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COMMUNITY STRUCTURE OF FISH AND MACROBENTHOS AT SELECTED SITES FRONTING SAND ISLAND, O'AHU, HAWAI'I, IN RELATION TO THE SAND ISLAND OCEAN OUTFALL, YEAR 9—1998

Richard E. Brock

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December 1998

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This report provides the results of the ninth year of an annual quantitative monitoring (carried out in August and September 1998) of shallow marine communities inshore of the Sand Island Ocean Outfall, Oahu, Hawaii. This monitoring effort focuses on benthic and fish community structure and is designed to detect changes in these communities. Marine communities offshore of Honolulu have received considerable perturbation over the last 100 years. Dumping of raw sewage in shallow water, which occurred from 1955 to 1977, was halted in 1978; however, point and nonpoint sources of pollution from both urban activities and industry continue. All of these disturbances may serve to obscure any impacts that may be caused by treated effluent discharged from the deep-ocean outfall. The marine communities show a considerable range in development that is probably related to historical impacts. Stations have been located to take advantage of these gradients. Analysis of the nine years of data showed that there has been no statistically significant change in any of the biological parameters measured in this study other than for the mean number of invertebrate species and numbers of individual invertebrates encountered per transect. In these cases the data for 1998 showed significantly greater numbers of species and individuals over other years. These changes are probably the result of higher than usual counts of the Christmas tree worm *Spirobranchus giganteus corniculatus* as well as just more invertebrate species present at most stations. All other measures of the communities in this study (i.e., percent coral cover, number of coral species, number of fish species, total number of fishes counted, and the biomass of fishes present at each station) showed no significant changes through the period of this study. Hurricane Iniki, which occurred in September 1992, impacted marine communities along the south shore of Oahu. Coral communities received considerable damage, especially at the westernmost study station. Recovery in these communities is evident from the six years of data collected since the storm. Thus far, this study has not detected a quantifiable negative impact from the operation of the Sand Island Ocean Outfall.

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ABSTRACT

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INTRODUCTION

Purpose

In recent years controversy has arisen regarding the impact that sewage effluent from the Sand Island Wastewater Treatment Plant may have on inshore coral reef species. Much of the geographical area of concern in this study was impacted by the release of 62 mgd (3 m^3/s) of raw sewage in 10 m of water off Sand Island from 1955 to 1977. Starting in 1978 sewage received advanced primary treatment and was released farther offshore of Sand Island from a deep-ocean outfall (67 to 73 m depth). Despite studies that demonstrated the recovery of inshore benthic communities once the shallow sewage stress was removed (e.g., Dollar 1979), concern continues over the possible impact that the release of sewage effluent from the deep-ocean outfall may be having on the shallow (less than 20 m depth) marine communities fronting Honolulu and Sand Island. Accordingly, beginning in 1990, this study was undertaken in an attempt to quantitatively ascertain the impacts that may be occurring. This document presents the results of the ninth annual survey carried out in August and September 1998.

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 to separate the impact signal from background "noise." Infrequent natural events may add considerably to the variability or background noise measured in a marine community. In September 1992 Hurricane Iniki struck the Hawaiian islands and impacted some marine communities along O'ahu's south shore. This rare event has provided this study with information on the magnitude of such natural impacts.

Rare storm events not withstanding, the potential impacts occurring to the marine ecosystem offshore of Sand Island and Honolulu are most probably those associated with chronic or progressive stresses. Because of the proximity of the population center and industry, marine communities fronting Honolulu are subjected to a wide array of impacts not usually occurring in other Hawai'i coral communities. 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 perturbations occurring in the waters fronting Honolulu.

Honolulu Harbor has been the primary commercial port for the State of Hawai'i since before the turn of the century (Scott 1968). The harbor is the result of dredging what was originally the drainage basin of Nu'uanu Stream. Dredging began before 1900, and periodic maintenance dredging still occurs. Until about 1960 spoils were dropped just outside of the harbor, generally to the east of the Sand Island Ocean Outfall. Besides shipping, the harbor is ringed with industry; pineapple canneries, gas and oil storage, and numerous other businesses have operated or are still operating here. Storm drainage into the harbor and nearby Ke'ehi Lagoon carries runoff from Honolulu's streets and suburbs into the ocean. Pollution is well known in the harbor; conditions are described as early as 1920 in references cited by Cox and Gordon (1970). Sewage has been pumped into the ocean offshore of Kewalo and Sand Island since the 1930s. The early inputs were all raw sewage released in water not exceeding 20 m in depth. The actual point of release varied through time as different pipes were constructed and used. The multitude of perturbations that occurred in shallow water (less than 20 m) until the construction of the present deep-water outfall in 1978 may serve to obscure the impacts from the present discharge.

The waters fronting Sand Island, into which the deep-ocean outfall discharges, may be considered in terms of gradients. There are numerous "gradients" owing to point-source and nonpoint-source (such as storm drains and streams) inputs into Honolulu Harbor and the surrounding area from the above-mentioned activities. Because many of these inputs have 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 Honolulu and the harbor are those that have evolved under the influence of these ongoing perturbations.

As noted above, if impacts are occurring in the shallow marine communities fronting Honolulu owing to sewage effluent discharged from the deep-ocean outfall, they are probably chronic in nature, thus causing a slow decline in the communities so affected. 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.

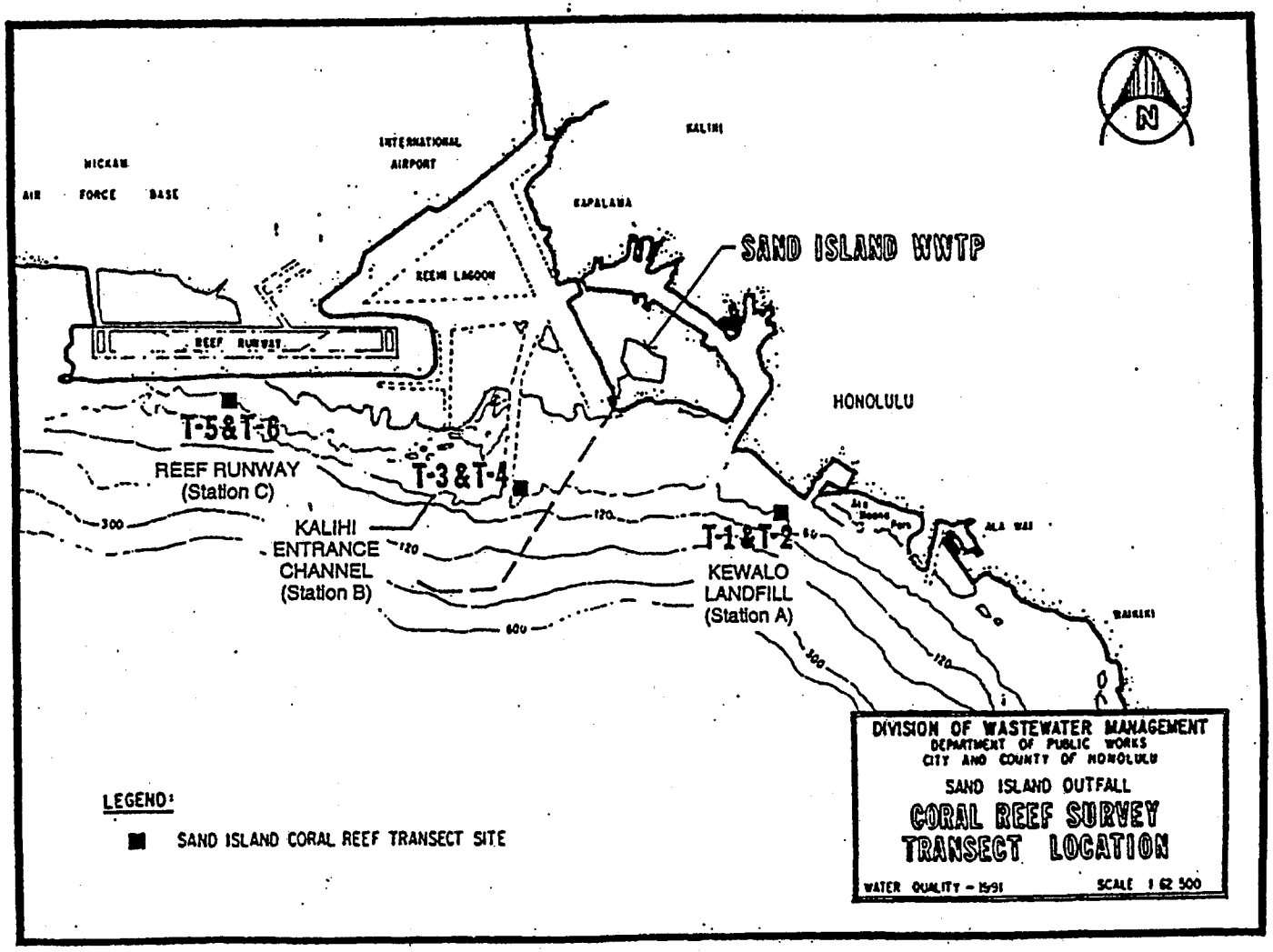
MATERIALS AND METHODS

The quantitative sampling of macrofauna of marine communities presents a number of problems; many of these are related to the scale on which one wishes to quantitatively enumerate organism abundance. Marine communities in the waters fronting Sand Island may be spatially defined in a range on the order of a few hundred square centimeters (such as the community living 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.

Three stations were selected for the monitoring of benthic and fish community response to possible sewage impacts. Their approximate locations are shown in Figure 1. The stations are close to some stations previously used by Dollar (1979). The stations and the rationale for their selection are given below:

Station A — (Kewalo Landfill)	Utilized as a control area. This station lies east of the present deep-ocean outfall in 17.0 to 18.2 m of water. Prevailing currents create a westerly movement of sewage effluent (Dollar 1979), thus the shallow Kewalo Landfill area is probably not directly impacted. At this location, corals occur in areas of emergent limestone. Local coverage over short linear distances may exceed 30%. This station is in the vicinity of Dollar's (1979) station 2.
Station B — (Kalihi Channel)	Located about 120 m east of the Kalihi Entrance Channel in approximately 15.0 m of water. This station is about 900 m west of the bypass (old) outfall in an area heavily impacted by the old (1955 to 1977) shallow-water discharge and is very close to Dollar's (1979) station 14. There is emergent limestone at this station, but coral coverage is low (less than 1%).
Station C — (Reef Runway)	Located in an area of complex limestone substratum in water ranging from 7.5 to 12.0 m in depth fronting Honolulu International Airport's Reef Runway. This station is located close to Brock's (1986) station that was monitored quarterly in 1977–78 (AECOS, Inc. 1979) and again in 1986. It is close to Dollar's (1979) station 19. This station was moderately impacted by the old shallow-water sewage outfall (Dollar 1979).

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 perpendicular to shore. Two transects were established at each location to provide some replication. Both sample approximately the same benthic communities. On each transect are five permanently marked locations (0 m, 5 m, 10 m, 15 m, and 20 m) for the taking of



Map courtesy of Oceanographic Team, Department of Wastewater Management, City and County of Honolulu.

FIGURE 1. General locations of the three permanent stations (two transects per station) sampled in this study. Station A is at the Kewalo Landfill, where Transects T-1 and T-2 were established; Station B is at the Kalihi Entrance Channel, where Transects T-3 and T-4 were established; and Station C is at the Reef Runway, where Transects T-5 and T-6 were established. The present deep-ocean outfall is shown as a dashed line.

photographs of the benthic communities. Cover estimates were also made in the field with a 1 m × 1 m quadrat placed at the -1 to 0 m, 4 to 5 m, 9 to 10 m, 14 to 15 m, and 19 to 20 m marks on the transect line in each survey.

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 to be adequate for sampling many Hawai'i benthic communities (see Brock 1982; Brock and Norris 1989) is used.

Information is collected at each transect location using methods including a visual assessment of fishes, benthic quadrats for cover estimates of sessile forms (e.g., algae, corals, and colonial invertebrates), and counts along the transect line for diurnally exposed motile macroinvertebrates. 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 notes all fishes in the prescribed area (method modified from Brock 1954). Besides counting the numbers of individuals of all fishes seen, the length of each is estimated for later use in the estimation of fish standing crop by 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, Naval Undersea Center (see Evans 1974), and the Hawai'i Division of Aquatic Resources using weight and body measurements of captured fishes; for many species the coefficients have been developed using sample sizes in excess of a hundred individuals. For the 1990 survey two weeks were allowed to elapse from the time of station selection and marking to the time of the first fish census to reduce the bias caused by wary fishes. The same individual (the author) performs all fish censuses to reduce bias.

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 'āweoweo (family Priacanthidae). This problem is compounded in areas of high relief and coral coverage that afford numerous shelter sites. Species lists and abundance estimates are more accurate for areas of low relief, although some fishes with cryptic habits or protective coloration, such as scorpionfishes or nohu (family Scorpaenidae) and flatfishes (family Bothidae), might still be missed. Another problem is the reduced effectiveness of the visual census technique in turbid water. This is compounded by the difficulty of counting fishes that move quickly or are very numerous. Additionally, bias related to the experience of the census taker should be considered in making comparisons between surveys. Despite these problems, the visual census technique

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) and the placing of 1 m × 1 m quadrats at marked locations for repeated measurements. Both the photographs and quadrats are used to estimate coverage of corals and other sessile forms. Photographs, which provide a permanent record from which to estimate coverage, were used in the eight most recent surveys (1991 through 1998); the 1 m × 1 m quadrats were used for an in-the-field appraisal of coverage in all surveys. Cover estimates from photographs and quadrats are all recorded as percent cover. 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.

Macrothalloid algae encountered in the 1 m × 1 m quadrats or photographs 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 while in the field. 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.

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

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

RESULTS

Field sampling was first undertaken on 27–29 December 1990. Station locations were selected and marked in November 1990. The permanent pins were deployed about a week

later. Figure 1 shows the approximate locations of the three stations, each with a pair of transects. Figures 2, 3, and 4 are sketches showing the orientation of the permanent photographic quadrats on each transect line. Data were collected from the same locations as follows: 1991 data on 5–6 December 1991; 1992 data on 21–22 December 1992 and 25 January 1993; 1993 data on 7–8 September 1993; 1994 data on 20 September and 13–14 October 1994; 1995 data on 28 August and 7 September 1995; 1996 data on 26 and 29 August as well as 20–21 November 1996; 1997 data on 14, 15, and 18 August as well as 11 and 23 September 1997; and 1998 data on 12 and 28 August as well as 10 and 16 September 1998.

Malfunction of a new Nikonos V camera caused the loss of all photographic quadrat data for all stations in the first (1990) field effort. Subsequently, the annual photography effort has been carried out by members of the Oceanographic Team, Department of Environmental Services (name change effective 1 July 1998), City and County of Honolulu. However, the 1990 visually assessed square-meter-quadrat survey provided information on benthic coverage. Subsequent surveys have used both photographic and quadrat methods to assess the benthic communities. It should be noted that the numbering of photo quadrats has changed since the 1991 survey, but the locations remain the same.

The results are presented below by station.

Station A – Kewalo Landfill

Station A is located 600 m offshore of the old Kewalo Landfill in water ranging from 17.0 to 18.2 m in depth on a substratum dominated by limestone with moderate coral community development. The two transects are 35 m apart, out of visual range of one another (see Figure 2). Water clarity at this station usually ranges from 15 to 20 m.

A summary of the data collected at Transect T-1 on 28 August 1998 is presented in Table 1. In the quadrat survey, five coral species having a mean estimated coverage of 26.3% were encountered; the dominant species were *Porites lobata* and *Pocillopora meandrina.* Three algal species (*Amansia glomerata*, *Spyridia filamentosa*, and *Porolithon onkodes*) having a mean coverage of 4.0% were noted in the quadrats, as was the red sponge *Spirastrella coccinea* with a mean coverage of 0.9%. The macroinvertebrate census noted the Christmas tree worm *Spirobranchus giganteus corniculatus*; the rock oyster *Spondylus tenebrosus*; the boring bivalve *Lithophaga* sp., two cone shells (*Conus miles* and *Conus lividus*), the pearl oyster *Pinctada margaritifera*; and two echinoderm species (the banded sea urchin or wana [*Echinothrix calamaris*] and the green sea urchin *Echinometra mathaei*). The results of the fish census carried out at Transect T-1 are summarized in Table 1 and given in detail in the Appendix. Table 2 presents the results of the photographic survey carried out on 10 September

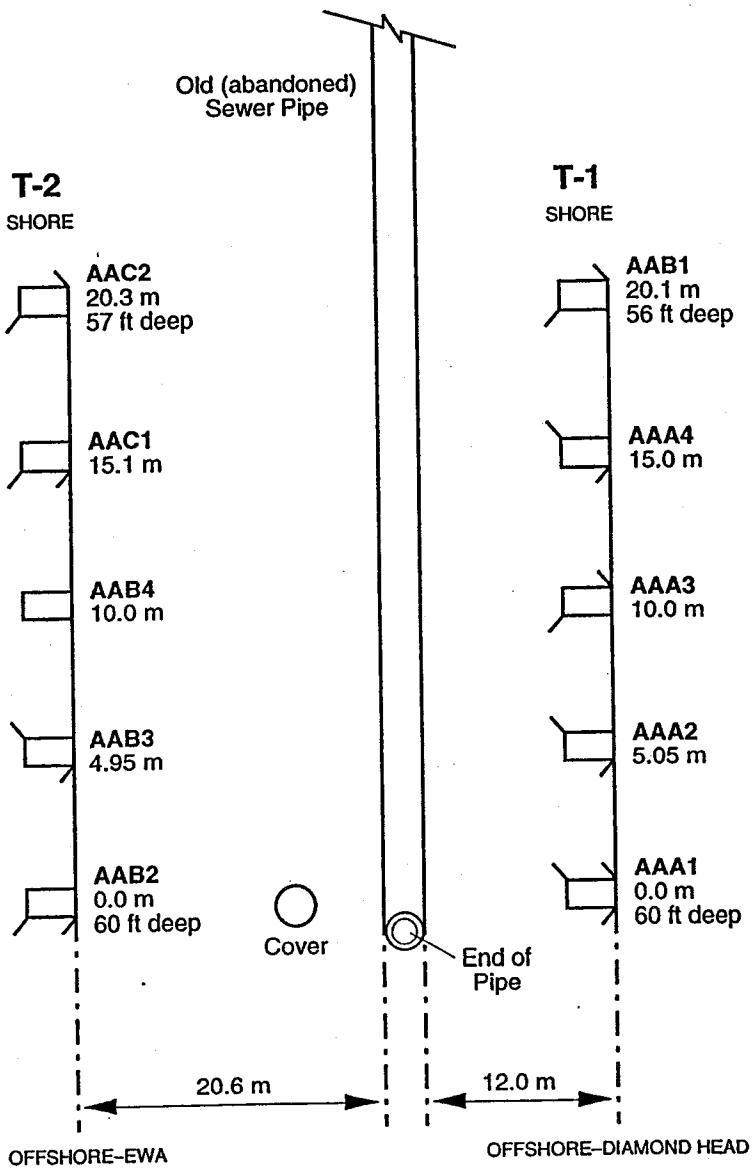


FIGURE 2. Sketch depicting locations of five photographic quadrats each on Transects T-1 and T-2, located offshore of the Kewalo Landfill (Station A) adjacent to an abandoned sewer line

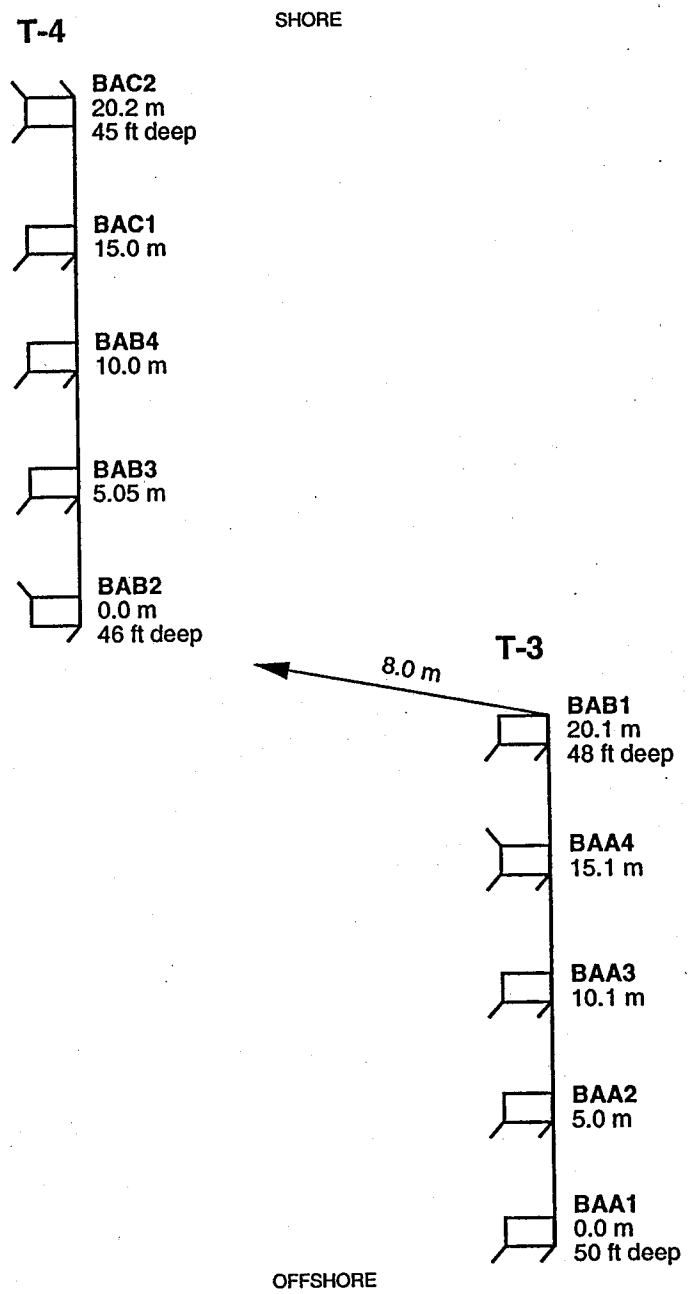


FIGURE 3. Sketch depicting locations of five photographic quadrats on Transects T-3 and T-4, located adjacent to the Kalihi Entrance Channel (Station B)

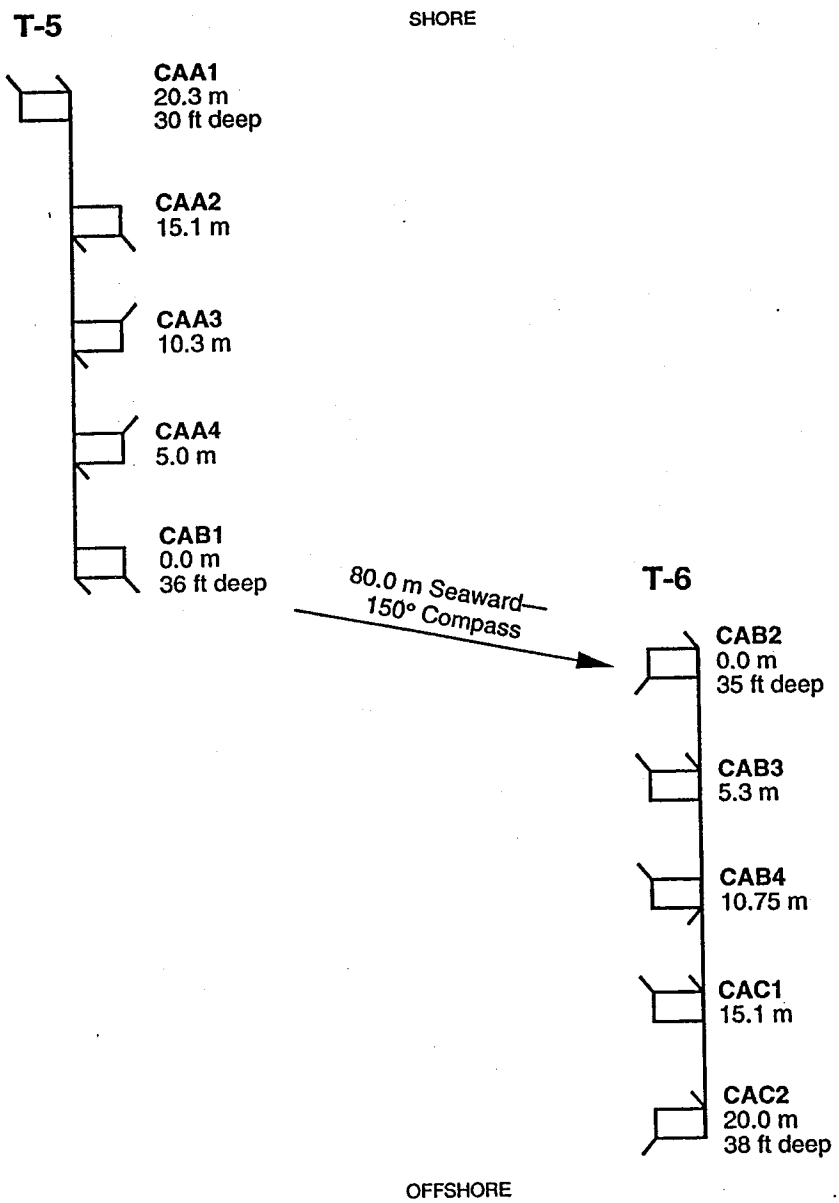


FIGURE 4. Sketch depicting locations of five photographic quadrats each on Transects T-5 and T-6, located offshore of the Honolulu International Airport Reef Runway (Station C)

TABLE 1. Summary of Biological Observations Made at Transect T-1, Offshore of Kewalo Landfill (Station A) on 28 August 1998

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Amansia glomerata	1.1				
Spyridia filamentosa		0.9		13.0	4.0
Porolithon onkodes				1.0	
Sponges					
Spirastrella coccinea	1.2				3.5
Corals					
Porites lobata	43.0	14.5	0.6	18.0	10.3
Porites compressa				1.5	
Pocillopora meandrina	3.5	9.0	4.8	13.5	9.0
Montipora verrucosa	0.1	0.2	1.2	0.3	
Montipora patula		0.9	0.2	0.8	
Sand	1.0		3.0	2.0	4.0
Rubble	9.0		15.0	3.0	21.0
Hard Substratum	41.1	74.5	75.2	46.9	48.2

II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals
Phylum Annelida	
Spirobranchus giganteus corniculatus	29
Phylum Mollusca	
Spondylus tenebrosus	1
Lithophaga sp.	1
Conus miles	1
Conus lividus	1
Pinctada margaritifera	1
Phylum Echinodermata	
Echinothrix diadema	77
Echinometra mathaei	1

III. Fish Census (4 m × 20 m)

34 Species
324 Individuals
Estimated Standing Crop = 151 g/m^2

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth ranges from 17.4 to 18.2 m; mean coral coverage is 26.3% (quadrat method).

TABLE 2. Summary of Results for the Photographic Quadrat Survey for 1998

Station A: Transect T-1 (Sampled 10 September 1998)	Photographic Quadrat				
	AAA1 (0 m)	AAA2 (5 m)	AAA3 (10 m)	AAA4 (15 m)	AAB1 (20 m)
Corals					
Porites lobata	32.8	10.1	0.8	23.0	5.9
Porites compressa				0.8	
Pocillopora meandrina	1.7	7.3	4.8	9.0	12.9
Montipora sp.				1.0	
Sand	1.4	0.6	2.8		0.8
Rubble	5.0		7.0		9.8
Hard Substratum	59.1	82.1	84.6	66.9	70.6

Mean Coral Coverage = 22.0%

Station A: Transect T-2 (Sampled 10 September 1998)	Photographic Quadrat				
	AAB2 (0 m)	AAB3 (5 m)	AAB4 (10 m)	AAC1 (15 m)	AAC2 (20 m)
Unidentified red sponge (probably *Spirastrella coccinea*)			1.1	0.3	
Unidentified grey sponge (probably *Plakortis simplex*)	0.1				
Corals					
Porites lobata	26.9	10.6	36.1	22.4	14.6
Porites compressa			4.5		
Pocillopora meandrina	1.7	5.0	3.9	3.6	4.5
Hard Substratum	71.3	84.3	54.3	73.7	81.0

Mean Coral Coverage = 26.8%

Station B: Transect T-3 (Sampled 10 September 1998)	Photographic Quadrat				
	BAA1 (0 m)	BAA2 (5 m)	BAA3 (10 m)	BAA4 (15 m)	BAB1 (20 m)
Unidentified grey sponge (probably *Plakortis simplex*)					4.8
Unidentified red sponge (probably *Spirastrella coccinea*)	0.1		0.3	0.1	0.1
Corals					
Porites lobata		1.7	0.8		
Pocillopora meandrina		0.6			
Montipora sp.			0.3		
Sand	7.0	5.3	2.5	2.5	2.5
Rubble		4.2		4.2	
Hard Substratum	92.9	88.2	96.1	93.1	92.6

Mean Coral Coverage = 0.7%

TABLE 2—*Continued*

Station B: Transect T-4 (Sampled 10 September 1998)	Photographic Quadrat				
	BAB2 (0 m)	BAB3 (5 m)	BAB4 (10 m)	BAC1 (15 m)	BAC2 (20 m)
Unidentified red sponge (probably *Spirastrella coccinea*)	0.1	0.1			0.6
Corals					
Porites lobata		11.5	1.1	0.8	0.8
Pocillopora meandrina	0.3		0.3	4.2	5.6
Sand	2.5	1.4	2.5	1.4	
Rubble	6.2	11.2		4.2	3.6
Hard Substratum	90.9	75.8	96.1	89.4	89.4

Mean Coral Coverage = 4.9%

Station C: Transect T-5 (Sampled 10 September 1998)	Photographic Quadrat				
	CAB1 (0 m)	CAA4 (5 m)	CAA3 (10 m)	CAA2 (15 m)	CAA1 (20 m)
Algae					
Porolithon onkodes		19.6	9.8	8.1	8.4
Soft Corals					
Palythoa tuberculosa		0.6			2.5
Corals					
Pocillopora meandrina			1.4	2.0	4.8
Pavona duerdeni				2.2	
Montipora sp.	0.6	2.0	0.6	0.6	0.3
Sand	0.8				
Rubble	98.6	7.6	17.4	18.5	
Hard Substratum		70.3	70.9	68.6	84.0

Mean Coral Coverage = 2.9%

Station C: Transect T-6 (Sampled 11 September 1998)	Photographic Quadrat				
	CAB2 (0 m)	CAB3 (5 m)	CAB4 (10 m)	CAC1 (15 m)	CAC2 (20 m)
Algae					
Porolithon onkodes	10.1			4.5	1.7
Corals					
Porites lobata	8.7			7.8	
Pocillopora meandrina	1.4	1.1		1.7	0.6
Montipora sp.	1.7	2.5		2.0	0.8
Sand		0.8	0.8		
Rubble		78.7		4.2	71.4
Hard Substratum	78.2	16.8	99.2	79.8	25.5

Mean Coral Coverage = 5.7%

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

1998. Mean coral coverage in the photographic survey was estimated at 22.0%, with *Porites lobata* being the dominant coral.

In total 34 species of fishes representing 324 individuals were encountered on Transect T-1. The most common species included the sleek unicornfish or kala holo (*Naso hexacanthus*), the bluelined surgeonfish or maiko (*Acanthurus nigroris*), the saddleback wrasse or hīnālea lauwili (*Thalassoma duperrey*), the black damselfish or 'ālo'ilo'i (*Dascyllus albisella*), the sergeant major or mamo (*Abudefduf abdominalis*), and the palenose parrotfish or uhu (*Scarus psittacus*). The standing crop of fishes on this transect was estimated at 151 g/m^2. The species contributing most heavily to this biomass were *S. psittacus* (20% of the total) and *T. duperrey* (17% of the total).

Transect T-2 was established 35 m west of Transect T-1 in water ranging from 17.0 to 18.2 m in depth. A summary of the biological information collected on this transect is presented in Table 3. Three algal species (*Amansia glomerata*, *Liagora tetrasporifera*, and *Porolithon onkodes*) having a mean coverage of 2.1% were noted in the quadrat survey. Also seen were the red sponge *Spirastrella coccinea* and the grey sponge *Plakortis simplex* with a mean coverage of 0.7%, the soft coral *Anthelia edmondsoni* with a coverage of 0.1%, and six coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora verrucosa*, *M. patula*, and *Leptastrea purpurea*) having an average coverage of 49.0%. The largest contributor to this coverage was *P. lobata.* The macroinvertebrate census noted two mollusk species (the rock oyster *Spondylus tenebrosus* and the boring bivalve *Lithophaga* sp.), one polychaete species (*Spirobranchus giganteus corniculatus*), and four sea urchin species (*Echinothrix diadema*, *E. calamaris*, *Tripneustes gratilla*, and *Echinometra mathaei*). The photographic quadrat survey carried out on 10 September 1998 noted both red and grey sponge species (probably *Spirastrella coccinea* and *Plakortis simplex*) and three coral species with a mean coverage of 26.8% (Table 2).

The results of the fish census are presented in the Appendix. Twenty-seven fish species representing 140 individuals were censused on this transect; the most abundant species included the yellowstripe goatfish or weke (*Mulloidichthys flavolineatus*), the smalltail wrasse *Pseudojuloides cerasinus*, and the palenose parrotfish or uhu (*Scarus psittacus*). The standing crop of fishes was estimated at 132 g/m^2, and the species that contributed the most were the school of *M. flavolineatus* (66% of the total) and *S. psittacus* (9% of the total).

Station B – Kalihi Entrance Channel

Station B is located about 2.2 km seaward of Mokauea Island, which is situated in Ke'ehi Lagoon, and about 900 m west of the old outfall, which is now used as an emergency bypass.

TABLE 3. Summary of Biological Observations Made at Transect T-2, Offshore of Kewalo Landfill (Station A) on 28 August 1998

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Amansia glomerata	1.0			7.0	
Porolithon onkodes			2.5		
Liagora tetrasporifera				0.1	
Sponges					
Spirastrella coccinea	0.6		2.5	0.3	
Plakortis simplex	0.3				
Soft Corals					
Anthelia edmondsoni		0.7			
Corals					
Porites lobata	33.0	46.0	32.0	43.0	63.0
Porites compressa		1.4	3.1	2.3	3.5
Pocillopora meandrina	0.5	0.6	3.4	5.0	1.0
Montipora verrucosa	0.1			0.2	0.3
Montipora patula	0.6	2.5	3.0	0.9	
Leptastrea purpurea					0.5
Sand			1.0		
Rubble			4.0	3.0	2.0
Hard Substratum	63.9	47.8	49.5	38.2	29.7

II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals
Phylum Mollusca	
Spondylus tenebrosus	1
Lithophaga sp.	2
Phylum Annelida	
Spirobranchus giganteus corniculatus	54
Phylum Echinodermata	
Echinothrix calamaris	1
Echinothrix diadema	132
Echinometra mathaei	3
Tripneustes gratilla	2

III. Fish Census (4 m × 20 m)

27 Species
140 Individuals
Estimated Standing Crop = 132 g/m^2

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth ranges from 17.0 to 18.2 m; mean coral coverage is 49.0% (quadrat method).

The two transects at this station were established on a limestone substratum about 120 m east of the Kalihi Entrance Channel in water ranging from 13.7 to 15.0 m in depth. Much of the substratum in the vicinity of this station is composed of sand and rubble. An area of low emergent limestone approximately 60 m wide × 110 m long, with the long axis oriented perpendicular to shore, is present. Transect T-3 is located on the deeper end of this hard substratum area. Transect T-4 is parallel to but shoreward and approximately 8 m to the west of Transect T-3 (see Figure 3). The lack of appropriate hard substratum at this station necessitated establishing the two transects in an end-to-end fashion relatively close to one another (8 m apart). Because of this proximity, the fish censuses on both transects at this station are carried out prior to any other data collection. During our 1998 survey water clarity at this station was greater than 15.1 m (Table 4).

Transect T-3 has an orientation that is perpendicular to shore on the limestone substratum in water ranging from 14.6 to 15.0 m in depth. A summary of the biological observations made at Transect T-3 is presented in Table 5. The quadrat survey noted one algal species (*Lyngbya majuscula*) with a mean coverage of 0.1%, three sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and *Plakortis simplex*) with a mean coverage of 1.6%, two soft coral species (*Anthelia edmondsoni* and *Palythoa tuberculosa*) having a mean coverage of 0.2%, and five coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa*, *M. patula*, and *M. verrilli*) having a mean estimated coverage of 2.5%. The macroinvertebrate survey noted the cone shell *Conus lividus*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, the polychaete tubeworm *Vermiliopsis* sp., and four echinoderm species (*Linckia diplax*, *Pseudoboletia indiana*, *Echinothrix calamaris*, and *E. diadema*). The photographic quadrat survey found two unidentified sponge species (probably *Plakortis simplex* and *Spirastrella coccinea*) with a mean coverage of 1.1% and three coral species (*Porites lobata*, *Pocillopora meandrina*, and *Montipora* sp.) having a mean coverage of 0.7% (up 0.1% from the last survey).

The fish census found 23 species representing 120 individuals and an estimated standing crop of 74 g/m^2 (Appendix). The most abundant fishes at Transect T-3 included the black damselfish or ʻālo‘ilo‘i (*Dascyllus albisella*) and the damselfish *Chromis vanderbilti*. The fish species contributing heavily to the biomass on Transect T-3 included the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*—37% of the total), the spotted unicornfish or kala lolo (*Naso brevirostris*—16% of the total), and two tableboss or ‘a‘awa (*Bodianus bilunulatus*—15% of the total).

Transect T-4 sampled the benthic and fish communities present in the vicinity of the Kalihi Entrance Channel. This transect sampled the limestone substratum at a depth ranging from 13.7 to 14.0 m. A summary of the biological data collected on 28 August 1998 is

TABLE 4. Summary of Physical Measurements Made at Each of Three Locations in the Vicinity of the Transect Pairs on 6 December 1991, 22 December 1992, 9 September 1993, 14 October 1994, 26 September 1995, 21 November 1996, 15 August 1997, and 28 August 1998

Location and Time	Oxygen (% Saturation)		Salinity (‰)	Temperature (°C)		Depth to Secchi Extinction (m)
	Top	Bottom		Top	Bottom	
6 DECEMBER 1991						
Kewalo Landfill 1035 hr	102	101	34	25.1	25.1	>18.3
Kalihi Entrance Channel 1100 hr	101	101	34	25.0	25.1	>15.1
Reef Runway 1150 hr	102	102	34	25.1	24.9	>12.0
22 DECEMBER 1992						
Kewalo Landfill 0900 hr	105	104	34	22.8	22.8	>18.3
Kalihi Entrance Channel 1000 hr	104	104	34	22.8	22.7	>15.1
Reef Runway 1035 hr	102	104	34	22.6	22.8	>12.0
9 SEPTEMBER 1993						
Kewalo Landfill 0830 hr	103	104	34	25.1	25.0	>18.3
Kalihi Entrance Channel 0910 hr	103	102	34	24.9	25.2	>15.1
Reef Runway 1020 hr	104	104	34	25.1	25.1	>12.0
14 OCTOBER 1994						
Kewalo Landfill 0835 hr	103	103	34	25.4	25.1	>18.3
Kalihi Entrance Channel 0920 hr	104	103	34	25.3	25.2	>15.1
Reef Runway 1030 hr	103	103	34	25.3	25.4	>12.0
26 SEPTEMBER 1995						
Kewalo Landfill 0900 hr	104	103	34	26.2	26.2	>18.3
Kalihi Entrance Channel 0950 hr	102	102	34	26.0	26.2	>15.1
Reef Runway 1115 hr	103	104	34	25.9	26.1	>12.0

TABLE 4—*Continued*

Location and Time	Oxygen (% Saturation)		Salinity (‰)	Temperature (°C)		Depth to Secchi Extinction (m)
	Top	Bottom		Top	Bottom	
21 NOVEMBER 1996						
Kewalo Landfill 0815 hr	102	104	34	26.1	26.0	>18.3
Kalihi Entrance Channel 0950 hr	103	102	34	26.0	26.2	>15.1
Reef Runway 1145 hr	102	103	34	26.2	26.1	>12.0
15 AUGUST 1997						
Kewalo Landfill 0820 hr	102	102	34	26.3	25.7	>18.3
Kalihi Entrance Channel 1000 hr	101	102	34	26.0	25.8	>15.1
Reef Runway 1200 hr	102	101	34	25.9	25.7	>12.0
28 AUGUST 1998						
Kewalo Landfill 0820 hr	101	102	34	25.7	25.5	>18.3
Kalihi Entrance Channel 1100 hr	102	102	34	26.0	25.6	>15.1
Reef Runway 1530 hr	101	102	34	25.6	25.7	>12.0

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

TABLE 5. Summary of Biological Observations Made at Transect T-3, East of the Kalihi Entrance Channel (Station B, about 2.2 km Offshore of Mokauea Island in Ke'ehi Lagoon) on 28 August 1998

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Lyngbya majuscula	0.3	0.2			
Sponges					
Spirastrella coccinea	0.1	0.7	1.2	1.4	1.1
Plakortis simplex					3.2
Chondrosia chucalla	0.1				
Soft Corals					
Anthelia edmondsoni			0.1	0.3	
Palythoa tuberculosa			0.4		
Corals					
Porites lobata	3.0	0.5	1.0	0.4	1.1
Pocillopora meandrina	0.5	0.7	1.4	1.3	
Montipora verrucosa			0.2	0.2	0.1
Montipora patula			1.6		0.2
Montipora verrilli					0.2
Sand	21.0	15.0	3.0	6.0	3.0
Rubble	6.0	12.0	1.0	14.0	4.0
Hard Substratum	61.0	70.9	90.1	76.4	87.1

II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals
Phylum Mollusca	
Conus lividus	1
Phylum Annelida	
Spirobranchus giganteus corniculatus	23
Vermiliopsis sp.	1
Phylum Echinodermata	
Echinothrix diadema	16
Echinothrix calamaris	12
Linckia diplax	1
Pseudoboletia indiana	1

III. Fish Census (4 m × 20 m)

23 Species
120 Individuals
Estimated Standing Crop = 74 g/m^2

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth ranges from 14.6 to 15.0 m; mean coral coverage is 2.5% (quadrat method).

presented in Table 6. The quadrat survey noted one algal species (limu kohu or *Asparagopsis taxiformis*) with a mean coverage of 0.02%, two sponge species (*Spirastrella coccinea* and *Chondrosia chucalla*) having a mean coverage of 0.8%, one soft coral species (*Anthelia edmondsoni*) with a mean coverage of 0.06%, and four coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa*, and *M. patula*). Coral coverage was estimated at 9.3% (up 3.5% from the last survey), with *Porites lobata* and *Pocillopora meandrina* being the major contributors. The macroinvertebrate census noted the brown hermit crab *Aniculus strigatus*, the Christmas tree worm *Spirobranchus giganteus corniculatus*, the featherduster worm *Sabellastarte sanctijosephi*, and five sea urchin species (*Echinostrephus aciculatum*, *Echinometra mathaei*, *Tripneustes gratilla*, *Echinothrix calamaris*, and *E. diadema*). In the photographic quadrat survey one sponge species (probably *Spirastrella coccinea*) with a mean coverage of 0.2% and two coral species (*Porites lobata* and *Pocillopora meandrina*) having a mean coverage of 4.9% were seen.

The fish census noted 88 individual fishes among 20 species (Appendix). The most common fishes present on this transect included the damselfish *Chromis vanderbilti* and the smalltail wrasse *Pseudojuloides cerasinus*. The standing crop of fishes on Transect T-4 was estimated at 42 g/m^2, with the important contributors including a single zebra moray or puhi (*Gymnomuraena zebra*—14% of the total), the manybar goatfish or moano (*Parupeneus multifasciatus*—17% of the total), and the orangebar surgeonfish or na'ena'e (*Acanthurus olivaceus*—31% of the total).

Station C – Reef Runway

Station C lies between 760 and 840 m seaward of the runway in water ranging from 7.5 to 12.0 m in depth. The substratum of this area is a mosaic of emergent limestone spur and groove formations grading seaward into a series of low limestone mounds. The general orientation of the spur and groove formations is perpendicular to the shoreline and direction of usual wave impact. The spurs, which are 5 to 40 m in width and 30 to 80 m in length, are spaced from 10 to 100 m apart. Sand is the dominant substratum in the intervening areas. The maximum topographical relief formed by these spurs is about 3.5 m. Just seaward of this is a zone of low emergent limestone where "patches" of hard bottom 5 m × 10 m to several hundred square meters in size are present. Spacing between these limestone areas is 10 to 50 m; again, sand is found in the intervening areas. Corals are restricted to the areas of hard substratum. Water clarity at this station was about 12 m during our 1998 visit; usually clarity here does not exceed 12 m. On 28 August 1998, the depth to secchi disk extinction was greater than the water depth (i.e., more than 12 m, see Table 4).

TABLE 6. Summary of Biological Observations Made at Transect T-4, East of the Kalihi Entrance Channel (Station B, about 2.2 km Offshore of Mokauea Island in Ke'ehi Lagoon) on 28 August 1998

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Asparagopsis taxiformis					0.1
Sponges					
Spirastrella coccinea	1.0	0.3	0.1	0.8	1.3
Chondrosia chucalla	0.3				
Soft Corals					
Anthelia edmondsoni	0.1			0.1	0.1
Corals					
Porites lobata	1.0	24.0	1.7	1.0	3.1
Pocillopora meandrina	1.1	0.1	0.3	3.7	6.2
Montipora verrucosa	0.1	0.3		0.2	
Montipora patula	0.4	2.4	0.2		0.5
Sand	12.0	3.0	3.0	12.0	8.0
Rubble	8.0		2.0	5.0	3.0
Hard Substratum	76.0	69.9	92.7	77.2	77.7

II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals
Phylum Arthropoda	
Aniculus strigatus	1
Phylum Annelida	
Spirobranchus giganteus corniculatus	28
Sabellastarte sanctijosephi	1
Phylum Echinodermata	
Echinostrephus aciculatum	4
Echinothrix calamaris	7
Echinothrix diadema	9
Echinometra mathaei	2
Tripneustes gratilla	1

III. Fish Census (4 m × 20 m)

20 Species
88 Individuals
Estimated Standing Crop = 42 g/m^2

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth ranges from 13.7 to 14.0 m; mean coral coverage is 9.3% (quadrat method).

Hurricane Iniki, which occurred in September 1992, caused considerable damage to the benthic communities at Station C. A large (approximately 60 m in diameter) sand patch located between Transects T-5 and T-6 had largely been replaced by coral rubble. Much of the hard substratum on both transects was broken and the underlying limestone rock exposed, and crevices and holes were filled in with coral rubble. These physical changes noted in the September 1992 survey were much the same in the August 1998 survey.

Transects T-5 and T-6 were established on spurs or ridges of limestone (see Figure 4). Transect T-5 was established on a limestone ridge at a depth of 9.1 to 11.0 m. Table 7 presents the results of the biological survey carried out at Transect T-5. The quadrat survey noted four algal species (*Porolithon onkodes*, *Desmia hornemannii*, *Tolypiocladia* sp., and *Sphacelaria furcigera*) having a mean coverage of 2.4%, one sponge species (*Chondrosia chucalla*) with a mean coverage of 0.02%, two soft coral species (*Palythoa tuberculosa* and *Anthelia edmondsoni*) with a mean coverage of 0.8%, and eight coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Psammocora stellata*, *Montipora patula*, *M. verrilli*, *Pavona varians*, and *P. duerdeni*) having a mean coverage of 5.1%. This coverage is up from 3.6% in the previous survey. The invertebrate census found the rock oyster *Spondylus tenebrosus* and three sea urchin species (*Echinometra mathaei*, *Echinothrix diadema*, and *Tripneustes gratilla*) in the transect area. The photographic quadrat survey completed on 10 September 1998 (Table 2) noted one algal species (the crustose coralline alga *Porolithon onkodes*) with a mean coverage of 9.2%; one soft coral species (*Palythoa tuberculosa*) with a mean coverage of 0.6%; and three coral species (*Pocillopora meandrina*, *Pavona duerdeni*, and *Montipora* sp.) having a mean estimated coverage of 2.9%, which is up 0.6% from last year.

The fish census (Appendix) noted 150 individuals among 22 species. The most common species included the brown surgeonfish or ma'i'i'i (*Acanthurus nigrofuscus*) and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fishes on Transect T-5 was estimated at 70 g/m^2, with the most important contributors including *C. strigosus* (27% of the total) and the manybar goatfish or moano (*Parupeneus multifasciatus*—14% of the total). Although not in the quadrats, the alga *Neomartensia flabelliformis* was seen in the transect area. This algal species identified by Dr. I. Abbott at the University of Hawaii is unusual and is not often encountered.

Transect T-6 was established approximately 80 m seaward of Transect T-5. The substratum at Transect T-6 was similar to that at Transect T-5 and is situated on a limestone spur that is about 40 m in width and 80 m in length. Water depth at this location varies between 10.7 and 11.6 m. A summary of the biological observations made on Transect T-6 is given in Table 8. The quadrat survey found two algal species (*Porolithon onkodes* and *Desmia hornemannii*) having a mean coverage of 0.7%, two sponge species (*Spirastrella coccinea* and

TABLE 7. Summary of Biological Observations Made at Transect T-5, Approximately 760 m Offshore of the Honolulu International Airport Reef Runway (Station C) on 12 August 1998

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Porolithon onkodes		3.0	2.0	4.0	1.0
Desmia hornemannii	0.1	0.2	0.5		
Tolypiocladia sp.	0.1		0.8		
Sphacelaria furcigera		0.2			
Sponge					
Chondrosia chucalla	0.1				
Soft Corals					
Anthelia edmondsoni		0.1			
Palythoa tuberculosa		0.8			3.0
Corals					
Porites lobata			0.5		
Porites compressa			0.2		
Psammocora stellata					0.1
Pocillopora meandrina		1.3	1.4	1.3	1.1
Montipora patula		0.4		3.3	2.1
Montipora verrilli			1.2		
Pavona varians		0.4			0.2
Pavona duerdeni				7.0	4.8
Sand	6.0				
Rubble	93.7	18.0	22.0	11.0	
Hard Substratum		75.6	71.4	73.4	87.7

II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals
Phylum Mollusca	
Spondylus tenebrosus	1
Phylum Echinodermata	
Echinothrix diadema	1
Tripneustes gratilla	1
Echinometra mathaei	2

III. Fish Census (4 m × 20 m)

22 Species
150 Individuals
Estimated Standing Crop = 70 g/m^2

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth ranges from 9.1 to 11.0 m; mean coral coverage is 5.1% (quadrat method).

TABLE 8. Summary of Biological Observations Made at Transect T-6, Approximately 840 m Offshore of the Honolulu International Airport Reef Runway (Station C) on 12 August 1998

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Porolithon onkodes	2.6				0.5
Desmia hornemannii		0.2	0.1		
Sponges					
Spirastrella coccinea			0.6		
Chondrosia chucalla			0.7		0.1
Soft Corals					
Anthelia edmondsoni				0.2	0.1
Palythoa tuberculosa					1.1
Corals					
Porites lobata	9.0			9.0	4.1
Pocillopora meandrina	3.6	1.1	1.2	2.0	1.1
Montipora patula	4.7	2.9	0.4	4.5	1.2
Montipora verrucosa				0.8	0.1
Pavona varians		1.0		0.3	
Sand		4.0	7.0		
Rubble		31.0	75.0	17.0	9.0
Hard Substratum	80.1	59.8	15.0	66.2	82.7

II. Macroinvertebrate Census (4 m × 20 m)	No. of Individuals
Phylum Mollusca	
Spondylus tenebrosus	1
Octopus cyanea	1
Phylum Arthropoda	
Aniculus strigatus	1
Charybdis orientalis	1
Phylum Annelida	
Loimia medusa	1
Spirobranchus giganteus corniculatus	3
Phylum Echinodermata	
Echinometra mathaei	5

III. Fish Census (4 m × 20 m)

29 Species
171 Individuals
Estimated Standing Crop = 89 g/m^2

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth ranges from 10.7 to 11.6 m; mean coral coverage is 9.4% (quadrat method).

Chondrosia chucalla) with a mean coverage of 0.3%, two soft coral species (*Anthelia edmondsoni* and *Palythoa tuberculosa*) with a mean coverage of 0.3%, and five coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora patula*, *M. verrucosa*, and *Pavona varians*) having a mean coverage of 9.4%. This coral coverage estimate is up 2.5% from the previous year. The census of macroinvertebrates noted seven species: the rock oyster *Spondylus tenebrosus*, the octopus or he'e (*Octopus cyanea*), the brown hermit crab *Aniculus strigatus*, the red swimming crab *Charybdis orientalis*, the polychaetes *Loimia medusa* and *Spirobranchus giganteus corniculatus*, and the green sea urchin *Echinometra mathaei*. The photo quadrat survey (Table 2) noted one algal species (*Porolithon onkodes*) with a mean coverage of 3.3% and three coral species (*Porites lobata*, *Pocillopora meandrina*, and *Montipora* sp.) with a mean coverage of 5.7%.

The fish census noted 171 individuals belonging to 29 species in the 4 m × 20 m area. The most abundant fishes on Transect T-6 included *Thalassoma duperrey*, *Scarus sordidus*, *Acanthurus nigrofuscus*, *Parupeneus multifasciatus*, and *Ctenochaetus strigosus*. The standing crop of fishes on this transect was estimated at 89 g/m^2, with the largest contributors including a single roi (*Cephalopholis argus*—15% of the total), forty-five *T. duperrey* (21% of the total), and two stareye parrotfish or pōnuhunuhu (*Calotomus carolinus*—14% of the total).

Physical Measurements and Biological Parameters

Physical measurements were made during the day on 28 August 1998. These data are presented in Table 4. Little variation was noted in temperature (25.5° to 26.0°C), percent oxygen saturation (101% to 102%), or salinity (all 34‰), despite the fact that measurements for oxygen and temperature were made both at the surface and about 1 m above the bottom. In all cases the secchi disk measurements did not yield an extinction value; water clarity was such that from the surface the disk was still plainly visible on the bottom. As has been suggested previously, 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 all nine surveys (1990 through 1998) are summarized as means for each transect in Table 9. The previous annual data are from Brock (1992a, 1992b, 1993, 1994, 1995, 1996, 1997, 1998). Differences are apparent for some of the parameters among the nine years. Some change is evident in the benthic measures (such as coral cover) between the 1991 and 1992 (pre- and post-hurricane) surveys, and this is to be expected. Despite these changes, the Kruskal–Wallis ANOVA shows that there has been no statistically significant change over the nine-year period except for the mean number of macroinvertebrate species per transect ($p > 0.05$, significant). The Student–Newman–Keuls multiple range test was used to

TABLE 9. Summary of Biological Parameters Measured at the Six Transect Locations in the Nine Annual Surveys

Parameter	1990 Transect (T-) 1	2	3	4	5	6	1991 Transect (T-) 1	2	3	4	5	6
% Coral Cover	18	30	4	3	2	10	18	29	4	3	2	7
No. of Coral Species	4	5	4	3	5	5	5	4	3	3	5	4
No. of Invertebrate Species	4	5	6	6	2	2	4	4	4	6	2	2
No. of Invertebrate Individuals	12	15	25	25	3	5	13	18	17	44	10	10
No. of Fish Species	38	37	24	16	29	31	31	26	22	12	28	29
No. of Fish Individuals	455	481	310	126	197	267	260	240	138	68	176	202
Fish Biomass (g/m^2)	763	824	91	30	129	293	148	221	72	20	101	183

Parameter	1992 Transect (T-) 1	2	3	4	5	6	1993 Transect (T-) 1	2	3	4	5	6
% Coral Cover	20	21	2	3	0.4	3	26	26	2	4	2	5
No. of Coral Species	6	6	4	4	4	6	6	7	5	4	5	6
No. of Invertebrate Species	6	5	6	5	3	3	8	7	6	6	2	4
No. of Invertebrate Individuals	15	12	21	14	7	6	22	20	12	12	6	6
No. of Fish Species	36	19	15	9	23	36	31	30	10	19	23	29
No. of Fish Individuals	312	153	33	27	136	247	343	150	43	63	152	247
Fish Biomass (g/m^2)	736	247	30	14	69	108	1,039	273	31	96	61	79

Parameter	1994 Transect (T-) 1	2	3	4	5	6	1995 Transect (T-) 1	2	3	4	5	6
% Coral Cover	26.2	31.4	1.6	3.9	1.9	8.3	23.1	37.8	1.7	3.6	3.5	5.3
No. of Coral Species	6	6	5	4	6	6	6	7	3	4	5	6
No. of Invertebrate Species	7	7	8	6	4	4	9	7	5	7	4	6
No. of Invertebrate Individuals	27	32	16	14	6	12	62	99	5	7	4	11
No. of Fish Species	27	22	13	9	26	27	37	37	17	19	32	34
No. of Fish Individuals	289	168	30	20	169	224	256	329	95	128	240	257
Fish Biomass (g/m^2)	726	723	27	23	63	86	301	457	27	25	77	93

TABLE 9—*Continued*

Parameter	1996						1997					
	Transect (T-)						Transect (T-)					
	1	2	3	4	5	6	1	2	3	4	5	6
% Coral Cover	27.3	33.8	2.6	4.6	3.7	6.6	27.6	40.0	2.5	5.8	3.6	6.9
No. of Coral Species	5	8	5	4	7	6	5	5	6	4	6	5
No. of Invertebrate Species	6	7	6	4	4	3	6	7	5	7	4	4
No. of Invertebrate Individuals	22	43	7	28	12	5	49	85	38	45	6	6
No. of Fish Species	33	27	25	11	19	30	37	28	24	13	27	28
No. of Fish Individuals	554	266	160	20	166	234	356	213	136	40	156	182
Fish Biomass (g/m^2)	444	868	157	15	72	83	602	720	35	9	71	71

Parameter	1998					
	Transect (T-)					
	1	2	3	4	5	6
% Coral Cover	26.3	49.0	2.5	9.3	5.1	9.4
No. of Coral Species	5	6	5	4	8	5
No. of Invertebrate Species	8	7	7	8	4	7
No. of Invertebrate Individuals	112	195	55	53	5	13
No. of Fish Species	34	27	23	20	22	29
No. of Fish Individuals	324	140	120	88	150	171
Fish Biomass (g/m^2)	151	132	74	42	70	89

NOTE: Each transect samples 80 m^2 of substratum for fishes and invertebrates other than corals. Coral data (given in percent cover) are from 5 m^2 of substratum sampled on each transect. Data for the 1990 through 1997 surveys are from Brock (1992a, 1992b, 1993, 1994, 1995, 1996, 1997, 1998).

separate those years that have statistically significant differences in the mean number of macroinvertebrate species per transect. This test noted that the 1998 survey had a significantly higher mean number of macroinvertebrates (6.8 individuals/transect) than found in the 1991 survey (3.7 individuals/transect, the lowest mean) and that the means for all other years were not statistically separable. Although the Kruskal–Wallis ANOVA did not note any significant differences among the different years, the Student–Newman–Keuls test showed that the mean number of invertebrate individuals censused per transect was statistically greater in 1998 (mean = 72 individuals/transect) than in the years from 1990 through 1994 and in 1996 (range from 12.5 to 19.5 individuals/transect). Other than the significant changes in the above two parameters, there have been no statistically significant changes from the 1990 survey through the 1998 field effort for mean coral cover on a transect ($p > 0.90$, df = 8, not significant), mean number of coral species on a transect ($p > 0.15$, df = 8, not significant), mean number of individual macroinvertebrates on a transect ($p > 0.58$, df = 8, not significant), mean number of fish species on a transect ($p > 0.61$, df = 8, not significant), mean number of individual fish on a transect ($p > 0.58$, df = 8, not significant), and mean standing crop of fishes on a transect ($p > 0.94$, df = 8, not significant). Other than those noted above, the Student–Newman–Keuls multiple range test demonstrated no statistically significant differences for these parameters among the six transects and nine sampling years.

The biological parameters measured in the nine surveys and summarized in Table 9 (i.e., number of coral species, percent coral cover, number of macroinvertebrate species, number of macroinvertebrate individuals, number of fish species, number of fish individuals, and biomass of fishes) point to the fact that the Kewalo Landfill station has the most diverse communities, followed by the Reef Runway station. The least diverse communities appear to be at the Kalihi Entrance Channel station. This hierarchy has not materially changed over the nine survey years; however, the high number of individual invertebrates counted at the Kalihi Entrance Channel station in 1998 is due primarily to more individual Christmas tree tubeworms being counted than previously. This tubeworm, *Spirobranchus giganteus corniculatus*, settles and lives on the coral *Porites lobata*. Although coral coverage is slowly increasing at the Kalihi Entrance Channel station, it probably does not fully explain the increase in abundance of this tubeworm at this station. The relatively low biological diversity at the Kalihi Entrance Channel station is not surprising in view of the fact that this station was heavily impacted by the old shallow-water outfall until 1978 and that there is not much topographic relief to provide shelter at this location.

From a commercial fisheries standpoint, a number of important species have been encountered consistently in the vicinity of the Kewalo Landfill and Reef Runway stations, including the yellowstripe goatfish or weke (*Mulloidichthys flavolineatus*), the yellowfin

goatfish or weke'ula (*Mulloidichthys vanicolensis*), the mackerel scad or 'ōpelu (*Decapterus macarellus*), and the brick soldierfish or menpachi (*Myripristis amaenus*). In some years the emperor fish or mu (*Monotaxis grandoculis*), the blue trevally or 'ōmilu (*Caranx melampygus*), and the grey snapper or uku (*Aprion virescens*) were also present.

Green Sea Turtle and Marine Mammal Observations

Prior to Hurricane Iniki, green sea turtles (*Chelonia mydas*) were usually seen in the vicinity of Transect T-6. These turtles have been absent in this area since the hurricane, probably due to the loss of resting habitat by infilling (i.e., the resting site was completely covered with coral rubble). The coral rubble continues to move about with each passing storm event. In 1994 coral rubble accounted for 10.2% of the substratum covered in the quadrats examined in the field. In September 1995 coralline rubble in these same quadrats covered 46.5% of the substratum, in November 1996 it covered 42.1%, in August 1997 it covered 52.1%, and in 1998, it covered 26.4%. The presence of this coralline rubble further decreases the availability of local shelter for fishes and invertebrates. During the August 1998 field work, green turtles were seen in other areas (about 200 m east of Transects T-5 and T-6). Also seen was a pod of approximately 25 spinner porpoises (*Stenella longirostris*) about 1 km offshore of the Reef Runway. The pod was seen east of the sampling station on 12 August 1998 at about 1400 hours. It appeared to be traveling in an easterly direction.

DISCUSSION

Since their delineation in December 1990, the six transects have been visited on a number of occasions to ensure that, among other things, the permanent markers are remaining in place. During these visits reconnaissance surveys are carried out in the areas surrounding the selected stations. At a minimum, these qualitative surveys cover about 4 hectares around each of the three stations. The resulting qualitative observations suggest that the marine communities sampled at the three stations are representative of those found in the surrounding areas.

The working hypothesis is that all three stations, being situated in relatively shallow water, are outside of the zone of influence of the present deep-ocean outfall. However, if impacts from the 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 up to 20 m deep in this study. Monitoring the

shallow-water stations provides additional information regarding the recovery of these communities from the perturbation of raw sewage released from the old shallow-water outfall from 1955 to 1977. Dollar's (1979) study showed that the Kewalo Landfill station was not directly impacted by discharge from the old outfall, but the Kalihi Entrance Channel station was "acutely" perturbed and the station offshore of the Reef Runway received an "intermediate" level of disturbance. Additionally, in the mid-1970s the construction of the Reef Runway must have contributed to the disturbance of benthic communities at this station (Chapman 1979). The result of these impacts is still evident in the average coral cover estimates made at these stations: the mean coverage offshore of the Kalihi Entrance Channel is only 3.5%, fronting the Reef Runway station it is 4.6%, and offshore of the Kewalo Landfill it is 28.4%.

The shallow marine ecosystem fronting Sand Island and Honolulu has received considerable perturbation from human activity over the last 100 years. Among the perturbations has been the disposal of raw sewage effluent in shallow water from the 1930s until 1977–78, when the deep-ocean outfall became operational. From 1955 through 1977 the shallow-water outfall released 62 mgd (3 m^3/s) of raw sewage. Dollar (1979) noted two distinct zones of impact to marine communities: the area of "acute" perturbation was an ellipse 500 m to the east and 1,000 m to the west of the outfall. Outside this area the impacts were evident in a decreasing gradient with distance from the outfall. The maximal extent of impact attributed to this sewage input was 1.9 km to the east and 5.8 km to the west of the outfall. The ellipsoid shape of the zone of influence was attributed to the predominant westerly direction of current flow.

The Kewalo Landfill station is 4.75 km east and inshore of the terminus of the outfall, the Kalihi Entrance Channel station is about 2.1 km east and inshore of the terminus, and the Reef Runway station is about 3.25 km inshore and west of the terminus (Figure 1). Presumably, the present outfall releases the sewage effluent below the pycnocline, and little interaction occurs with the inshore biota. Dollar's (1979) findings suggest that if the material is carried to inshore waters, impacts to shallow marine communities would occur in those communities situated primarily to the west of the outfall.

The Kewalo Landfill station serves as a control station in this study; although coral coverage and fish community development are greater at this location, the station has received perturbations in the past. The two transects (T-1 and T-2) that sample the Kewalo Landfill station are situated close to an old, nonoperable sewage discharge pipe. Operations utilizing this discharge pipe ceased sometime before 1955; the pipe was probably used sometime in the 1940s (A. Muranaka, Oceanographic Team, Division of Wastewater Management, City and County of Honolulu, 1990: personal communication). The development of Kewalo Basin and the entrance channel in the mid-1930s would have created considerable turbidity that probably

impacted this station, which is about 200 m west of the Kewalo Basin entrance channel. From a historical perspective, human-induced perturbations have probably occurred in all marine communities situated in shallow waters fronting Honolulu during the last 100 years. The Kewalo Landfill station was selected as the control station for this study because of its relatively diverse coral and fish communities, as well as its location well to the east of the present deep-ocean outfall (presumably out of the zone of influence).

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 south, east, and west shores of O'ahu, Kaua'i, Maui, Lāna'i, and Hawai'i; this damage was primarily to coral communities. In many areas a large amount of sand and other loose material was moved and/or advected out of the shallow areas (i.e., depths of less than 27 m) into deeper waters. On O'ahu, storm waves emanating from the southeast were estimated to exceed 7 m in height and were breaking in water at least 20 m deep (personal observations).

Storm damage to benthic and fish communities is frequently patchy, resulting in a mosaic of destruction (personal observations; Walsh 1983), and an occasional storm event generating high surf is one of the most important parameters in determining the structure of Hawai'i coral communities (Dollar 1982). 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 depths less than 30 m attest to the force and frequency of these events (Brock and Norris 1989). These same wave forces also impinge upon and impact fish communities (Walsh 1983).

Hurricane Iniki caused damage to coral communities at all three study sites. The greatest impact occurred to the benthic communities at Station C (Reef Runway), where portions of the *Porolithon*-covered substratum (up to 1 m × 2 m in area and up to 0.75 m in depth) were completely removed. Other areas 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 the increase in the number of coral species seen in some quadrats between the pre- (1991) and post-hurricane (1992 through 1998) surveys. This phenomenon (i.e., live fragments) also served to lessen the decrease in coral cover encountered in some of the quadrats where coverage was low prior to the storm. Despite these large changes, many of

the benthic components survived, and these communities are recovering well, as evidenced in the increases in coral cover. However, since Hawai'i corals are relatively slow growing, it will be years before the impact of the hurricane will no longer be evident in the benthic communities at the study sites.

The hurricane also impacted the fish communities at the sample sites. Coral rubble deposited in depressions serves to lessen the rugosity of the submarine topography (i.e., shelter) available to fishes. The loss of local shelter causes fishes to move and take up residence elsewhere. At the Reef Runway station, where considerable rubble was present, many of the resident fishes (such as the school of emperor fish or mu [*Monotaxis grandoculis*]) were no longer found on Transect T-6 after the hurricane. These fish had moved about 100 m east to an area where the coral and benthic communities remained relatively intact.

Despite the impact of Hurricane Iniki, the summary data in Table 9, which spans nine years (December 1990 to August 1998), show that there has been no statistically significant change in any of the biological parameters measured in this study other than for the mean number of invertebrate species and numbers of individuals encountered per transect. In these cases the data for 1998 showed significantly greater numbers of species and individuals over some other years. These changes are probably the result of higher than usual counts of the Christmas tree worm *Spirobranchus giganteus corniculatus* as well as just more species present at most stations. Despite the lack of significant change with the other parameters, several show high variability through time. Among these are the number of fish censused and the estimated standing crop of fish. These changes have been greatest at the Kewalo Landfill station. Relative to many other locations in the Hawaiian islands, the fish community is well developed at the Kewalo Landfill station. The high standing crop estimates in many years are much greater than for 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). Three explanations for the high biomass of fishes at the Kewalo Landfill station are (1) the shelter created by the old sewage discharge pipe and growth of coral on this pipe locally enhances the fish community, (2) chance encounters occur with roving predators or planktivorous and/or other schooling species during censuses, and (3) commencing in the summer of 1993 a scuba dive tour operation began feeding the fish in the vicinity of the pipe. The fish feeding has resulted in an aggregating effect of some species such as the yellowstripe goatfish or weke (*Mulloidichthys flavolineatus*), the bluelined snapper or ta'ape (*Lutjanus kasmira*), and the black triggerfish or humuhumu ele'ele (*Melichthys niger*).

Space and cover are important agents governing the distribution of coral reef fishes (Risk 1972; Sale 1977; Gladfelter and Gladfelter 1978; Brock et al. 1979; Ogden and Ebersole 1981; Anderson et al. 1981; Shulman et al. 1983; Shulman 1984; Eckert 1985; Walsh 1985; Alevizon

et al. 1985). Similarly, the standing crop of fishes on a reef is correlated with the degree of vertical relief of the substratum. Thus Brock (1954), using visual techniques on Hawai'i reefs, estimated the standing crop of fishes to range from 4 g/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. The additional topographical relief is usually in the form of artificial reefs, but any underwater structure (such as a deployed sewer line) will have a similar effect. The old sewage discharge pipe is set above the seafloor, creating considerable local topographical relief (about 2 m high) in an area where the maximum natural vertical relief does not exceed 25 cm. The shelter and high topographical relief must foster greater development of the fish community (see Brock and Norris 1989).

Chance encounters with large roving predators (such as the grey snapper or uku [*Aprion virescens*], the emperor fish or mu [*Monotaxis grandoculis*], the amberjack or kahala [*Seriola dumerili*], the blue trevally or 'ōmilu [*Caranx melampygus*], and the island jack or pāpio [*Caranx orthogrammus*]), schools of planktivorous fishes (such as the mackerel scad or 'ōpelu [*Decapterus macarellus*], the sleek unicornfish or kala holo [*Naso hexacanthus*], the spotted unicornfish or kala lolo [*N. brevirostris*], the milletseed butterfly fish or lauwiliwili [*Chaetodon miliaris*], and the sergeant major or mamo [*Abudefduf abdominalis*]), or other schooling species (such as the yellowstripe goatfish or weke [*Mulloidichthys flavolineatus*]) may greatly increase the counts and biomass at a particular transect. The presence of the sewage discharge pipe serves to focus numerous predators and schooling fishes in the vicinity of the two transects at the Kewalo Landfill station; hence, an encounter with these fishes during a census will result in high biomass estimates. In 1990, at Transect T-6 (Reef Runway) chance encounters with a small school of *Monotaxis grandoculis* accounted for 51% of the biomass there, whereas at Transect T-2 (Kewalo Landfill) chance encounters with *Naso hexacanthus* and *N. brevirostris* accounted for 40% of the biomass and with *Seriola dumerili* and *Caranx orthogrammus*, for 21% of the biomass. In 1991 *N. hexacanthus* and *N. brevirostris* and some predators were present around Transects T-1 and T-2 but did not enter the actual census area while the counts were being made, thus they do not appear in the data. In 1992 the large school of *M. flavolineatus* that is resident to the old sewage discharge pipe made up 78% and 93% of the biomass on Transect T-1 and Transect T-2, respectively; in 1993, 87% and 79%; in 1994, 31% and 44%; in 1995, 68% and 72%; in 1997, 71% and 81%; and in 1998, 0% and 66%.

In the 1996 census an interesting encounter was made with a roving school of juvenile yellowfin tuna or shibi (*Thunnus albacares*) on Transect T-2. These fishes remained in the general area for the duration of our underwater sampling on 20 November. The estimated weight of that part of the school entering the census area was 63.9 kg, accounting for 92% of

the standing crop at this transect. Encounters with tuna in shallow water are rather unusual, but if they do occur, it is usually in areas where fish communities are relatively well-developed, such as on artificial reefs. In general, these predaceous fishes are attracted to areas where there is a likelihood of encountering forage. The encounter with these tuna supports the point that the fish communities in the vicinity of the Kewalo transects are relatively diverse and well-developed.

Making biological measurements underwater can often be a time-consuming process; use of the photographic technique lessens bottom time in measuring coral and other benthic species coverage. However, as noted by Brock (1992b), inspection of the results of the coral coverage data from visual assessment of quadrats in the field relative to the data obtained using the photographic method points out several things. First, mean coral coverage estimates are in reasonable agreement using either method, and the regression of visual versus the photographic coverage data shows a statistically significant relationship. However, the photographic quadrat technique does not discern small coral colonies or other small colonial benthic species such as the soft coral *Anthelia edmondsoni*; these are easily seen in the field using the visual assessment method. Both methods work, but the technique selected should be done so while keeping the objectives of the study in mind. This study will continue to use both methods.

The six transects selected for this study show a considerable range in community development that is probably related to historical impacts. Separating the impact of advanced primary-treated effluent released at depth from a multitude of other ongoing and historical impacts that have occurred in and to the shallow marine communities fronting Sand Island is difficult at best. The added natural disturbance of Hurricane Iniki on 11 September 1992 provided additional impact to these communities that varied tremendously with location. However, the siting of these permanent stations to capitalize on presumed gradient(s) of impact created by the variety of land-derived sources, as well as the repeated sampling of these permanent stations, should allow delineation of any changes attributable to the discharge of sewage effluent from the Sand Island deep-ocean outfall. The sampling of these stations during the first two years (1990 and 1991) showed that there was little change to the communities during that time, suggesting that there was no quantitatively definable impact to shallow-water benthic and fish communities due to the operation of the outfall. Many of the changes seen in the 1992 survey appear to be related to the natural storm event that occurred in September of that year. The 1993 through 1998 data suggest that recovery from the hurricane is well underway, particularly in the coral communities.

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APPENDIX

Results of the Quantitative Visual Fish Censuses Conducted at Six Locations Offshore of Sand Island, O'ahu, Hawai'i, 12 and 28 August 1998

FAMILY and Species	Transect					
	T-1	T-2	T-3	T-4	T-5	T-6
MURAENIDAE						
Gymnomuraena zebra				1		
SERRANIDAE						
Cephalopholis argus						1
LUTJANIDAE						
Alphareus furcatus	1					
Aprion virescens	1					
LETHRINIDAE						
Monotaxis grandoculis	8					
MULLIDAE						
Mulloidichthys flavolineatus		14				
Parupeneus multifasciatus	8	4	3	4	8	10
Parupeneus pleurostigma		2	1		1	1
CHAETODONTIDAE						
Forcipiger flavissimus	2					
Chaetodon multicinctus	2	7	2	2	2	2
Chaetodon quadrimaculatus		3				
Chaetodon miliaris	19	4				
POMACANTHIDAE						
Centropyge potteri			1			
POMACENTRIDAE						
Dascyllus albisella	35	13	11			
Plectroglyphidodon johnstonianus	1				1	1
Abudefduf abdominalis	31					
Chromis vanderbilti	9		53	27		
Chromis hanui				2		
Chromis agilis						2
Chromis ovalis		6				
Chromis verator	12					
Stegastes fasciolatus						4
CIRRHITIDAE						
Paracirrhites arcatus	5	4	4	3		
Cirrhitops fasciatus		1				
Cirrhitus pinnulatus					1	
LABRIDAE						
Bodianus bilunulatus	1		2	1		
Cheilinus bimaculatus			1			
Pseudocheilinus octotaenia	2					1
Pseudocheilinus tetrataenia		1				
Thalassoma duperrey	36	12	6	3	12	45
Gomphosus varius	4	1			1	2
Coris gaimard	1				1	1
Coris venusta			2			2
Pseudojuloides cerasinus	7	16	5	16		1
Stethojulis balteata	2	1		1	1	5
Macropharyngodon geoffroy	1					4
Anampses chrysocephalus			1	2		
Halichoeres ornatissimus						1

Results—*Continued*

FAMILY and Species	Transect					
	T-1	T-2	T-3	T-4	T-5	T-6
SCARIDAE						
Calotomus carolinus	1	3				2
Scarus psittacus	34	23			8	7
Scarus sordidus	1				6	10
BLENNIIDAE						
Plagiotremus ewaensis				1		
ACANTHURIDAE						
Acanthurus triostegus					2	
Acanthurus nigrofuscus	25	12	9	12	33	41
Acanthurus nigroris	34					4
Acanthurus dussumieri					1	
Acanthurus olivaceus			4	3		
Ctenochaetus strigosus					54	10
Zebrasoma flavescens		1				
Naso lituratus		1			2	2
Naso hexacanthus	27					
Naso unicornis	2	1	2		2	
Naso brevirostris	3		5	1		1
Zanclus cornutus	3	3	1			
BALISTIDAE						
Melichthys niger					2	4
Melichthys vidua		1				
Sufflamen bursa	3	1	2	4	6	1
Sufflamen fraenatus			1	1		
Rhinecanthus aculeatus				1		
MONACANTHIDAE						
Pervagor melanocephalus						1
Pervagor spilosoma	1				1	
Cantherhines sandwichiensis	1	1			1	1
Cantherhines dumerilii			1			
OSTRACIIDAE						
Ostracion whitleyi		1				
TETRAODONTIDAE						
Canthigaster jactator	1	3	2	1	4	4
Canthigaster cinctus			1			
Canthigaster coronata				2		
Total No. of Species	34	27	23	20	22	29
Total No. of Individuals	324	140	120	88	150	171
Estimated Standing Crop (g/m^2)	151	132	74	42	70	89

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