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 5—1994

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Project Report PR-95-08

January 1995

PREPARED FOR

City and County of Honolulu
Department of Wastewater Management

Project Report
for
“The Assessment of the Impact of Ocean Outfalls on the Marine Environment off Oahu, Hawaii”

Project No.: C59390

Project Period: 21 February 1990–31 December 1994

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ABSTRACT

This report provides the results of the fifth year of an annual quantitative monitoring (carried out on 20 September and 13–14 October 1994) 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 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 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 five years of data showed that there has been no statistically significant change in the following biological measures: percent coral cover, 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. The mean number of coral species has shown a statistically significant increase over the five-year 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 is evident from the two 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.

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 from the deep ocean outfall may be having on 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 fifth annual survey carried out in September and October 1994.

Strategy

Marine environmental surveys are usually performed to evaluate 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 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. 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 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 (<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 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, 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 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) has proved to be adequate for sampling many Hawaiian benthic communities (see Brock 1982; Brock and Norris 1989).

Information 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 Hawaii, Naval Undersea Center (see Evans 1974), and the Hawaii Division of Aquatic Resources 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 is reduced 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 1 m ∞ 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 four most recent surveys (1991, 1992, 1993, and 1994); 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.

If macrothalloid algae were encountered in the 1 m ∞ 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 by 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, 1993 data on 7–8 September 1993, and 1994 data on 20 September and 13–14 October 1994.

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 survey, but the locations have remained 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 1994 is presented in Table 1. In the quadrat survey, six coral species having a mean estimated coverage of 26.2% were encountered; the dominant species were *Porites lobata* and *Pocillopora meandrina*. Five algal species (*Desmia hornemannii*, *Amansia glomerata*, *Liagora maxima*, *Sphacelaria furcigera*, and *Enteromorpha* sp.) having a mean coverage of 1.1% were noted in the quadrats. The macroinvertebrate census noted two polychaetes (the Christmas tree worm *Spirobranchus giganteus corniculatus* and the featherduster worm *Sabellastarte sanctijosephi*), the boring bivalve *Lithophaga* sp., three sea urchin species (the long-spined sea urchin [or wana] *Echinothrix diadema*, the black urchin *Tripneustes gratilla*, and the green sea urchin *Echinometra mathaei*), as well as the sea star *Linckia multiflora*. 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 20 September 1994. Mean coral coverage in the photographic survey was estimated at 17.9%, with *Porites lobata* being the dominant coral.

In total 27 species of fishes representing 289 individuals were encountered on Transect T-1. The most common species included the yellowstripe goatfish or weke (*Mulloidichthys flavolineatus*), the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*), and the sleek unicornfish or kala holo (*Naso hexacanthus*). The standing crop of fishes on this transect was estimated at 726 g/m^2. The species contributing most heavily to this biomass were *Mulloidichthys flavolineatus* at 31%, *Naso hexacanthus* at 28%, and *Acanthurus olivaceus* at 21% of the total.

Transect T-2 was established 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. Four macroalgal species (*Amansia glomerata*, *Porolithon onkodes*, *Sphacelaria furcigera*, *Polysiphonia* sp., and *Liagora* sp.) having a mean coverage of 1.9% were noted in the quadrat survey. Also seen were one sponge species (*Spirastrella coccinea*) and six coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *P. eydouxi*, *Montipora verrucosa*, and *M. patula*) having an average coverage of 31.4%. The largest contributor to this coverage was *Porites lobata*. The macroinvertebrate census noted two polychaete species (*Spirobranchus giganteus corniculatus* and *Sabellastarte sanctijosephi*), the rock oyster *Spondylus tenebrosus*, the cone shell *Conus imperialis*, and three sea urchin species (*Tripneustes gratilla*, *Echinostrephus aciculatum*, and *Echinometra mathaei*). The photographic quadrat survey carried out on 20 September 1994 noted the coralline alga *Porolithon onkodes*, *Liagora* sp., and five coral species with a mean coverage of 25.1% (Table 2).

The results of the fish census are presented in the Appendix. Twenty-two fish species representing 168 individuals were censused on this transect; the most abundant species included *Mulloidichthys flavolineatus* and *Acanthurus olivaceus*. The standing crop of fishes was estimated at 723 g/m^2, and the species that contributed the most to this estimated weight was the roving school of *Mulloidichthys flavolineatus* (44% of the total).

Station B – Kalihi Entrance Channel

This station 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. 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, the fish censuses on both transects at this station are carried out prior to any other data collection. During our 1994 survey water clarity at this station was greater than 15 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 m in depth. A summary of the biological observations made at Transect T-3 is presented in Table 5. The quadrat survey noted two algal species (*Tolypiocladia glomerulata* and *Halimeda opuntia*) having a mean coverage of 0.5%, three sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and *Plakortis simplex*) with a mean coverage of 1.1%, two soft corals (*Palythoa tuberculosa* and *Anthelia edmondsoni*) having a mean coverage of 0.3%, and five coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa*, *M. verrilli*, and *M. patula*) having a mean estimated coverage of 1.6% (a decrease of 0.1% from the previous survey). The macroinvertebrate census noted an unidentified green and black polyclad species, one rock oyster (*Spondylus tenebrosus*), a hermit crab (*Aniculus strigatus*), four sea urchin species (*Echinostrephus aciculatum*, *Echinometra mathaei*, *Echinothrix calamaris*, and *E. diadema*) as well as the black sea cucumber *Holothuria atra*. The photographic quadrat survey found two unidentified sponge species and two coral species (*Porites lobata* and *Pocillopora meandrina*) having a mean coverage of 0.3% (down from 0.6% in the last survey).

The fish census found 13 species representing 30 individuals and an estimated standing crop of 27 g/m^2. The most abundant fishes at Transect T-3 included the lei triggerfish or humuhumu lei (*Sufflamen bursa*), 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 included a single spiny puffer or ‘o‘opu okala (*Diodon holocanthus*—56% of the total), and *Sufflamen bursa* (27% 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 (*Martensia fragilis* and *Tolypiocladia glomerulata*) with a mean coverage of 0.04%, three sponge species (*Spirastrella coccinea*, *Chondrosia chucalla*, and *Plakortis simplex*) having a mean coverage of 1.3%, a soft coral (*Anthelia edmondsoni*), and four coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa*, and *M. patula*). Coral coverage was estimated at 3.9% (up from 3.5% in the last survey), with *Porites lobata* and *Pocillopora* *meandrina* being the major contributors. The macroinvertebrate census noted the polychaete *Spirobranchus giganteus corniculatus*), the crab *Thalamita edwardsi*, three sea urchin species (i.e., the boring urchin *Echinostrephus aciculatum*, the green urchin *Echinometra mathaei*, and the black urchin *Echinothrix diadema*), as well as the starfish *Linckia diplax*. In the photographic quadrat survey two unidentified sponge species and three corals (*Porites lobata*, *Pocillopora meandrina*, and *Montipora* sp.) having a mean coverage of 2.4% were seen.

The fish census noted 20 individual fishes among 9 species (Appendix). The most common fishes present on this transect included *Sufflamen bursa*, *Pseudojuloides cerasinus*, *Acanthurus olivaceus*, and the sharpback puffer *Canthigaster jactator*. The standing crop of fishes on Transect T-4 was estimated at 23 g/m^2, and the important contributors to this biomass included a single barred filefish or ‘o(¯,o)‘ili (*Cantherhines dumerilii*—24% of the total) and *Acanthurus olivaceus* (42% 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 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 ranged from 10 to 15 m during our 1994 visits; usually clarity here does not exceed 12 m. On 14 October 1994, 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 October 1994 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 four algal species (*Porolithon onkodes*, *Amansia glomerata*, *Cladymenia pacifica*, and *Tolypiocladia glomerulata*) having a mean coverage of 16.3%, the soft coral *Palythoa tuberculosa* with a mean coverage of 0.1%, and six coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Pavona duerdeni*, *P. varians*, and *Montipora patula*) having a mean coverage of 1.9%. This coverage is up from 1.5% in the previous survey. The invertebrate census found one tiger cowry (*Cypraea tigris*), and three sea urchin species (*Tripneustes gratilla*, *Echinothrix calamaris*, and *Echinometra mathaei*) in the transect area. The photographic quadrat survey completed on 19 September 1994 (Table 2) noted three algal species (*Porolithon onkodes*, *Hydrolithon reinboldii*, and *Gibsmithsia hawaiiensis*), the soft coral *Palythoa tuberculosa*, and three coral species (*Pocillopora meandrina*, *Porites lobata*, and *Montipora* sp. [?]) having a mean estimated coverage of 0.8% (up from 0.4% in the previous year).

The fish census (Appendix) noted 169 individuals among 26 species. The most common species included the brown surgeonfish or maʻiʻi (*Acanthurus nigrofuscus*), a damselfish (*Chromis hanui*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fishes on Transect T-5 was estimated at 63 g/m^2, with the most important contributors including *Ctenochaetus strigosus* (25% of the total weight), the bulletnose parrotfish or uhu (*Scarus sordidus*—21% of the total), and *Acanthurus nigrofuscus* (14% 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 three algal species (*Porolithon onkodes*, *Martensia fragilis*, and *Tolypiocladia* sp.) having a mean coverage of 11.4%, 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 8.3%. This coral coverage estimate is up from last year's estimate of 5.2%. The census of macroinvertebrates noted four species: the terebellid polychaete worm *Loimia medusa*, the banded shrimp (*Stenopus hispidus*), the green sea urchin (*Echinometra mathaei*), and the long-spined black sea urchin or wana (*Echinothrix diadema*). The photo quadrat survey (Table 2) noted *Porolithon onkodes* with a mean coverage of

11.2%, the soft coral *Palythoa tuberculosa*, and four coral species (*Porites compressa*, *P. lobata*, *Pocillopora meandrina*, and *Montipora* sp. [?]) with a mean coverage of 6.5%.

The fish census noted 224 individuals belonging to 27 species in the 4 m ∞ 20 m area. The most abundant fishes on Transect T-6 included the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*), the goldring surgeonfish or kole (*Ctenochaetus strigosus*), and the bulletnose parrotfish or uhu (*Scarus sordidus*). The standing crop of fishes on this transect was estimated at 86 g/m^2; the largest contributors to this biomass included *Scarus sordidus* (31% of the total), *Ctenochaetus strigosus* (20% of the total), and *Acanthurus nigrofuscus* (15% 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 October 1994 field work, green sea 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 14 October 1994. These data are presented in Table 4. Little variation was noted in temperature (25.1° to 25.4°C), percent oxygen saturation (103% to 104%), 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 five surveys (1990, 1991, 1992, 1993, and 1994) are summarized as means for each transect in Table 9. The previous annual data are from Brock (1992a, 1992b, 1993, 1994). Differences are apparent for some of the parameters among the five 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 is only one parameter showing any statistically significant change over the five-year period. Parameters showing no statistically significant changes from the 1990 survey to the 1994 field effort include the mean coral cover on a transect ($p > 0.91$, df = 4, not significant), mean number of invertebrate species on a transect ($p > 0.16$, df = 4, not significant), mean number of individual invertebrates on a transect ($p > 0.81$, df = 4, not significant), mean number of fish species on a transect ($p > 0.41$, df = 4, not significant), mean number of individual fish on a transect ($p > 0.29$, df = 4, not significant), and mean standing crop on a transect ($p > 0.73$, df = 4, not significant). The mean number of coral species on a transect has generally increased during the period of this study, resulting in a statistically significant change ($p > 0.05$, df = 4). However, the Student–Newman–Keuls multiple range test demonstrated that there are no statistically significant differences among any of these parameters between the six stations and five sampling periods.

The biological parameters measured in the five 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 five 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 *Mulloidichthys flavolineatus* and weke‘ula or *M. vanicolensis*), amberjack or kahala (*Seriola dumerili*), emperor fish or mu (*Monotaxis grandoculis*), grey snapper or uku (*Aprion virescens*), and squirrelfish or menpachi (*Myripristis amaenus*).

DISCUSSION

Since their delineation in December 1990, the six transects have been visited on a number of occasions to insure 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 qualititative 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 of 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 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%; at the Reef Runway station it is 4%, and offshore of the Kewalo Landfill it is 25%.

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 1000 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 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, Lo(¯,a)na‘i, and Hawai‘i; this damage was primarily to coral communities. In many areas a large amount of sand and other loose material was moved and/or advected out of the shallow areas (i.e., depths of less than 27 m) into deeper waters. On O‘ahu, storm waves emanating from the southeast were estimated to exceed 7 m in height and were breaking in water at least 20 m deep (personal observations).

Storm damage to benthic and fish communities is frequently patchy, resulting in a mosaic of destruction (personal observations; 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 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 areas 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

1994) 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 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 five years (December 1990 to October 1994), show that there has been no statistically significant change in the biological parameters measured in this study other than for the mean number of coral species. In this case, the mean number of coral species has significantly increased through time, suggesting an improvement in conditions. This increase is probably related to the dispersion of live coral fragments by the hurricane and their subsequent survival and growth, rather than any real change in environmental conditions at the sampled stations.

In Table 9 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, 1993, and 1994 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 occur 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 (*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 Hawaiian reefs, estimated the standing crop of fishes to range from 4 g/m^2 on sand flats to a maximum of 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 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 *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, 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% to 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 *Mulloidichthys flavolineatus* that are resident to the old sewage discharge pipe made up 78% of the biomass present on Transect T-1 and 93% on Transect T-2; in 1993 this same school comprised 87% of the biomass present on Transect T-1 and 79% on Transect T-2. In 1994 *Mulloidichthys flavolineatus* made up 31% of the standing crop on Transect T-1 and 44% on Transect T-2.

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 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 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. Both the 1993 and 1994 data suggest that recovery from the hurricane is well underway, particularly in the coral communities.

REFERENCES CITED

AECOS, Inc. 1979. Postconstruction water quality, benthic habitat and epifaunal survey for the reef runway, Honolulu International Airport. Final report, Part B: Benthic biology. In Honolulu International Airport reef runway post-construction environmental impact report, vol. 2, technical report, ed. G.A. Chapman (unlisted appendix, 69 pp.). Prepared by Parsons Hawaii for Air Transportation Facilities Division, Department of Transportation, State of Hawaii.

Alevizon, W., R. Richardson, P. Pitts, and G. Serviss. 1985. Coral zonation and patterns of community structure in Bahamian reef fishes. *Bull. Mar. Sci.* 36:304–318.

Anderson, G.R.V., A.H. Ehrlich, P.R. Ehrlich, J.D. Roughgarden, B.C. Russell, and F.H. Talbot. 1981. The community structure of coral reef fishes. *Am. Nat.* 117:476–495.

Brock, R.E. 1982. A critique on the visual census method for assessing coral reef fish populations. *Bull. Mar. Sci.* 32:269–276.

Brock, R.E. 1986. Postconstruction biological survey for the Honolulu International Airport reef runway: Eight years later. In Survey of the water quality, benthic habitat and infaunal populations for Keehi Lagoon, Hickam Harbor and marine pond, Honolulu International Airport, ed. OI Consultants, Inc., B1–B28. Prepared for KFC Airport, Inc., Honolulu.

Brock, R.E. 1992a. Community structure of fish and macrobenthos at selected sites fronting Sand Island, Oahu, in relation to the Sand Island deep ocean outfall, December 1990 survey. Special Report 03.24:92, Water Resources Research Center, University of Hawaii at Manoa, Honolulu. 27 pp.

Brock, R.E. 1992b. Community structure of fish and macrobenthos at selected sites fronting Sand Island, Oahu, in relation to the Sand Island deep ocean outfall, December 1991 survey. Special Report 04.30:92, Water Resources Research Center, University of Hawaii at Manoa, Honolulu. 36 pp.

Brock, R.E. 1993. Community structure of fish and macrobenthos at selected sites fronting Sand Island, O‘ahu, in relation to the Sand Island deep ocean outfall, Year 3—1992. Special Report 01.29:93, Water Resources Research Center, University of Hawaii at Manoa, Honolulu. 37 pp.

Brock, R.E. 1994. 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. Project Report PR-94-14, Water Resources Research Center, University of Hawaii at Manoa, Honolulu. 36 pp.

Brock, R.E., C. Lewis, and R.C. Wass. 1979. Stability and structure of a fish community on a coral patch reef in Hawaii. *Mar. Biol.* 54:281–292.

Brock, R.E., and J.E. Norris. 1989. An analysis of the efficacy of four artificial reef designs in tropical waters. *Bull. Mar. Sci.* 44:934–941.

Brock, V.E. 1954. A preliminary report on a method of estimating reef fish populations. *J. Wildlife Mgmt.* 18:297–308.

Chapman, G.A. (ed.). 1979. Honolulu International Airport reef runway post-construction environmental impact report, vol. 2, technical report. Prepared by Parsons Hawaii for Air Transportation Facilities Division, Department of Transportation, State of Hawaii. 76 pp. + appendixes.

Connell, J. 1978. Diversity in tropical rain forests and coral reefs. *Science* 199:1302–1310.

Cox, D.C., and L.C. Gordon, Jr. 1970. Estuarine pollution in the state of Hawaii—Volume 1: Statewide study. Tech. Rep. No. 31, Water Resources Research Center, University of Hawaii at Manoa, Honolulu. 151 pp.

Dollar, S.J. 1979. Ecological response to relaxation of sewage stress off Sand Island, O‘ahu, Hawai‘i. Tech. Rep. No. 124, Water Resources Research Center, University of Hawaii at Manoa, Honolulu. 78 pp.

Dollar, S.J. 1982. Wave stress and coral community structure in Hawaii. *Coral Reefs* 1:71–81.

Eckert, G.J. 1985. Settlement of coral reef fishes to different natural substrata and at different depths. *Proc. 5th Int. Coral Reef Congr.* 5:385–390.

Evans, E.C. (ed.). 1974. Pearl Harbor biological survey—final report. Report No. NUC-TN-1128, Naval Undersea Center, Hawaii Laboratory.

Gladfelter, W.B., and E.H. Gladfelter. 1978. Fish community structure as a function of habitat structure on West Indian patch reefs. *Rev. Biol. Trop.* 26(Supplement 1):65–84.

Goldman, B., and F.H. Talbot. 1975. Aspects of the ecology of coral reef fishes. In *Biology and Geology of Coral Reefs,* Vol. III, Biology 2, ed. O.A. Jones and R. Endean, 124–154. New York: Academic Press.

Grigg, R. 1983. Community structure, succession and development of coral reefs in Hawaii. *Mar. Ecol. Prog. Ser.* 11:1–14.

Grigg, R., and J. Maragos. 1974. Recolonization of hermatypic corals on submerged lava flows in Hawaii. *Ecology* 55:387–395.

Odgen, J.C., and J.P. Ebersole. 1981. Scale and community structure of coral reef fishes: A long-term study of a large artificial reef. *Mar. Ecol. Prog. Ser.* 4:97–104.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Bd. Canada* 191. 382 pp.

Risk, M.J. 1972. Fish diversity on a coral reef in the Virgin Islands. *Atoll Res. Bull.* 153:1–6.

Sale, P.J. 1977. Maintenance of high diversity in coral reef fish communities. *Am. Nat.* 111:337–359.

SAS Institute, Inc. 1985. SAS user's guide: Basics, version 5 edition. SAS Institute Inc., Cary, N.C. 1,290 pp.

Scott, E.B. 1968. *The saga of the Sandwich Islands.* Crystal Bay, Lake Tahoe, Nevada: Sierra-Tahoe Publishing Co. 933 pp.

Shulman, M.J. 1984. Resource limitation and recruitment patterns in a coral reef fish assemblage. *J. Exp. Mar. Biol. Ecol.* 74:85–109.

Shulman, M.J., J.C. Ogden, J.P. Ebersole, W.N. McFarland, S.L. Miller, and N.G. Wolf. 1983. Priority effects in the recruitment of juvenile coral reef fishes. *Ecology* 64:1508–1513.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. New York: McGraw-Hill Book Co. 312 pp.

Sokal, R.R., and F.J. Rohlf. 1981. *Biometry,* 2nd ed. New York: W.H. Freeman. 855 pp.

Walsh, W.J. 1983. Stability of a coral reef fish community following a catastrophic storm. *Coral Reefs* 2:49–63.

Walsh, W.J. 1985. Reef fish community dynamics on small artificial reefs: The influence of isolation, habitat structure, and biogeography. *Bull. Mar. Sci.* 36:357–376.

Woodley, J.D., and 19 others. 1981. Hurricane Allen's impact on Jamaican coral reefs. *Science* 214:749–755.

TABLE 1. Summary of Biological Observations Made at Transect T-1, Offshore of Kewalo Landfill (Station A) on 20 September 1994

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Desmia hornemannii	2.6				
Amansia glomerata			0.1	0.7	
Enteromorpha sp.		0.1	0.1		
Liagora maxima				0.8	0.3
Sphacelaria furcigera					1
Sponges					
Spirastrella coccinea	0.1	0.1			
Corals					
Porites lobata	38	11	10	32	4
Porites compressa	0.7		0.2	3.2	
Pocillopora meandrina	1	5.5	3.4	6.5	15
Montipora verrucosa		0.1	0.1		
Montipora verrilli			0.1		
Montipora patula			0.2	0.1	0.1
Sand	2		3	0.7	7
Rubble	3		4		7
Hard Substratum	52.6	83.2	78.8	56	65.6

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Annelida					
Spirobranchus giganteus corniculatus	13				
Sabellastarte sanctijosephi	2				
Phylum Mollusca					
Lithophaga sp.	1				
Phylum Echinodermata					
Echinothrix diadema	5				
Tripneustes gratilla	1				
Echinometra mathaei	2				
Linckia multiflora	3				

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

289 Individuals					
Estimated Standing Crop = 726 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 26.2% (quadrat method).

TABLE 2. Summary of Results for the Photographic Quadrat Survey for 1994

Station A: Transect 1-1 (Sampled 20 September 1994)	Photographic Quadrat				
	AAA1 (0 m)	AAA2 (5 m)	AAA3 (10 m)	AAA4 (15 m)	AAB1 (20 m)
Corals					
Porites lobata	25.8	8.7	1.1	23.5	3.6
Porites compressa			0.3	2.0	
Pocillopora meandrina		3.6	3.6	9.2	8.1
Sand	1.4		2.8	0.3	1.7
Rubble	4.5	1.4	6.7	0.6	6.7
Hard Substratum	68.3	86.3	85.4	64.4	79.8

Mean Coral Coverage = 17.9%

Station A: Transect 1-2 (Sampled 20 September 1994)	Photographic Quadrat				
	AAB2 (0 m)	AAB3 (5 m)	AAB4 (10 m)	AAC1 (15 m)	AAC2 (20 m)
Algae					
Porolithon onkodes			0.3		
Liagora sp.					0.3
Corals					
Porites lobata	21.8	9.2	44.0	21.6	12.9
Porites compressa	0.03		0.6		
Pocillopora meandrina		1.1	4.8	2.5	5.0
Pocillopora eydouxi (?)				2.0	
Montipora patula		0.1			
Sand	0.8	0.3		0.3	0.6
Rubble	2.5		4.2	2.0	
Hard Substratum	74.5	89.2	45.9	71.7	81.2

Mean Coral Coverage = 25.1%

Station B: Transect 1-3 (Sampled 22 September 1994)	Photographic Quadrat				
	BAA1 (0 m)	BAA2 (5 m)	BAA3 (10 m)	BAA4 (15 m)	BAB1 (20 m)

Unidentified red sponge					
(probably *Spirastrella coccinea*)	0.1				0.6
Unidentified black sponge					
(probably *Chondrosia chucalla*)	0.3				
Corals					
Porites lobata		0.3		0.1	
Pocillopora meandrina			0.7	0.3	
Sand	9.5	5.6	2.2	5.0	2.5
Rubble	3.1			5.0	
Hard Substratum	87.0	94.1	97.2	89.4	96.9

Mean Coral Coverage = 0.3%

TABLE 2—*Continued*

Station B: Transect 1-4 (Sampled 22 September 1994)	Photographic Quadrat				
	BAB2	BAB3	BAB4	BAC1	BAC2
	(0 m)	(5 m)	(10 m)	(15 m)	(20 m)
Unidentified red sponge					
(probably *Spirastrella coccinea*)	0.6	0.8	0.8	0.3	
Unidentified black sponge					
(probably *Chondrosia chucalla*)				0.1	
Corals					
Porites lobata		6.2	0.4	0.6	
Pocillopora meandrina			0.8	1.1	2.5
Montipora sp.			0.3		
Sand	1.7	0.6	2.8	2.0	2.0
Rubble	5.6	4.5			3.6
Hard Substratum	92.2	88.0	94.8	95.9	91.9

Mean Coral Coverage = 2.4%

Station C: Transect 1-5 (Sampled 19 September 1994)	Photographic Quadrat				
	CAB1	CAA4	CAA3	CAA2	CAA1
	(0 m)	(5 m)	(10 m)	(15 m)	(20 m)
Algae					
Porolithon onkodes		7.3	8.4	11.2	11.2
Hydrolithon reinboldii			4.5		1.1
Gibsmithsia hawaiiensis			0.3		
Soft Corals					
Palythoa tuberculosa		0.3			1.7
Corals					
Porites lobata				1.7	
Pocillopora meandrina		0.3		0.3	0.4
Montipora (?)		0.7		0.6	
Sand	3.9				
Rubble	11.2	22.4	23.5		
Hard Substratum	84.9	69.0	63.3	86.3	85.6

Mean Coral Coverage = 0.8%

Station C: Transect 1-6 (Sampled 19 September 1994)	Photographic Quadrat				
	CAB2 (0 m)	CAB3 (5 m)	CAB4 (10 m)	CAC1 (15 m)	CAC2 (20 m)
Algae					
Porolithon onkodes	23.8	5.8		21.3	5.3
Soft Corals					
Palythoa tuberculosa					0.8
Corals					
Porites lobata	16.0			9.5	4.2
Porites compressa	0.1				
Pocillopora meandrina	0.6				
Montipora sp. (?)	0.8	0.7		0.6	
Sand			0.6		
Rubble			99.4	7.8	
Hard Substratum	58.7	93.4		60.8	89.6

Mean Coral Coverage = 6.5%

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) on 20 September 1994

	Quadrat Distance Along Transect				
I. Quadrat Survey	0 m	5 m	10 m	15 m	20 m
Algae					
Amansia glomerata	0.7				0.1
Porolithon onkodes			0.7		
Sphacelaria furcigera	0.5	1		2	4
Polysiphonia sp.	0.2				
Liagora sp.					0.1
Sponges					
Spirastella coccinea			1	0.5	0.2
Corals					
Porites lobata	26	11	53	36	11
Porites compressa			0.6	0.2	
Pocillopora meandrina		1.1	3.3	4	3.5
Pocillopora eydouxi				4	
Montipora verrucosa		0.1	2.8		0.1
Montipora patula		0.1			
Sand	1				2
Hard Substratum	71.6	86.9	41.4	53.3	79
II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Spondylus tenebrosus	3				
Conus imperialis	1				
Phylum Annelida					
Spirobranchus giganteus corniculatus	23				
Sabellastarte sanctijosephi	1				
Phylum Echinodermata					
Tripneustes gratilla	2				
Echinostrephus aciculatum	1				
Echinometra mathaei	1				
III. Fish Census (4 m ∞ 20 m)					
22 Species					
168 Individuals					

Estimated Standing Crop = 723 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 31.4% (quadrat method).

TABLE 4. Summary of Physical Measurements Made at Each of Three Locations in the Vicinity of Transect Pairs on 6 December 1991, 22 December 1992, 9 September 1993, and 14 October 1994

Location and Time	Oxygen (% of Saturation)		Salinity	Temperature (°C)		Depth to Secchi Extinction
	Top	Bottom	(‰)	Top	Bottom	(m)
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

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 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, and 14 October 1994

Location and Time	Oxygen (% of Saturation)		Salinity	Temperature (°C)		Depth to Secchi Extinction
	Top	Bottom	(‰)	Top	Bottom	(m)
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

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 Keehi Lagoon) on 13 October 1994

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Tolypiocladia glomerulata	2	0.2		0.3	
Halimeda opuntia				0.1	
Sponge					
Spirastrella coccinea	0.4	0.2	1.3	1	1
Chondrosia chucalla	0.2	0.1		0.1	
Plakortis simplex					1.2
Soft Coral					
Palythoa tuberculosa			0.2		
Anthelia edmondsoni			0.1	0.1	1
Corals					
Porites lobata	1.7	0.6	0.9	0.4	0.3
Pocillopora meandrina		1.2	0.6	0.3	
Montipora verrucosa	0.1	0.1	0.1		0.7
Montipora patula			0.9		0.1
Montipora verrilli			0.1		
Sand	25	29	4	19	4
Rubble	2	2	2	9	4
Hard Substratum	68.6	66.6	89.8	69.7	87.7

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Platyhelminthes					
Polyclad sp.	1				
Phylum Mollusca					
Spondylus tenebrosus	1				
Phylum Arthropoda					
Aniculus strigatus	1				
Phylum Echinodermata					
Echinostrephus aciculatum	4				
Echinometra mathaei	1				
Echinothrix calamaris	3				
Echinothrix diadema	4				
Holothuria atra	1				

III. Fish Census (4 m ∞ 20 m)					
13 Species					
30 Individuals					
Estimated Standing Crop = 27 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 1.6% (quadrat method).

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 Keehi Lagoon) on 13 October 1994

I. Quadrat Survey		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Algae						
Martensia fragilis						0.1
Tolypiocladia glomerulata				0.1		
Sponge						
Spirastrella coccinea		0.8	1.1	1	1.1	2
Chondrosia chucalla				0.1	0.1	
Plakortis simplex					0.1	0.1
Soft Corals						
Anthelia edmondsoni				0.1		0.1
Corals						
Porites lobata		2.2	8.4	0.2	0.9	2.4
Pocillopora meandrina				0.8	1.2	1.3
Montipora verrucosa		0.1	0.3	0.1	0.1	
Montipora patula		0.2	1.1			0.2
Sand		18	9	7	17	2
Rubble		5	9		3	
Hard Substratum		73.7	71.1	90.6	77.5	91.8

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Annelida					
Spirobranchus giganteus corniculatus	3				
Phylum Arthropoda					
Thalmita edwardsi	1				
Phylum Echinodermata					
Echinostrephus aciculatum	4				
Echinometra mathaei	2				
Echinothrix diadema	3				
Linckia diplax	1				

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

20 Individuals					
Estimated Standing Crop = 23 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 3.9% (quadrat method).

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 13 October 1994

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Porolithon onkodes		31	22	13	15
Amansia glomerata	0.2				
Cladymenia pacifica				0.1	
Tolypiocladia glomerulata	0.1				
Soft Coral					
Palythoa tuberculosa		0.2	0.1	0.2	0.2
Corals					
Porites compressa			0.2		
Porites lobata			0.2		
Pocillopora meandrina	0.1	0.1	0.2	0.1	1.1
Pavona duerdeni				5	0.6
Pavona varians		0.1			0.4
Montipora patula		0.2		1	0.3
Tunicates					
Bortryllus sp.			0.1		
Sand	1		1		
Rubble	56.6	5	18	2	
Hard Substratum	42	63.4	58.2	78.6	82.4

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Mollusca					
Cypraea tigris	1				
Phylum Echinodermata					
Tripneustes gratilla	1				
Echinothrix calamaris	1				
Echinometra mathaei	3				

III. Fish Census (4 m ∞ 20 m)					
26 Species					
169 Individuals					
Estimated Standing Crop = 63 g/m²					

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 1.9% (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 13 October 1994

I. Quadrat Survey	Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Algae					
Porolithon onkodes	29	8		14	5
Tolypiocladia sp.		0.4			0.1
Martensia fragilis					0.3
Soft Coral					
Anthelia edmondsoni		0.3	0.2	0.3	
Palythoa tuberculosa	0.8				2
Corals					
Porites lobata	10	0.3	0.2	10	14.1
Pocillopora meandrina	1	0.2	0.1	0.1	0.1
Montipora verrucosa				1	
Montipora patula	1.3	1.2		1.2	
Pavona duerdeni		0.5			
Pavona varians		0.1		0.3	
Sand			2		
Rubble		51			
Hard Substratum	57.9	38	97.5	73.1	78.4

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals
Phylum Annelida	
Loimia medusa	2
Phylum Arthropoda	
Stenopus hispidis	2
Phylum Echinodermata	
Echinometra mathaei	7
Echinothrix diadema	1

III. Fish Census (4 m ∞ 20 m)
27 Species
224 Individuals
Estimated Standing Crop = 86 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 8.3% (quadrat method).

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

Parameter	1990						1991					
	Transect (T-)						Transect (T-)					
	1	2	3	4	5	6	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						1993					
	Transect (T-)						Transect (T-)					
	1	2	3	4	5	6	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

Parameter	1994											
	Transect (T-)											
	1	2	3	4	5	6						

% Coral Cover	26.2	31.4	1.6	3.9	1.9	8.3						
No. of Coral Species	6	6	5	4	6	6						
No. of Invertebrate Species	7	7	8	6	4	4						
No. of Invertebrate Individuals	27	32	16	14	6	12						
No. of Fish Species	27	22	13	9	26	27						
No. of Fish Individuals	289	168	30	20	169	224						
Biomass (g/m^2)	726	723	27	23	63	86						

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 1990, 1991,1992, and 1993 are from Brock (1992a, 1992b, 1993, 1994).

APPENDIX

Results of the Quantitative Visual Fish Censuses Conducted at Six Locations Offshore of Sand Island, O‘ahu, Hawai‘i, 20 September and 13–14 October 1994

FAMILY and Species	Transect					
	T-1	T-2	T-3	T-4	T-5	T-6
MURAENIDAE						
Gymnothorax meleagris		2				
HOLOCENTRIDAE						
Myripristis amaenus					1	
CARANGIDAE						
Scomberoides laysan	2					
LUTJANIDAE						
Aprion virescens	4	1				
MULLIDAE						
Mulloidichthys flavolineatus	52	80				
Mulloidichthys vanicolensis					1	
Parupeneus multifasciatus	5	2			3	1
Parupeneus porphyreus	2					
Parupeneus pleurostigma	3					
CHAETODONTIDAE						
Forcipiger flavissimus	2	2			1	2
Chaetodon multicinctus	4		2			2
POMACANTHIDAE						
Centropyge potteri			1		1	
POMACENTRIDAE						
Dascyllus albisella						6
Plectroglyphidodon johnstonianus	3					
Chromis vanderbilti		13	2		4	9
Chromis hanui					14	8
Chromis agilis						3
Stegastes fasciolatus					8	2
CIRRHITIDAE						
Paracirrhitus arcatus	7	3	3		2	1

Cirrhitops fasciatus					1	1
Cirrhitus pinnulatus					1	1
LABRIDAE						
Labroides phthirophagus						2
Bodianus bilunulatus	2					
Chelio inermis	1					
Cheilinus bimaculatus		3	1			
Pseudocheilinus octotaenia					3	
Thalassoma duperrey	8		5	2	11	17
Thalassoma ballieui						1
Gomphosus varius					5	7
Coris gaimard	2	2				1
Coris venusta					2	1
Pseudojuloides cerasinus	2		4	3		
Stethojulis balteata					2	11
Macropharyngodon geoffroy					2	
Anampses chrysocephalus						1
Halichoeres ornatissimus	2				1	1

Continued

FAMILY and Species	Transect					
	T-1	T-2	T-3	T-4	T-5	T-6
SCARIDAE						
Calotomus carolinus	1					
Scarus psittacus	12	4				
Scarus sordidus					12	37
Scarus perspicillatus	5					
Scarus rubroviolaceus		1				
GOBIIDAE						
Gnathelepis anjerensis			2	2		
ACANTHURIDAE						
Acanthurus nigrofuscus	15	13	1		30	47
Acanthurus nigroris		4				
Acanthurus olivaceus	27	15		3		
Acanthurus dussumieri		1		1		
Acanthurus triostegus	12					
Ctenochaetus strigosus					46	54

Naso lituratus					5	
Naso hexacanthus	108					
Naso brevirostris	1					
Naso unicornis		10			4	
ZANCLIDAE						
Zanclus cornutus		2				
BOTHIDAE						
Bothus pantherinus			1			
BALISTIDAE						
Melichthys niger					2	3
Melichthys vidua		1				
Sufflamen bursa	3	3	6	4		1
Rhinecanthus aculeatus				1		
MONACANTHIDAE						
Pervagor spilosoma					1	
Pervagor melanocephalus						1
Cantherhines dumerilii				1		
CANTHIGASTERIDAE						
Canthigaster jactator	2	4	1	3	6	3
Canthigaster coronata	2					
TETRAODONTIDAE						
Diodon holocanthus		1	1			

Total No. of Species	27	22	13	9	26	27
Total No. of Individuals	289	168	30	20	169	224
Estimated Standing Crop (g/m^2)	726	723	27	23	63	86

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.