	4.0		2.1	4.0	4.0
Pocillopora meandrina		0.8	0.1		
Montipora patula			1.7	1.4	
Montipora flabellata			0.4		
Montipora verrucosa			0.1		
Sand		5.0	5.0		
Rubble	32.0	65.9	46.6	61.1	
Hard Substratum	51.0	23.0	41.0	28.0	8.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Spondylus tenebrosus	1				
Octopus cyanea	1				
Lithophaga sp.	1				
Phylum Annelida					
Spirobranchus giganteus corniculatus	7				
Phylum Echinodermata					
Linckia diplax	1				
Echinothrix diadema	3				

III. Fish Census (4 m ∞ 20 m)					
38 Species					
410 Individuals					
Estimated Standing Crop = 109 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 15.8 m; mean coral coverage is 25.3% (visual quadrat method).

TABLE 4. Summary of Biological Observations Made at Transect BP-2-A, 0.25 km East of the Discharge Pipe and 1.5 km Inshore and Northeast of Barbers Point Ocean Outfall Terminus, on 19 June 1995

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Avrainvillea amadelpha	1.0			0.2	
Asparagopsis taxiformis	0.1				
Amansia glomerata	1.7	0.1	0.1		
Padina japonica	0.1			0.1	
Dictyopteris australis				1.0	
Sponges					
Chondrosia chucalla	0.4	0.1	1.0	1.8	1.9
Spirastrella coccinea	0.1	0.1			0.3
Soft Corals					
Anthelia edmondsoni	0.1			0.1	
Corals					
Porites lobata	2.6	0.8	0.6	0.6	0.3
Pocillopora meandrina				0.1	0.7
Sand	2.0	35.0	7.0		5.0
Hard Substratum	91.9	63.9	91.3	96.1	91.8

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Conus imperialis	1				
Conus lividus	2				
Conus quercinus	2				
Phylum Annelida					
Spirobranchus giganteus corniculatus	1				
Phylum Echinodermata					
Echinostrephus aciculatum	2				
Tripneustes gratilla	1				

III. Fish Census (4 m ∞ 20 m)					
9 Species					
22 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 is 11.3 m; mean coral coverage is 1.0% (visual quadrat method).

TABLE 5. Summary of Biological Observations Made at Transect BP-2-B, 0.25 km East of the Discharge Pipe and 1.5 km Inshore and Northeast of Barbers Point Ocean Outfall Terminus, on 19 June 1995

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Amansia glomerata	0.1	0.5	1.2	0.4	0.6
Asparagopsis taxiformis				0.1	
Avrainvillea amadelpha	0.1		2.0		0.1
Dictyopteris australis			0.1	0.9	
Halimeda opuntia		0.1			
Martensia fragilis				0.1	
Sponges					
Chondrosia chucalla		0.3	2.0	0.3	0.9
Spirastrella coccinea	0.8			0.1	
Soft Corals					
Anthelia edmondsoni	0.1	0.1	0.1	0.1	0.1
Corals					
Porites lobata	0.4	1.1	0.5	0.4	
Pocillopora meandrina			0.2	0.1	
Sand	12.0	6.0			2.0
Hard Substratum	86.5	91.9	93.9	97.5	98.3

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Conus imperialis	1				
Streptopinna saccata	1				
Phylum Annelida					
Spirobranchus giganteus corniculatus	6				
Phylum Arthropoda					
Stenopus hispidus	2				
Phylum Echinodermata					

Echinothrix calamaris	4				
Echinothrix diadema	1				
Echinostrephus aciculatum	3				
III. Fish Census (4 m ∞ 20 m)					
15 Species					
68 Individuals					
Estimated Standing Crop = 26 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 11.6 to 11.9 m; mean coral coverage is 0.6% (visual quadrat method).

TABLE 6. Summary of Biological Observations Made at Transect BP-3-A, 3.3 km West and Inshore of Barbers Point Ocean Outfall Terminus, on 20 June 1995

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Sponges					
Chondrosia chucalla	0.1			1.2	0.4
Spirastrella coccinea	2.0			2.8	0.9
Corals					
Porites lobata		1.6		23.0	
Porites compressa				3.8	
Pocillopora meandrina				4.0	
Montipora verrucosa					0.1
Pavona varians				0.4	
Sand	14.0	4.0	67.0		6.0
Rubble	57.9	66.4	33.0	17.8	74.6
Hard Substratum	26.0	28.0		47.0	18.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Spondylus tenebrosus	2				
Phylum Echinodermata					
Echinometra mathaei	1				
Echinothrix diadema	2				
Echinothrix calamaris	7				
Tripneustes gratilla	1				
Heterocentrotus mammillatus	3				

III. Fish Census (4 m ∞ 20 m)					
35 Species					
189 Individuals					
Estimated Standing Crop = 157 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 6.5% (visual quadrat method).

TABLE 7. Summary of Biological Observations Made at Transect BP-3-B, 3.3 km West and Inshore of Barbers Point Ocean Outfall Terminus, on 20 June 1995

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Sponges					
Spirastrella coccinea	0.2				0.6
Chondrosia chucalla	0.3	0.7			0.1
Corals					
Porites lobata	1.4	3.1		4.2	
Porites compressa	1.0			0.2	
Pocillopora meandrina	0.1		0.6		0.1
Montipora patula	0.9			0.2	
Sand	1.0		3.0	3.0	5.0
Rubble	83.1	55.2	96.4	66.4	82.2
Hard Substratum	12.0	41.0		26.0	12.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Spondylus tenebrosus	1				
Phylum Arthropoda					
Dardanus sp. (juv.)	1				
Phylum Echinodermata					
Tripneustes gratilla	8				
Echinothrix calamaris	8				
Echinometra mathaei	5				
Heterocentrotus mammillatus	1				

III. Fish Census (4 m ∞ 20 m)					
29 Species					
156 Individuals					
Estimated Standing Crop = 128 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 16.5 m; mean coral coverage is 2.4% (visual quadrat method).

TABLE 8. Summary of Biological Observations Made at Transect BP-4-A, Situated on the Basalt Caprock of the Barbers Point Discharge Pipe, Approximately 1.4 km Inshore (North) of Barbers Point Ocean Outfall Terminus, on 19 June 1995

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Porolithon onkodes					10.0
Soft Corals					
Chondrosia chucalla			1.0		0.1
Corals					
Porites lobata	19.0	46.0	26.0	27.0	22.0
Rubble	11.0	6.0	11.0	2.0	
Hard Substratum	70.0	48.0	62.0	71.0	67.9

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Spondylus tenebrosus	1				
Pteraeolidia ianthina	12				
Phylum Annelida					
Loimia medusa	4				
Sabellastarte sanctijosephi	3				
Phylum Arthropoda					
Panulirus penicillatus	1				
Phylum Echinodermata					
Tripneustes gratilla	4				
Echinothrix calamaris	1				
Echinothrix diadema	93				
Echinometra mathaei	1				

III. Fish Census (4 m ∞ 20 m)					
48 Species					

943 Individuals					
Estimated Standing Crop = 440 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 15.2 to 15.8 m; mean coral coverage is 28.0% (visual quadrat method).

TABLE 9. Summary of Biological Observations Made at Transect BP-4-B, Situated on Smooth Limestone Substratum 15 m East of the Basalt Caprock of the Barbers Point Discharge Pipe, Approximately 1.4 km Inshore (North) of Barbers Point Ocean Outfall Terminus, on 19 June 1995

	Percent Cover				
I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Sponges					
Plakortis simplex	0.4	0.1	0.7		
Chondrosia chucalla				0.8	0.6
Spirastrella coccinea				0.1	0.1
Soft Corals					
Anthelia edmondsoni	0.1	0.1		0.1	0.1
Corals					
Porites lobata	0.7	0.3	1.3	2.0	1.5
Pocillopora meandrina	8.0		1.0	3.8	0.1
Montipora patula	3.0				
Sand		6.0	5.0		
Hard Substratum	87.8	93.5	92.0	93.2	97.6
II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Conus leopardus	1				
Phylum Annelida					
Spirobranchus giganteus corniculatus	3				
Phylum Arthropoda					
Aniculus strigatus	1				
Phylum Echinodermata					
Echinostrephus aciculatum	3				
III. Fish Census (4 m ∞ 20 m)					
10 Species					

96 Individuals					
Estimated Standing Crop = 16 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 17.7 m; mean coral coverage is 4.3% (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, and 22 June 1995

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

Station BP-2									
1010 hr	102	101		34		22.7	23.0		>11.0
Station BP-3									
1100 hr	101	101		34		23.0	23.0		>16.5
Station BP-4									
1040 hr	103	103		34		23.1	23.0		>13.0
22 JUNE 1995									
Station BP-1									
0930 hr	102	102		34		25.5	25.3		>15.0
Station BP-2									
1015 hr	104	103		34		25.6	25.5		>11.0
Station BP-3									
1110 hr	102	103		34		25.0	25.0		>16.5
Station BP-4									
1050 hr	102	102		34		25.3	25.4		>13.0

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.

Results of Quantitative Visual Fish Censuses Conducted on Two Transects Each at Four Stations Offshore of ‘Ewa Beach, O‘ahu, Hawai‘i, 19–20 June 1995

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
MURAENIDAE								
Gymnothorax eurostus		1						
Gymnothorax petelli				1				
Gymnothorax meleagris					1			
Gymnothorax flavimarginatus							2	
AULOSTOMIDAE								
Aulostomus chinensis		1					4	
HOLOCENTRIDAE								
Myripristis amaenus	23	30					74	
Adioryx xantherythrus	14	7						
SCORPAENIDAE								
Scorpaenopsis cacopsis							2	
FISTULARIIDAE								
Fistularia commersoni	1						2	
APOGONIDAE								
Apogon kallopterus	4				1		5	
LUTJANIDAE								
Aprion virescens							1	
Alphareus furcatus							1	
CARANGIDAE								
Scomberoides laysan					4			
SPARIDAE								
Monotaxis grandoculis	5	4						
MULLIDAE								
Parupeneus pleurostigma	4	4	1		7			
Parupeneus multifasciatus	7	16		1	13	17	26	
Parupeneus cyclostomus							1	
Parupeneus bifasciatus							15	

CHAETODONTIDAE								
Forcipiger flavissimus		4					4	
Chaetodon multicinctus	4	7			3			
Chaetodon fremblii				1			2	
Chaetodon kleinii					2		6	
Chaetodon auriga					2			
Chaetodon miliaris	1		1	2	2		9	
Chaetodon ornatissimus	1	2						
Chaetodon lunula							2	
POMACANTHIDAE								
Centropyge potteri	3	6				1		
POMACENTRIDAE								
Dascyllus albisella	58	46		13	28	8	325	
Plectroglyphidodon johnstonianus	2	4			1	1	1	
Abudefduf abdominalis							65	
Chromis vanderbilti					22	13		7

Results—*Continued*

FAMILY and Species	Transect (BP-)							
	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B
Chromis hanui	13	24				1		
Chromis ovalis	47	98			8	6	65	
Chromis agilis							4	
Stegastes fasciolatus	7						7	
CIRRHITIDAE								
Paracirrhitus arcatus		2		1		1		2
Paracirrhitus forsteri	1	1					1	
Cirrhitops fasciatus	1				3	2	3	
LABRIDAE								
Labroides phthirophagus						1	1	
Bodianus bilunulatus					2	2	2	
Cheilinus bimaculatus			11	9		1		6
Pseudocheilinus octotaenia	3				1		4	
Thalassoma duperrey	7	21	1	26	8	23	4	12
Coris gaimard	1	1			2	1	2	
Coris venusta					1	2		17
Coris flavovittata							1	
Pseudojuloides cerasinus	6	6	1	5	5	23		20
Stethojulis balteata		2			10	1	4	
Macropharyngodon geoffroy	3	2					14	
Anampses chrysocephalus								
Anampses cuvier	1							
Gomphosus varius		1					1	
Halichoeres ornatissimus	1			3	1		2	
Hemipteronotus leclusei			1					
SCARIDAE								
Calotomus carolinus		1				1		
Scarus sordidus	4	2			6	3	14	
Scarus psittacus	18	9				5	18	
BLENNIIDAE								
Exallis brevis							1	
Plagiotremus ewaensis					1			
PARAPERCIDAE								
Parapercis schauinslandi			3					

ACANTHURIDAE								
Acanthurus nigrofuscus	18	11		1	11	13	29	
Acanthurus nigroris	4	2			4	3		
Acanthurus olivaceus	2			1	14	16	12	
Acanthurus triostegus							34	
Acanthurus dussumieri							3	
Acanthurus leucoparieus					2			
Ctenochaetus strigosus	71	77			10	2	125	
Zebrasoma flavescens	3	5					1	
Naso hexacanthus	8	1					21	27
Naso lituratus	2	1			2		16	
ZANCLIDAE		1				2		
Zanclus cornutus								

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	2	3			1	2		
Melichthys vidua		1		1	2		2	
Sufflamen bursa	2	4			3	2	3	2
Sufflamen fraenatus		1						
MONACANTHIDAE								
Pervagor melanocephalus		1				1		
Cantherhines dumerili			2				2	1
Cantherhines sandwichiensis	1			1				
OSTRACIONTIDAE								
Ostracion cubicus					1			
CANTHIGASTERIDAE								
Canthigaster jactator	2			2	5	2		
Canthigaster coronata			1					
Canthigaster cinctus								2
Total No. of Species	38	38	9	15	35	29	48	10
Total No. of Individuals	355	410	22	68	189	156	943	96
Estimated Standing Crop (g/m^2)	108	109	11	26	157	128	440	16

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.