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 4—1993

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ABSTRACT

This report provides the results of the fourth year of an annual quantitative monitoring (carried out on 7–8 September 1993) of shallow marine communities inshore of the Sand Island Ocean Outfall, O‘ahu, Hawai‘i. 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 for 100 years. Raw sewage was dumped in shallow water until 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 discharge 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 data for four years showed that there has been no statistically significant change in the biological measures (i.e., percent coral cover, number of coral species, number of invertebrate species, total number of invertebrates counted, number of fish species, total number of fishes counted, and the biomass of fishes present at each station) quantified in the study during this period. Hurricane Iniki, which occurred in September 1992, impacted marine communities along the south shore of O‘ahu. Coral communities received considerable damage, especially at the westernmost study station. Recovery in these communities was evident in the year following the storm.

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 further 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 from the deep ocean outfall may be having in the shallow (<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 fourth annual survey carried out in September 1993.

Strategy

Marine environmental surveys are usually performed to evaluate the feasibility of and ecosystem response to specific proposed activities. Appropriate survey methodologies reflect the nature of the proposed action(s). An action that may have an acute impact (such as channel dredging) requires a survey designed to determine the route of least harm and the projected rate and degree of ecosystem recovery. Impacts that are more chronic or progressive require different strategies for measurement. Management of chronic stress to a marine ecosystem requires identification of system perturbations that exceed boundaries of natural fluctuations. Thus a thorough understanding of normal ecosystem variability is required 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 Hawaiian 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 Hawaii since before the turn of the century (Scott 1968). The harbor is the result of dredging what was originally the drainage basin of Nuʻuanu 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 Keʻehi 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 (<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 (such as storm drains and streams) and nonpoint 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 the deep ocean outfall, these 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 in 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. The approximate locations of these sites 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 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 Entrance Channel	Located about 120 m east of the Kalihi Entrance Channel in approximately 15 m of water. This station is about 900 m west of the of the bypass (old) outfall in an area heavily impacted by the old (1955–77) 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 (<1%).
Station C — Reef Runway	Located in an area of complex limestone substratum in water ranging from 7.5 to 12 m in depth fronting Honolulu International Airport's Reef Runway. This station location is 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 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, 5, 10, 15, and 20 m) for the taking of photographs of the benthic communities. Cover estimates were also made in the field with a 1 ∞ 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) has proved to be adequate for sampling many Hawaiian benthic communities (see Brock 1982; Brock and Norris 1989).

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 ∞ 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 fish species 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 Hawaii, Naval Undersea Center (see Evans 1974), and the Hawaii Division of Aquatic Resources from weight and body measurements of captured fishes; for many species the coefficients have been developed using sample sizes in excess of a hundred individuals. 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 aweoweo (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) and 1 ∞ 1 m quadrats placed at marked locations for repeated measurements. The photographs and quadrats are both 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 three most recent surveys (1991, 1992, and 1993); the 1 ∞ 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 ∞ 20 m corridor used in the fish counts.

If macrothalloid algae were encountered in the 1 ∞ 1 m quadrats or photographs, they were quantitatively recorded as percent cover. Emphasis was placed on those species that were visually dominant, and no attempt was made to quantitatively assess the multitude of microalgal species that constitute the “algal turf” so characteristic of many coral reef habitats.

As requested by permit agencies, divers made simple physical measurements at the three stations 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 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 sample period; this procedure is outlined in Siegel (1956) and Sokal and Rohlf (1981). The a posteriori Student-Newman-Keuls multiple-range test (SAS Institute, Inc. 1985) was also used to elucidate differences between locations.

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

RESULTS

Field sampling was 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, and 1993 data on 7–8 September 1993.

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 Wastewater Management, City and County of Honolulu. However, the 1990 visually assessed square-meter-quadrat data provided information on benthic coverage in this first annual effort. 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 and 1992 surveys, but the locations are the same.

The results are presented below by station.

Station A — Kewalo Landfill

This station is located 600 m offshore of the old Kewalo Landfill in water ranging from 17 to 18 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 in September 1993 is presented in Table 1. In the quadrat survey, six coral species having a mean estimated coverage of 25.8% were encountered; the dominant species were *Porites lobata* and *Pocillopora meandrina.* One algal species (*Laurencia obtusa*) was noted in the quadrats. The macroinvertebrate census noted two polychaetes (the Christmas tree worm *Spirobrachus giganteus corniculatus* and the featherduster worm *Sabellastarte sanctijosephi*), four 0.5 to 1 kg spiny lobsters or ‘ula (*Panulirus marginatus*), four sea urchin species (the long-spined sea urchin [or wana] *Echinothrix diadema,* the banded urchin *Echinothrix calamaris,* the black urchin *Tripneustes gratilla,* and the boring sea urchin *Echinostrephus aciculatum),* as well as the sea star *Linckia diplax.* 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 2 September 1993. Mean coral coverage in the photographic survey was estimated at 16.0%, with *Porites lobata* being the dominant coral.

In total 31 fish species representing 343 individuals were encountered on Transect T-1. The most common species include the yellowstripe goatfish or weke (*Mulloides flavolineatus*), the damselfish *Chromis vanderbilti,* the sergeant major or mamo (*Abudefduf abdominalis*), and the brown surgeonfish or maʻiʻi (*Acanthurus nigrofuscus*). The standing crop of fishes on this transect was estimated at 1 039 g/m^2. The species contributing most heavily to this biomass was *Mulloides flavolineatus,* which made up 87% (72 kg) of the total standing crop encountered at this transect.

Transect T-2 was established approximately 35 m west of Transect T-1 in water ranging from 17 to 18.2 m in depth. A summary of the biological information collected on this transect is presented in Table 3. One macroalgal species (*Liagora tetrasporifera*) and seven coral species (*Porites lobata, P. compressa, Pocillopora meandrina, P. eydouxi, Leptastrea purpurea, Montipora verrucosa,* and *M. patula*) having an average coverage of 25.8% were noted in the quadrat survey. The largest contributor to this coverage was *Porites lobata*. The invertebrate census noted two polychaete species (*Spirobranchus giganteus corniculatus* and *Sabellastarte sanctijosephi*), the rock oyster *Spondylus tenebrosus,* the cone shell *Conus lividus,* and four sea urchin species (*Echinothrix diadema, E. calamaris, Echinostrephus aciculatum,* and *Echinometra mathaei*). The photographic quadrat survey carried out on 2 September 1993 noted an unidentified red sponge (probably *Spirastrella coccinea*) and four coral species having a mean coverage of 26.7% (Table 2).

The results of the fish census are presented in the Appendix. Thirty fish species representing 150 individuals were censused on this transect; the most abundant species included *Mulloides flavolineatus* and *Acanthurus nigrofuscus*. The standing crop of fishes was estimated at 273 g/m^2, and the species that contributed most to this weight was the roving school of *Mulloides flavolineatus* (93% of the total biomass).

Site B — Kalihi Entrance Channel

This station is located about 2.2 km seaward of Mokauea Island, which is situated in Keʻehi Lagoon, and about 900 m west of the old outfall, which is now used as an emergency bypass. 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 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, fish censuses at this station are carried out on both transects prior to any other data collection. During our 1993 surveys water clarity at this station was greater than 15 m (Table 4).

Transect T-3 has an orientation perpendicular to shore on the limestone substratum in water ranging from 14.6 to 15 m in depth. A summary of the biological observations made at Transect T-3 is presented in Table 5. The quadrat survey noted the red encrusting sponge *Spirastrella coccinea,* one soft coral (*Palythoa tuberculosa*), and five coral species (*Porites lobata, Pocillopora meandrina, Montipora verrucosa, M. verrilli,* and *M. patula*) having a mean estimated coverage of 1.7% (a decrease of 0.3% from the previous survey). The invertebrate census noted one rock oyster (*Spondylus tenebrosus*), a cone shell (*Conus marmoratus*), three sea urchin species (*Echinostrephus aciculatum, Echinometra mathaei,* and *Echinothrix calamaris*), as well as the black sea cucumber *Holothuria atra*. The photographic quadrat survey found an unidentified red sponge species and two coral species (*Porites lobata* and *Pocillopora meandrina*) having a mean coverage of 0.6% (down from 4% in the last survey).

The fish census found 10 species representing 43 individuals and an estimated standing crop of 31 g/m^2 (Appendix). The most abundant fishes at Transect T-3 included the spectacled parrotfish or uhu ahu‘ula (*Scarus perspicillatus*), the smalltail wrasse *Pseudojuloides cerasinus*, and the saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*). The fish species contributing heavily to the biomass on Transect T-3 include a single tableboss or a‘awa (*Bodianus bilunulatus*—45% of the total weight), the spectacled parrotfish or uhu ahu‘ula (*Scarus perspicillatus*—16% of the total), and the manybar goatfish or moano (*Parupeneus multifasciatus*—13% of the total).

Transect T-4 sampled the benthic and fish communities present in the vicinity of the Kalihi Entrance Channel. As with Transect T-3, Transect T-4 sampled the limestone substratum at a depth ranging from 13.7 to 14 m. A summary of the biological data collected on Transect T-4 is presented in Table 6. The quadrat survey noted two algal species (*Neomeris annulata* and *Sphacelaria furcigera*), the red sponge *Spirastrella coccinea,* and four coral species (*Porites lobata, Pocillopora meandrina, Montipora verrucosa,* and *M. verrilli*). Coral coverage was estimated at 3.5% (up from 3.2% in the last survey), with *Porites lobata* and *Pocillopora meandrina* being the major contributors. The invertebrate census noted the mantis shrimp *Gonodactylus falcatus,* the polychaete *Spirobranchus giganteus corniculatus,* three sea urchin species (the boring urchin *Echinostrephus aciculatum,* the green urchin *Echinometra mathaei,* and the banded urchin *Echinothrix calamaris*), as well as the starfish *Linckia diplax*. In the photographic quadrat survey an unidentified red sponge species and two coral species (*Porites lobata* and *Pocillopora meandrina*) having a mean coverage of 2.1% were seen.

The fish census noted 63 individual fishes among 19 species (Appendix). The most common fishes present on this transect included a small roving school of mackeral scad or opelu (*Decapterus macarellus*), the damselfish *Chromis vanderbilti,* and the spectacled parrotfish or uhu ahu‘ula (*Scarus perspicillatus*). The standing crop of fishes on Transect T-4 was estimated at 96 g/m^2, and the important contributors to this biomass included *Decapterus macarellus* (47% of the total weight), a single tableboss or a‘awa (*Bodianus bilunulatus*—15% of the total), and a single spiny puffer or ‘o‘opu okala (*Diodon holocanthus*—12% of the total).

Station C — Reef Runway

This station lies between 760 and 840 m seaward of the runway in water ranging from 7.5 to 12 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 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 ∞ 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 ranged from 8 to 18 m during our 1993 visits; usually clarity does not exceed 12 m. On 8 September 1993, the depth to secchi disk extinction was greater than the water depth (i.e., more than 15 m; see Table 4).

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 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 8 September 1993 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 m. Table 7 presents the results of the biological survey carried out at Transect T-5. The quadrat survey noted the coralline algal species (*Porolithon onkodes, P. gardineri,* and *Jania* sp.), the fleshy alga

Dictyota divaricata, the soft coral *Palythoa tuberculosa,* and five coral species (*Porites compressa, Pocillopora meandrina, Pavona duerdeni, P. varians,* and *Montipora patula*) having a mean coverage of 1.5%. This coverage is up from 0.4% in the previous survey. The invertebrate census found one hermit crab (*Aniculus strigatus*) and five black sea urchin (*Tripneustes gratilla*) in the transect area. The photographic quadrat survey completed on 20 September 1993 (Table 2) noted three algal species (*Porolithon onkodes, Dictyota divaricata,* and *Palythoa tuberculosa*), and two coral species (*Pocillopora meandrina* and *Montipora patula*?) having a mean estimated coverage of 0.4% (up from 0.2% in the previous year).

The fish census (Appendix) noted 156 individuals among 23 species. The most common species included the saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*), 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 to be 61 g/m^2, with the most important contributors including the manybar goatfish or moano (*Parupeneus multifasciatus*—8% of the total weight), *Ctenochaetus strigosus* (35% of the total), and *Thalassoma duperrey* (24% of the total).

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 one algal species (*Porolithon onkodes*) having a mean coverage of 17.4%, two soft corals (*Anthelia edmondsoni* and *Palythoa tuberculosa*), and six coral species (*Porites lobata, Pocillopora meandrina, Montipora patula, M. verrucosa, Pavona duerdeni,* and *P. varians*) having a mean coverage of 5.2%. This coral coverage estimate is up from last year’s estimate of 3.1%. The census of macroinvertebrates noted four species: the terebellid polychaete worm *Loimia medusa,* the hermit crab *Dardanus deformis,* the green sea urchin *Echinometra mathaei,* and the long-spined urchin or wana (*Echinothrix diadema*). The photo quadrat survey (Table 2) noted *Porolithon onkodes* with a mean coverage of 12.9%, *Palythoa tuberculosa,* and four coral species (*Porites compressa, P. lobata, Pocillopora meandrina,* and *Montipora* sp.?) with a mean coverage of 5.1%.

The fish census noted 247 individuals belonging to 29 species in the 4 ∞ 20 m area. The most abundant fishes on Transect T-6 include the damselfish *Chromis vanderbilti*), the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*), the goldring surgeonfish or kole (*Ctenochaetus strigosus*), and the saddleback wrasse or hinalea lauwili (*Thalassoma duperrey)*. The standing crop of fishes on this transect was estimated to be 79 g/m^2; the largest contributors to this biomass included *Thalassoma duperrey* (20% of the total weight), *Ctenochaetus strigosus* (16% of the total), the spectacled parrotfish or uhu ahu‘ula (*Scarus perspicillatus*—11% of the total), and the black triggerfish or humuhumu ele‘ele (*Melichthys niger*—8% of the total).

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). During the September 1993 field work, green turtles were seen in other areas (about 200 m east of Transects T-5 and T-6).

Physical measurements were made in the morning on 9 September 1993. These data are presented in Table 4. Little variation was noted in temperature (24.9° to 25.1°C), percent oxygen saturation (102% to 104%), or salinity (all 34°/oo) 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 four surveys (1990, 1991, 1992, and 1993) are summarized as means for each transect in Table 9. The previous annual data are from Brock (1992a, 1992b, 1993). Differences are apparent for some of the parameters among the four 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 are no statistically significant changes from the 1990 survey to the 1993 field effort for mean coral cover on a transect ($p > 0.82$, df = 3, not significant.), mean number of coral species on a transect ($p > 0.10$, d f= 3, n.s.), mean number of invertebrate species on a transect ($p > 0.33$, df = 3, n.s.), mean number of individual invertebrates on a transect ($p > 0.88$, df = 3, n.s.), mean number of fish species on a transect ($p > 0.53$, df = 3, n.s.), mean number of individual fish on a transect ($p > 0.23$, df = 3, n.s.), and mean standing crop on a transect ($p > 0.67$, df = 3, n.s.). The Student-Newman-Keuls multiple range test likewise demonstrated that there are no statistically significant differences among these parameters among the six transects and four sampling periods.

The biological parameters measured in the four surveys (i.e., number of coral species, percent cover, number of macroinvertebrate species, number of fish species, number of individual fish, 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 changed over the four survey years. The 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 consistently encountered in the vicinity of the Kewalo Landfill and Reef Runway stations, including goatfishes (weke or *Mulloides flavolineatus* and weke‘ula or *M. vanicolensis*), amberjack or kahala (*Seriola dumerili*), emperor or mu (*Monotaxis grandoculis*), grey snapper or uku (*Aprion virescens*), and the squirrelfish or mempachi (*Myripristes amaenus*).

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 have been carried out in the areas surrounding the selected stations. At a minimum, these qualitative surveys have covered about 4 hectares around each of the three stations. These 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 the zone of influence of the present deep ocean outfall. However, if impacts from the present deep ocean 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 to the perturbation of raw sewage released from the old shallow-water outfall that was terminated in 1977–78. Dollar’s (1979) study showed that the Kewalo Landfill station was not directly impacted by 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%, at the Reef Runway station it is 4%, and offshore of the Kewalo Landfill it is 26%.

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 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 deep ocean 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 deep ocean outfall terminus (Figure 1). Presumably, the present outfall releases the sewage below the pycnocline, and little interaction occurs with the inshore biota. Dollar's (1979) findings suggest that if the material was 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 (Mr. A. Muranaka, Oceanographic Team, Department of Wastewater Management, City and County of Honolulu, 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 of 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 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 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 Hawaiian coral communities (Dollar 1982). Numerous studies have shown that storm-generated surf may keep coral reefs in a nonequilibrium or subclimax 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 wave forces also impinge 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 areas of the *Porolithon*-covered substratum (up to 1 ∞ 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 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 (1992–93) 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 Hawaiian corals are relatively slow growing, it will be years before the impact of this large storm will no longer be evident in the benthic communities at the study sites.

The hurricane also impacted the fish communities at the sampling 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 or mu [*Monotaxis grandoculis*]) were no longer found on Transect T-6 in both the 1992 and 1993 surveys. They 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 four years (December 1990 to September 1993), show that there has been no statistically significant change in the biological parameters measured in this study. The most variable parameters through time have been 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 1990, 1992, and 1993 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 sewer pipe and growth of coral on this pipe locally enhances the fish community, (2) chance encounters with roving predators or planktivorous and/or other schooling species during censuses, and (3) 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 (*Mulloides 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 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. 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 sewer 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 uku or *Aprion virescens,* mu or *Monotaxis grandoculis,* kahala or *Seriola dumerili,* papio or *Caranx melampygus* or *C. orthogrammus*), schools of planktivorous fishes (opelu or *Decapterus macarellus,* kala holo or *Naso hexacanthus,* kala lolo or *N. brevirostris,* lauwiliwili or *Chaetodon miliaris,* mamo or *Abudefduf abdominalis*), or other schooling species (weke or *Mulloides flavolineatus*) may greatly increase the counts and biomass at a particular transect. The presence of the sewer 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 at that transect, and 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 *Naso 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 *Mulloides flavolineatus* that are resident to the old sewer pipe made up 78% of the biomass present on Transect T-1 and 93% on Transect T-2; in 1993 this school comprised 87% of the biomass present on Transect T-1 and 79% on Transect T-2.

Making biological measurements underwater can often be a time-consuming process; use of the photographic quadrat 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 quadrat 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 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 Sand Island deep ocean outfall. The sampling of these stations over the first two years (1990 and 1991) shows 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 Sand Island deep ocean 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 data suggest that recovery from the hurricane is well underway, particularly in the coral communities.

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TABLE 1. Summary of Biological Observations Made at Transect T-1, Offshore of Kewalo Landfill (Station A), 7 September 1993

I. Quadrat Survey	Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Laurencia obtusa		0.1			
Corals					
Porites lobata	31	12.5	8	38	4
P. compressa	0.8		0.2	6.5	
Pocillopora meandrina	2	4.2	4	4.2	13
Montipora verrucosa	0.1		0.1	0.1	
M. patula			0.1		
Pavona varians					0.1
Sand	4	1	5	1	14
Rubble	5		57.6		9
Hard Substratum	57.1	82.2	25	50.2	59.9

II. Invertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Annelida	
Spirobranchus giganteus corniculatus	6
Sabellastarte sanctijosephi	1
Phylum Arthropoda	
Panulirus marginatus	4
Phylum Echinodermata	
Echinostrephus aciculatum	1
Echinothrix diadema	7
E. calamaris	1
Tripneustes gratilla	1
Linckia diplax	1

III. Fish Census (4 ∞ 20 m)
31 Species
343 Individuals
Estimated Standing Crop = 1 039 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 25.8% (quadrat method).

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

Station A: Transect 1-1 (Sampled 2 September 1993)	Photographic Quadrat				
	AAA1 (0 m)	AAA2 (5 m)	AAA3 (10 m)	AAA4 (15 m)	AAB1 (20 m)
Corals					
Porites lobata	26.3	9.8	1.7	19.6	3.6
P. compressa		0.3		1.4	
Pocillopora meandrina		2.5	3.9	5	5.9
Sand	1.4	5.6	13.1	0.6	5.6
Rubble	19.3	2.2	42	3.9	16
Hard Substratum	53	79.6	39.3	69.5	68.9

Mean Coral Coverage = 16.0%

Station A: Transect 1-2 (Sampled 2 September 1993)	Photographic Quadrat				
	AAB2 (0 m)	AAB3 (5 m)	AAB4 (10 m)	AAC1 (15 m)	AAC2 (20 m)
Unidentified red sponge (probably *Spirastrella coccinea*)			0.3		
Corals					
Porites lobata	19.6	10.6	52.1	22.1	12
P. compressa			1.4	1.4	
Pocillopora meandrina		3.1	4.2	2.0	3.9
P. eydouxi				1.1	
Sand	3.1	3.6		1.1	2.5
Rubble	5.9				
Hard Substratum	71.4	82.7	42	72.3	81.6

Mean Coral Coverage = 26.7%

Station B: Transect 1-3 (Sampled 11 October 1993)	Photographic Quadrat				
	BAA1 (0 m)	BAA2 (5 m)	BAA3 (10 m)	BAA4 (15 m)	BAB1 (20 m)
Unidentified red sponge (probably *Spirastrella coccinea*)	0.3		0.3		0.3
Corals					

Porites lobata	0.3	0.6	1.1	0.3	
Pocillopora meandrina		0.3	0.6		
Sand	3.4	5.9	2.8	5	2.2
Rubble	5.6				
Hard Substratum	90.4	93.2	95.2	85.8	97.5

Mean Coral Coverage = 0.6%

TABLE 2—*Continued*

Station B: Transect 1-4 (Sampled 11 October 1993)	Photographic Quadrat				
	BAB2	BAB3	BAB4	BAC1	BAC2
	(0 m)	(5 m)	(10 m)	(15 m)	(20 m)
Unidentified red sponge (probably *Spirastrella coccinea*)	0.3	0.3	0.3	0.3	0.3
Corals					
Porites lobata		5.9	0.6	0.3	
Pocillopora meandrina			0.8	1.1	2.0
Sand	6.7	1.4	8.4	2.5	0.8
Rubble	56.9	23	4.2	27.7	9.8
Hard Substratum	36.1	69.4	85.7	68.1	87.1

Mean Coral Coverage = 2.1%

Station C: Transect 1-5 (Sampled 20 October 1993)	Photographic Quadrat				
	CAB1	CAA4	CAA3	CAA2	CAA1
	(0 m)	(5 m)	(10 m)	(15 m)	(20 m)
Algae					
Porolithon onkodes		7.0	8.4	11.2	12
Dictyota divaricata	10.6				
Soft Corals					
Palythoa tuberculosa					0.3
Corals					
Pocillopora meandrina		0.1		0.3	0.8
Montipora patula ?		0.6			
Sand	3.1		0.3		
Rubble	28	23.5	19.1	21.3	
Hard Substratum	58.3	68.8	72.2	67.2	86.9

Mean Coral Coverage = 0.4%

Station C: Transect 1-6 (Sampled 20 October 1993)	Photographic Quadrat				
	CAB2	CAB3	CAB4	CAC1	CAC2
	(0 m)	(5 m)	(10 m)	(15 m)	(20 m)

Algae					
Porolithon onkodes	22.1	13.2	0.3	20.5	8.4
Soft Corals					
Palythoa tuberculosa					0.6
Corals					
Porites lobata	13.2	0.3		8.1	2.8
P. compressa	0.3				
Pocillopora meandrina	0.3				
Montipora sp.?	0.3	0.3	0.1		
Rubble			99.6	5.6	42.9
Hard Substratum	63.8	86.2		65.8	45.3

Mean Coral Coverage = 5.1%

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

TABLE 3. Summary of Biological Observations Made at Transect T-2, Offshore of Kewalo Landfill (Station A), 7 September 1993

I. Quadrat Survey	Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Liagora tetrasporifera		0.1			
Corals					
Porites lobata	18	12	52	10	14
P. compressa			1	2.6	
Pocillopora meandrina	0.5	2.5	4.8	6	1.7
P. eydouxi					0.3
Montipora verrucosa		0.1	2.3	0.1	
M.patula	0.1	0.1	1		
Leptastrea purpurea			0.1		
Sand		1			1
Hard Substratum	81.4	84.2	38.8	81.3	83

II. Invertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Mollusca	
Conus lividus	2
Spondylus tenebrosus	2
Phylum Annelida	
Spirobranchus giganteus corniculatus	2
Sabellastarte sanctijosephi	3
Phylum Echinodermata	
Echinothrix diadema	6
E. calamaris	2
Echinostrephus aciculatum	1
Echinometra mathaei	2

III. Fish Census (4 ∞ 20 m)
30 Species
150 Individuals
Estimated Standing Crop = 273 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 to 18.2 m; mean coral coverage is 25.8% (quadrat method).

TABLE 4. Summary of Physical Measurements Made at Each of Three Locations in the Vicinity of Transect Pairs, 6 December 1991, 22 December 1992, and 9 September 1993

Location and Time	Oxygen (% of 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

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 Kalihi Entrance Channel (Station B, About 2.2 km Offshore of Mokauea Island in Ke‘ehi Lagoon), 8 September 1993

I. Quadrat Survey	Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Sponge					
Spirastrella coccinea	1	0.1	1.2	1	0.5
Soft Coral					
Palythoa tuberculosa			0.1		
Corals					
Porites lobata	2.1	0.5	1	0.8	1
Pocillopora meandrina	0.1	1.4	0.5	0.3	
Montipora verrucosa			0.1		0.2
M. patula	0.1		0.2		0.1
M. verrilli		0.1			
Sand	14	9	3	14	2
Rubble	3	3	9	8	
Hard Substratum	79.7	85.9	84.9	75.9	96.2

II. Invertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Mollusca	
Spondylus tenebrosus	1
Conus marmoratus	1
Phylum Echinodermata	
Echinostrephus aciculatum	6
Echinometra mathaei	2
Echinothrix calamaris	1
Holothuria atra	1

III. Fish Census (4 ∞ 20 m)
10 Species
43 Individuals
Estimated Standing Crop = 31 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 m; mean coral coverage is 1.7% (quadrat method).

TABLE 6. Summary of Biological Observations Made at Transect T-4, East of Kalihi Entrance Channel (Station B, About 2.2 km Offshore of Mokauea Island in Ke‘ehi Lagoon), 8 September 1993

I. Quadrat Survey	Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Neomeris annulata		0.1			
Sphacelaria furcigera					0.3
Sponge					
Spirastrella coccinea	1	0.1	0.1	0.3	0.1
Corals					
Porites lobata	1.3	9.5	0.4	0.2	2.5
Pocillopora meandrina	0.1		0.5	1	1.3
Montipora verrucosa		0.2			0.2
M. verrilli	0.1				0.1
Sand	8	7	7.5	15	7
Rubble 4	6	2.5	4	3	
Hard Substratum	86.7	77.9	88.3	79.8	84.2

II. Invertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Annelida	
Spirobranchus giganteus corniculatus	1
Phylum Arthropoda	
Gonodactylus falcatus	1
Phylum Echinodermata	
Echinostrephus aciculatum	5
Echinometra mathaei	1
Echinothrix calamaris	3
Linckia diplax	1

III. Fish Census (4 ∞ 20 m)
19 Species
63 Individuals
Estimated Standing Crop = 96 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 m; mean coral coverage is 3.5% (quadrat method).

TABLE 7. Summary of Biological Observations Made at Transect T-5, Approximately 760 m Offshore of Honolulu Airport Reef Runway (Station C), 8 September 1993

I. Quadrat Survey	Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Porolithon onkodes		5	14	19	18
P. gardineri					0.2
Jania sp.	0.1				
Dictyota divaricata	18				
Soft Coral					
Palythoa tuberculosa		0.2		0.2	4
Corals					
Porites compressa	0.1		0.2		0.1
Pocillopora meandrina			0.1	0.1	0.7
Pavona duerdeni				3.5	1
P. varians		0.3			
Montipora patula		0.1		1.3	0.1
Sand	3		1		
Rubble	56.8	8	3		
Hard Substratum	22	86.4	81.7	75.9	75.9

II. Invertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Arthropoda	
Aniculus strigatus	1
Phylum Echinodermata	
Tripneustes gratilla	5

III. Fish Census (4 ∞ 20 m)
23 Species
152 Individuals
Estimated Standing Crop = 61 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 m; mean coral coverage is 1.5% (quadrat method).

TABLE 8. Summary of Biological Observations Made at Transect T-6, Approximately 840 m Offshore of Honolulu Airport Reef Runway (Station C), 8 September 1993

I. Quadrat Survey	Quadrat Distance Along Transect (m)				
	0	5	10	15	20
Algae					
Porolithon onkodes	32	16		32	7
Soft Coral					
Anthelia edmondsoni			0.1		
Palythoa tuberculosa					0.3
Corals					
Porites lobata	8.2		0.1	8.5	6.5
Pocillopora meandrina	0.2				
Montipora verrucosa	0.1		0.2		
M. patula	0.1	1.2		0.3	0.2
Pavona duerdeni					0.2
P. varians			0.1		
Rubble		22	99.5	6	39
Hard Substratum	59.4	60.8		53.2	46.8

II. Invertebrate Census (4 ∞ 20 m)	No. of Individuals
Phylum Annelida	
Loimia medusa	1
Phylum Arthropoda	
Dardanus deformis	1
Phylum Echinodermata	
Echinometra mathaei	3
Echinothrix diadema	1

III. Fish Census (4 ∞ 20 m)
29 Species
247 Individuals
Estimated Standing Crop = 79 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 5.2% (quadrat method).

TABLE 9. Summary of Biological Parameters Measured at Six Transect Locations for 1990, 1991, 1992, and 1993

Parameter	1990 Transect 1	2	3	4	5	6	1991 Transect 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
Biomass (g/m^2)	763	824	91	30	129	293	148	221	72	20	101	183

Parameter	1992 Transect 1	2	3	4	5	6	1993 Transect 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
Biomass (g/m^2)	736	247	30	14	69	108	1039	273	31	96	61	79

NOTE: Each transect samples 80 m^2 of substratum for fishes and invertebrates other than corals. Coral data (given in percent cover) is from 5 m^2 sampled on each transect. Data for 1990, 1991, and 1992 are from Brock (1992a, 1992b, 1993).

Results of Quantitative Visual Fish Censuses Conducted at Six Locations Offshore of Sand Island, O‘ahu, Hawai‘i, 7–8 September 1993

FAMILY and Species	Transect					
	1	2	3	4	5	6
MURAENIDAE						
Gymnothorax meleagris						1
G. petelli		1				
AULOSTOMIDAE						
Aulostomus chinensis	1					
SCORPAENIDAE						
Scorpaenopsis diabolus	1					
CARANGIDAE						
Decapterus macarellus				19		
MULLIDAE						
Mulloides flavolineatus	117	28				
Parupeneus multifasciatus	12	10	4	5	6	14
P. cyclostomus		1				1
P. bifasciatus	4	1			2	
CHAETODONTIDAE						
Forcipiger flavissimus	3	2			1	1
Chaetodon multicinctus	2	4				
C. miliaris	1					
C. unimaculatus	2					
C. quadrimaculatus	1					
POMACANTHIDAE						
Centropyge potteri		1				1
POMACENTRIDAE						
Dascyllus albisella						9
Abudefduf abdominalis	27					
Chromis vanderbilti	50	1		6	10	31
C. hanui		1			7	8
C. ovalis	10					
C. agilis						11
Stegastes fasciolatus					3	7

CIRRHITIDAE						
Paracirrhitus arcatus	6	6		1		
P. forsteri					1	
Cirrhitops fasciatus		1			1	
Cirrhitus pinnulatus					1	
LABRIDAE						
Labroides phthirophagus						1
Bodianus bilunulatus			1	1		
Cheilinus bimaculatus	1		1	2		
Pseudocheilinus octotaenia		1			1	1
Thalassoma duperrey	10	10	7		29	27
T. ballieui		1			2	6
Gomphosus varius					1	

Continued

FAMILY and Species	Transect					
	1	2	3	4	5	6
Coris gaimard				1	1	
C. venusta				2	1	
Pseudojuloides cerasinus	20	18	7	5	1	4
Stethojulis balteata	5	1				1
Macropharyngodon geoffroy		1			2	7
Anampses chrysocephalus		1				
Halichoeres ornatissimus					1	
SCARIDAE						
Scarus psittacus	3	1				
S. sordidus						12
S. perspicillatus	2		9	6		22
BLENNIIDAE						
Cirripectus variolosus						1
Gnatholepis anjerensis				1		
ACANTHURIDAE						
Acanthurus nigrofuscus	37	26	4	2	24	20
A. nigroris	5	10	6			12
A. olivaceus	2	1		2		1
A. dussumieri	1					
A. mata		7				

Ctenochaetus strigosus	5				46	33
Zebrasoma flavescens		1				
Naso lituratus	2					2
N. hexacanthus	8	3				
ZANCLIDAE						
Zanclus cornutus						2
BALISTIDAE						
Melichthys niger					2	3
Sufflamen bursa	1	3	3	3	1	1
Rhinecanthus rectangulus				2		
MONACANTHIDAE						
Pervagor spilosoma		1				
Cantherhines dumerili				1		
OSTRACIONTIDAE						
Lactoria fornasini		1				
CANTHIGASTERIDAE						
Canthigaster jactator	1	6	1		8	5
C. cornata	2			2		
TETRAODONTIDAE						
Arothron hispidus	1			1		
Diodon holocanthus				1		

Continued

FAMILY and Species		Transect					
		1	2	3	4	5	6
Total No. of Species		31	30	10	19	23	29
Total No. of Individuals		343	150	43	63	152	247
Estimated Standing Crop (g/m^2)		1,039	273	31	96	61	79

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.