COMMUNITY STRUCTURE OF FISH AND MACROBETHOS AT SELECTED SITES FRONTING SAND ISLAND, O‘AHU, IN RELATION TO THE SAND ISLAND DEEP OCEAN OUTFALL, DECEMBER 1991 SURVEY

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ABSTRACT

This report constitutes the second year of an annual monitoring (carried out on 5–6 December 1991) of shallow marine communities inshore of the Sand Island deep ocean outfall. This quantitative 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. Raw sewage was dumped in shallow water until 1978; point and non-point sources of pollution from both urban sources and industry continue. All of these disturbances may serve to obscure any possible impacts from the deep ocean outfall discharge. The marine communities show a considerable range in development that is probably related to past (historical) impacts. Stations have been sited to take advantage of these gradients. Analysis of the first year's data show that there has been no statistically significant change in the biological measures quantified in this study. These measures include the 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. Thus, in this second year, there has not been a quantitatively discernable impact to the shallow water benthic and fish communities that could be attributed to the operation of the deep 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 3 m^3/sec (62 mgd) 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 (67–73 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) marine communities fronting Honolulu and Sand Island. Accordingly, this study was undertaken commencing in 1990 in an attempt to quantitatively ascertain the impacts that may be occurring. This document presents the results of the second annual survey, carried out in 1991.

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 acute potential impact (as channel dredging) demands a survey designed to determine the route of least harm and the projected rate and degree of ecosystem recovery. Impacts that are chronic or progressive require different strategies for measurement. Management of chronic stress to a marine ecosystem demands identification of system perturbations which exceed boundaries of natural fluctuations. Thus a thorough understanding of normal ecosystem variability is required in order to separate the impact signal from background "noise."

The potential impacts confronting the marine ecosystem offshore of Sand Island and Honolulu Harbor are most probably those associated with chronic or progressive stresses. Because of the proximity of the population center and industry, marine communities fronting Honolulu Harbor 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 Nuuanu Stream. This dredging commenced before 1900 and periodic maintenance dredging has been undertaken up to the present time. Up until about 1960 dredging spoils were dropped just outside of the harbor; generally to the east of the Sand Island Sewer Outfall. In addition to shipping, the harbor is ringed with industry; pineapple canneries, gas and oil storage, and numerous other businesses operate around the harbor. Storm drainage into the harbor and nearby Ke'ehi Lagoon carries runoff from Honolulu's streets and suburbs into the ocean. Pollution is well known in the harbor. Cox and

Gordon (1970) cite references describing these conditions as early as 1920. Sewage has been pumped into the ocean offshore of Kewalo and Sand Island since the 1930's. These 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 have occurred, or are still occurring, in shallow water (< 20 m) up until the construction of the present deep water outfall in 1978 serve to obscure the impacts that the present discharge of effluent may be having.

The waters fronting Sand Island, into which the deep ocean outfall discharges, may be considered in terms of gradients. There are numerous "gradients" due to point (storm drains, streams, etc.) and non-point inputs into Honolulu Harbor and environs 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 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 due to the deep ocean outfall, these are probably chronic in nature thus causing a slow decline in the communities so impacted. Gradients of "stress" or "impact" should be evident with distance from impact source(s). Thus to quantitatively define these impacts, one should monitor these communities through time in areas suspected of being impacted as well as in similar communities at varying distances away from the suspected source(s). This rationale has been used in developing the sampling strategy for this study.

MATERIALS AND METHODS

The quantitative sampling of macrofauna of marine communities presents a number of problems; many of 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 residing in a *Pocillopora meandrina* coral head) to major biotopes covering many hectares. Because considerable interest focuses on visually dominant corals, diurnally exposed macroinvertebrates, and fishes, a sampling program was designed that attempted to delineate changes that may be occurring in communities at this scale.

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

Station A (Kewalo Landfill) lying east of the present deep ocean outfall in about 16 m of water was utilized as a control area (Fig. 1). 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 percent. This station is in the vicinity of Dollar's (1979) Station 2.

Station B (Kalihi Channel) was located about 120 m east of the Kalihi Entrance channel in approximately 15 m of water. This station was about 900 m west of the of the bypass (old) outfall in an area heavily impacted by the old (1955–1977) shallow water discharge and was very close to Dollar's (1979) Station 14. Again, there was emergent limestone at this station but coral coverage was low (>1%).

Station C (Reef Runway) was located in an area of complex limestone substratum, in water ranging from 7.5 to 12 m deep, fronting Honolulu International Airport's Reef Runway. This station location was close to Brock's (1986) station that was monitored quarterly in 1977–1978 (AECOS, Inc. 1979) and again in 1986. It was close to Dollar's (1979) Station 19. This site was moderately impacted by the old, shallow water sewage outfall (Dollar 1979).

At each site two transect lines were permanently established using metal stakes and plastic coated no. 14 copper wire. Transects were 20 m in length and were orientated perpendicular to shore. Two transects were established at each location to provide some replication. At each station, both transects sampled approximately the same benthic community. On each transect there were five permanently marked locations (0 m, 5 m, 10 m, 15 m, 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 the first (1990) survey.

Fish abundance and diversity is 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) sample more than one community and thereby obscure distinctive features of individual communities. To alleviate this problem, a short transect (20 m in length) has proven adequate for sampling many Hawaiian benthic communities (see Brock 1982; Brock and Norris 1989).

Information collected at each transect location included a visual assessment of fishes and 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 macro-invertebrates. Fish censuses were conducted over a 20 ∞ 4 m corridor (the permanent transect line) and all fishes within this area to the water's surface were counted. A single diver equipped with SCUBA, slate and pencil entered the water, counted and noted 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 was estimated; these length data were later used in the estimation of fish standing-crop by linear regression techniques (Ricker 1975). Species specific regression coefficients have been developed over the last thirty years by the author and others at the University of Hawaii, Naval Undersea Center (see Evans 1974) and the Hawaii State Division of Aquatic Resources through capturing, weighing and measuring fishes; for many species, sample sizes were in excess of a hundred individuals. 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 (R. Brock) performed 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, e.g., squirrelfishes (Family Holocentridae), bigeyes or aweoweos (Family Priacanthidae), etc. 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 (e.g., the nohus [Family Scorpaenidae] and the flatfishes [Family Bothidae]) might still be missed. Obviously the effectiveness of the visual census technique is reduced in turbid water and species of fishes which move quickly and/or are very numerous may be difficult to count. Additionally, bias related to the experience of the diver conducting counts should be considered in making comparisons between surveys. In spite of these drawbacks, the visual census technique probably provides the most accurate nondestructive assessment of diurnally active fishes presently available (Brock 1982).

A number of methods were utilized to quantitatively assess benthic communities at each station; these methods included the use of photographs taken at locations marked for repeated sampling through time (each covering 0.67 m^2) and the establishment of 1 ∞ 1 m quadrats also placed at marked locations for repeated measurements. The photographs and quadrats were both used to estimate coverage of corals and other sessile forms. Photographs provided a permanent record from which to estimate coverage and were used in 1991. The 1 ∞ 1 m quadrats were used for an "in the field" appraisal of coverage in both 1990 and 1991. Cover estimates from photographs and quadrats were all recorded as percent cover. Diurnally exposed motile macroinvertebrates greater than 2 cm in some dimension were 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, simple physical measurements were made at the three sites while in the field. Measurements were made of percent oxygen concentration and temperature with a YSI Model 57 oxygen meter, salinity was measured with a hand held refractometer, and a 12-inch secchi disk was used to determine water clarity.

Data were subjected to simple non-parametric statistical procedures provided in the SAS Institute statistical package (SAS Institute 1985). Non-parametric methods were used to avoid meeting requirements of normal distribution and homogeneity of variance in the data. Data analysis utilized the Wilcoxon matched-pairs signed-ranks test as outlined by Siegel (1956).

During the course of the fieldwork, an effort was made to note 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 presents 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. The 1991 data were collected on 5–6 December 1991 from the same locations.

Malfunction of a new camera caused the loss of all photographic quadrat data for all stations in the previous (1990) field effort. After having photographed all quadrat sites in December 1990, the camera and undeveloped film were placed in a drawer and left until mid-1991 when the film was submitted for development. Camera malfunction was responsible for this loss of data and the camera was subsequently repaired. To avoid a recurrence of this problem, the 1991 photographic data were collected by Mr. A. Muranaka (City and County of Honolulu) for the 1991 survey. However, the 1990 square meter quadrat data provided information on benthic coverage in the first annual effort. In the 1991 survey both photographic and quadrat methods were used to assess the benthic communities.

The results are presented below by station.

Station A – Kewalo Landfill Station

This station was located 600 m offshore of the old Kewalo Landfill in water ranging from 17 to 18 m deep on a substratum dominated by limestone with moderate coral community development. The two transects were 35 m apart, out of visual range of one another (see Fig. 2). Visibility at this station usually ranged from 15 to 20 m.

A summary of the data collected at Transect 1 in December 1991 is presented in Table 1. In the quadrat survey, five coral species were encountered having a mean estimated coverage of 18 percent; the dominant species were *Porites lobata* and *Pocillopora meandrina*. One red sponge (*Spirastrella coccinea*) was noted in the quadrats. The macroinvertebrate census noted one cone shell (*Conus miles*), a polychaete (the Christmas tree worm [*Spirobrachus giganteus corniculatus*]), and two echinoderms (the sea cucumber [*Holothuria atra*] and the long-spined sea urchin or wana [*Echinothrix diadema*]). The results of the fish census carried out at Transect 1 are given in Appendix Table A. Table 2 presents the results of the photographic survey. The mean coral coverage in the photographic survey was estimated to be 12 percent with *Porites lobata* being the dominant coral.

In total, 31 species of fishes and 260 individuals were encountered on Transect 1. The most common species included: the manybar goatfish or moano (*Parupeneus multifasciatus*), the damselfish (*Chromis vanderbilti*), saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*), smalltail wrasse (*Pseudojuloides cerasinus*), and the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*). The standing crop of fishes on this transect was estimated to be 148 g/m^2. The species contributing most heavily to this biomass were the yellowmargin moray eel or puhi-paka (*Gymnothorax flavomarginatus*), the saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*), and the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*).

Transect 2 was also established offshore of the Kewalo Landfill approximately 35 m west of Transect 1 in water ranging from 17 to 18.2 m deep. Table 3 presents a summary of the biological information collected at this transect site. The quadrat survey noted one macroalgal species (*Desmia hornemanni)* and four coral species (*Porites lobata, P. compressa, Pocillopora meandrina,* and *Montipora verrucosa*) having an average coverage of 29.3 percent. The largest contributor to this coverage is *Porites lobata*. The invertebrate census counted one cone shell (*Conus lividus)*, two polychaete species (the Christmas tree worm [*Spirobranchus giganteus corniculatus*] and the feather duster worm [*Sabellastarte sanctijopsephi*]), and one sea urchin species (*Echinothrix diadema*). The photographic quadrat survey noted two algal species (*Porolithon onkodes* and *Corallina* sp) as well as three coral species having a mean coverage of 24 percent. Also present was an unidentified sponge which was probably *Spirastrella coccinea* (Table 2).

The results of the fish census are presented in Appendix Table A. Twenty-six fish species were counted (240 individuals) on this transect. The most abundant species included the yellowstripe goatfish or weke (*Mulloides flavolineatus*), damselfish (*Chromis vanderbilti*), the saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*), the smalltail wrasse (*Pseudojuloides cerasinus*), the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*), and the sleek unicornfish or kala holo (*Naso hexacanthus*). The standing crop of fishes was estimated to be 221 g/m^2 and the species that contributed the most to this estimated weight included the yellowstripe goatfish or weke (*Mulloides flavolineatus*), the saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*), and the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*).

Station B – Kalihi Entrance Channel

Two transects (numbers 3 and 4) were established on a limestone substratum about 120 m east of the Kalihi Entrance Channel in 13.7 to 15 m of water. This station was located about 2.2 km seaward of Mokauea Island situated in Ke‘ehi Lagoon and about 900 m west of the old outfall which is presently used as an emergency bypass. Much of the substratum in the vicinity of this station was comprised of sand and rubble. An area of low emergent limestone approximately 60 m wide and 110 m in length with the long axis oriented perpendicular to shore was present; Transect 3 was located on the deeper end of this hard substratum area. Transect 4 paralleled Transect 3 but was shoreward of this, and approximately 8 m to the west (see Fig. 3). Visibility at this station ranged from 6 to 10 m. The lack of appropriate hard substratum necessitated establishing the two transects at this station on an "end to end" fashion relatively close to one another (8 m apart). Because of the close proximity, the fish censuses at these stations were carried out on both transects prior to any other data collection.

Transect 3 had an orientation perpendicular to shore on the limestone substratum in water from 14.6 to 15 m in depth. Table 4 presents a summary of the biological observations made at Transect 3. The quadrat survey noted one sponge species (*Microciona maunaloa*), a soft coral (*Anthelia edmondsoni*), and three coral species (*Porites lobata*, *Pocillopora meandrina*, and *Montipora verrucosa*). The corals had an estimated mean coverage of 3.9 percent with *Pocillopora meandrina* providing the greatest coverage. The invertebrate census noted one rock oyster (*Spondylus tenebrosus*) and three sea urchin species (*Echinostrephus aciculatum, Echinometra mathaei,* and *Echinothrix diadema*). The photographic quadrat survey found an unidentified red sponge species (probably *Microciona maunaloa* which is in the area) and three coral species (*Porites lobat*a, *Pocillopora meandrina,* and *Fungia scutaria*) having a mean coverage of 4 percent.

The fish census (App. Table A) found 22 species, 138 individuals, and an estimated standing crop of 72 g/m^2. The most abundant fishes at Transect 3 included the manybar goatfish or moano (*Parupeneus multifasciatus)*, damselfish (*Chromis vanderbilti*), smalltail wrasse (*Pseudojuloides cerasinus*), and the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*). The fish species contributing heavily to the biomass on Transect 3 included the manybar goatfish or moano (*Parupeneus multifasciatus*), the tableboss or a‘awa (*Bodianus bilunulatus),* and the barred filefish or ‘o‘ili (*Cantherhines dumerili*).

Transect 4 also sampled the benthic and fish community present in the vicinity of the Kalihi Entrance Channel. As with the previous transect, Transect 4 sampled the limestone substratum at a depth ranging from 13.7 to 14 m. Table 5 presents a summary of the biological data collected on Transect 4. The quadrat survey noted one sponge species (*Tedania ignis)* and three coral species (*Porites lobata, Pocillopora meandrina,* and *Montipora verrucosa*). Coral coverage was estimated to be 3.4 percent. *Porites lobata* as well as *Pocillopora meandrina* were the major contributors to this coverage. The invertebrate census noted one small cone shell (*Conus lividus*) and five sea urchin species (the boring urchin [*Echinostrephus aciculatum*], the black urchin [*Tripneustes gratilla*]*,* the green urchin [*Echinometra mathaei*], and long spined urchins or wana [*Echinothrix diadema* and *E. calamaris*]). In the photographic quadrat survey an unidentified red sponge species was seen and three corals (*Porites lobata*, *P. compressa,* and *Pocillopora meandrina*) having a mean coverage of 4 percent were also identified.

The fish census noted 68 individual fishes among 12 species (App. Table A). The most common fishes present on this transect included the damselfish (*Chromis vanderbilti*) and the smalltail wrasse (*Pseudojuloides cerasinus*). The standing crop of fishes on Transect 4 was estimated to be 20 g/m^2. Important contributors to this biomass included the devil scorpionfish or nohu ‘omakaha (*Scorpaenopsis diabolus*) and the lei triggerfish or humuhumu lei (*Sufflamen bursa*).

Station C – Reef Runway

Two transects (numbers 5 and 6) were established on limestone substratum offshore of the Honolulu International Airport Reef Runway. This station lay between 760 and 840 m seaward of the runway in water ranging from 9.1 to 11.6 m in depth. The substratum in 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 was perpendicular to the shoreline and direction of usual wave impact. The spurs were from 5 to 40 m in width, 30 to 80 m in length, spaced from 10 to 100 m apart. Sand was the dominant substratum in the intervening areas. The maximum topographical relief formed by these spurs was about 3.5 m. Just seaward of this was a zone of low emergent limestone. These “patches” of hard bottom were from 5 ∞ 10 m to several hundred square meters in size. Spacing of these limestone areas was between 10 to 50 m and sand was again found in the intervening areas. Corals were restricted to the areas of hard substratum. Visibility at this station ranged from 4 to 15 m. Usually visibility did not exceed 12 m.

Both transects were established on spurs or ridges of limestone (see Fig. 4). Transect 5 was established on a limestone ridge in a depth from 9.1 to 11 m. Table 6 presents the results of the biological survey carried out at Station 5. The quadrat survey noted two soft corals (*Anthelia edmondsoni* and *Palythoa tuberculosa*) and five coral species (*Porites lobata*, *P.*

compressa, *Pocillopora meandrina*, *Pavona varians*, and *Montipora verrucosa*) having a mean coverage of 2.1 percent. The invertebrate census found two sea urchin species, the long-spined urchin or wana (*Echinothrix diadema*) and the green sea urchin (*Echinometra mathaei*). The photographic quadrat survey noted the encrusting coralline algae (*Porolithon onkodes*) as being the dominant benthic form. Other species seen in this survey included the soft coral (*Palythoa tuberculosa*) and three coral species (*Porites lobata*, *P. compressa,* and *Pocillopora meandrina*) having a mean estimated coverage of 2 percent.

The fish census (App. Table A) counted 176 individuals amongst 28 species. The most common species included the manybar goatfish or moano (*Parupeneus multifasciatus*), the yellowfin goatfish or weke‘ula (*Mulloides vanicolensis*), 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 5 was estimated to be 101 g/m^2. The most abundant species were also the most important contributors to the estimated standing crop.

Transect 6 was established approximately 80 m seaward of Transect 5. The substratum at Transect 6 was similar to Transect 5 and was situated on a limestone spur that was about 40 m in width and 80 m in length. Water depth at this site varied between 10.7 and 11.6 m. A summary of the biological observations made on Transect 6 are given in Table 7. The quadrat survey again found two soft coral species (*Anthelia edmondsoni* and *Palythoa tuberculosa*) as well as five coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *Montipora flabellata* and *M. verrucosa*) having a mean coverage of 6.7 percent. The census of macroinvertebrates noted just two species: the banded shrimp (*Stenopus hispidus*) and the green sea urchin (*Echinometra mathaei*). The photo quadrat survey noted coralline algae (*Porolithon onkodes*) with a mean coverage of 19 percent as well as two coral species (*Porites compressa* and *P. lobata*) with a mean coverage of 6 percent.

The fish census found 202 individuals belonging to 29 species in the 4 ∞ 20 m census area. The most abundant fishes on Transect 6 include brick soldierfish or mempachi (*Myripristes amaenus*), saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*), the bullethead parrotfish or uhu (*Scarus sordidus*), the brown surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*) and the goldring surgeonfish or kole (*Ctenochaetus strigosus*). The standing crop of fishes on this transect was estimated to be 183 g/m^2. The largest contributors to this biomass included the brick soldierfish or mempachi (*Myripristes amaenus*), the bluespot grouper or roi (*Cephalopholis argus*), the yellowfin goatfish or weke‘ula (*Mulloides vanicolensis*), the bullethead parrotfish or uhu (*Scarus sordidus*), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*).

Usually present at Transect 6 were from one to three green sea turtles (*Chelonia mydas*). During the present survey one individual was seen resting on the bottom in the transect area; this individual had an estimated straight line carapace length of 60 cm. In the 1990 survey three green turtles were seen; one of these was in the same location (carapace length 70 cm) as the turtle encountered in the 1991 survey. Green turtles are regularly encountered in the vicinity of Transect 6. None of these turtles appeared to have tags or obvious tumors present.

Physical measurements were made on the morning of 6 December 1991. These data are presented in Table 8. Little variation was noted in temperature (24.9 to 25.1°C), percent oxygen saturation (101 to 102%) or salinity (all 34‰) despite the fact that measurements for oxygen and temperature were made both at the surface and about 1 m above the bottom. In all cases secchi disk measurements did not yield an extinction value; water clarity was such that the disk on the bottom was still plainly visible from the surface. Probably a better method of determining water clarity would be to collect water samples and measure turbidity with a nephalometer in the laboratory.

The biological data for both 1990 and 1991 were summarized as means for each transect in Table 9. The 1990 data, other than for fish, were from Brock (1991). The 1990 fish census data is presented in Appendix Table B. Inspection of some parameters (e.g., coral coverage, number of coral species, and number of invertebrate species) suggest little change between the two sample periods. Other parameters (number of fish species, number of fish individuals, and fish biomass) suggest that some change has occurred. However, statistical comparison of the parameters between the two annual surveys shows that none of the changes are statistically significant (Wilcoxon matched-pairs signed-ranks test for coral coverage $P > 0.86$, N.S.; number of coral species $P > 0.62$, N.S.; number of invertebrate species $P > 0.69$, N.S.; number of fish species $P > 0.29$, N.S.; number of individual fish $P > 0.13$, N.S.; and fish biomass $P > 0.38$, N.S.).

The biological parameters measured in the 1990 and 1991 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 site has the most diverse communities, followed by the Reef Runway. The least diverse community appears to be at the Kalihi Entrance Channel site; this hierarchy did not change between the two surveys. The low biological diversity at the Kalihi Entrance Channel site is not surprising in view of the fact that this station was heavily impacted by the old shallow water sewage outfall until 1978.

From a commercial fisheries standpoint, a number of important species were encountered at both the Kewalo Landfill and Reef Runway sites including goatfishes (weke [*Mulloides* *flavolineatus*] and weke'ula [*M. vanicolensis*]), emperor or mu (*Monotaxis grandoculis*), and the squirrelfish or menpachi (*Myripristes amaenus*).

DISCUSSION

Since their delineation in December 1990, the six transects were visited on a number of occasions to insure that the permanent markers remained in place, etc. During these visits reconnaissance surveys were carried out in the areas surrounding the selected stations. At a minimum, these quantitative surveys covered about 4 hectares around each of the three sites. 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 study sites, being situated in relatively shallow water, are outside of the zone of influence of the present deep water outfall. However, if impacts from the present deep ocean outfall are occurring in 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 20 m or less in depth in this study. Monitoring the shallow-water stations provided additional information regarding the recovery of these communities from the damage done by the release of raw sewage from the old shallow-water outfall, a practice terminated in 1977–1978. Dollar (1979) 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 experienced an "intermediate" level of disturbance. The result of these impacts was still evident in the average coral cover estimates made at these stations: the mean coverage offshore of the Kalihi Entrance Channel was only 4 percent, at the Reef Runway station it was 5 percent, and offshore of the Kewalo Landfill it was 24 percent.

The shallow marine ecosystem fronting Sand Island and Honolulu has been subject to considerable disturbance from human activity over the last 100 years. Among the disturbing factors was the disposal of raw sewage effluent in shallow water from the 1930's up until 1977–1978 when the deep ocean outfall became operational. In the period from 1955 to 1977 the shallow outfall released 3 m^3/sec (62 mgd). Dollar (1979) noted two distinct zones of impact to marine communities: the area of "acute" impact was an ellipse 500 m to the east and 1,000 m to the west of the outfall. Outside of 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 elliptical shape of the zone of influence was attributed to the predominant westerly direction of current flow.

The Kewalo Landfill station was 4.75 km east and inshore of the terminus of the deep ocean outfall, the Kalihi Entrance Channel station was about 2.1 km east and inshore of the terminus and the Reef Runway station was about 3.25 km inshore and west of the deep ocean outfall terminus (Fig. 1). Presumably the present outfall releases the sewage below the thermocline and little interaction occurs with the inshore biota. If, however, the effluent was carried into inshore waters, impacts to shallow marine communities would occur in those communities situated primarily to the west of the outfall based on Dollar's (1979) findings.

The Kewalo Landfill station served as a "control" site in this study; despite the fact that coral coverage and fish community development was greater at this location, the Kewalo Landfill station has been subject to sewage impacts in the past. The two transects (T-1 and T-2) at the Kewalo Landfill site were situated close to an old, non-operable sewage discharge pipe. Operations utilizing this pipe ceased sometime prior to 1955. The pipe was probably used sometime in the 1940's (Mr. A. Muranaka, Oceanographic Section, Division of Wastewater Management, City and County of Honolulu). The development of Kewalo Basin and the entrance channel 200 m to the east in the mid-1930's would have created considerable turbidity that probably impacted this site. From the historical perspective, human impacts have probably occurred in all marine communities situated in shallow waters fronting Honolulu over the last 100 years. The Kewalo Landfill site was selected as the "control" site for this study because of the relatively diverse coral and fish communities present and because it was well to the east of the present deep ocean outfall (presumably out of the zone of influence).

The data over the two observation periods (December 1990 and December 1991) show that no statistically significant change has occurred in the biological parameters measured in this study. Inspection of Table 9 (the summary table) suggests that some change has occurred in the numbers of fishes identified and counted and the standing crop or biomass of fishes at several of the transect sites between the two surveys. In particular, the number of individual fish and biomass decreased between the two surveys at Transects 1 and 2 (the Kewalo Landfill station). Relative to many other locations in the Hawaiian Islands, the fish community was well developed at the Kewalo Landfill station. The high standing crop estimates in 1990 were much greater than those found on most coral reefs; the maximum fish standing crop encountered on natural coral reefs is about 200 g/m^2 (Goldman and Talbot 1975; Brock et al. 1979). There are two explanations for the high biomass of fishes at the Kewalo Landfill site: (1) the shelter created by the old sewer pipe locally enhanced the fish community, and (2) chance encounters with roving predators or planktivorous schooling species during censuses.

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; and 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 construction activity (such as the deployment of a sewer line) will have a similar effect. The old sewer discharge pipe was 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 [*Aprion virescens*], mu [*Monotaxis grandoculis*], kahala [*Seriola dumerili*], papio [*Caranx melampygus* or *C. orthrogrammus*]) or schools of planktivorous fishes (opelu [*Decapterus macarellus*], kala holo [*Naso hexacanthus*], kala lolo [*N. brevirostris*], lauwiliwili [*Chaetodon milaris*], and mamo [*Abudefduf abdominalis*]) may greatly increase the counts and biomass of a particular transect. The presence of the sewer pipe serves to focus numerous predators and planktivorous fishes in the vicinity of the two transects at the Kewalo Landfill site and encounters with these fishes during a census will result in high biomass estimates. Chance encounters with a small school of mu or emperor (*Monotaxis grandoculis*) at Station 6 (Reef Runway) accounted for 51 percent of the biomass of that station in 1990. On Transect 2 (Kewalo Landfill) the two planktivorous surgeonfishes (kala holo and kala lolo [*Naso hexacanthus* and *N. brevirostris*]) accounted for 40 percent of the biomass and the two roving predators the kahala (*Seriola dumerili*) as well as the papio (*Caranx orthogrammus*) contributed 21 percent to the biomass estimate for that transect in 1990. In 1991 these planktivorous surgeonfishes and some predators were present around Transects 1 and 2 at the Kewalo Landfill site but did not enter the actual census area while the counts were proceeding and thus do not appear in the data.

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, inspection of the results of the coral coverage data from visual appraisal of quadrats in the field (Tables 1, 3, 4, 5, 6, and 7) relative to the data from the photographic method (Table 2) points out several things. First, mean coral coverage estimates are in reasonable agreement by either method. Regressing the 1991 visual versus photographic coverage data results in a statistically significant relationship ($r^2 = 0.98$), given by the equation $Y = 1.29X - 0.67$ where X is the coral coverage measured by photo techniques on a transect and Y is the expected coverage obtained by visual techniques on that same transect. A drawback to the photo quadrat technique is that it does not discern small coral colonies or other small colonial benthic species such as the soft coral *Anthelia edmondson.* These are easily seen in the field using the visual assessment method. Both methods work but method selection should be done keeping the objectives of the study in mind.

The six transects selected for this study showed a considerable range in community development probably related to past (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. 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 one year apart shows that there has been little change to the communities over that period of time. This finding suggests that over this one year period, there has not been a quantitatively definable impact to shallow water benthic and fish communities due to the operation of the Sand Island deep ocean outfall.

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TABLE 1. SUMMARY OF BIOLOGICAL OBSERVATIONS MADE AT

TABLE 2. SUMMARY OF RESULTS FOR PHOTO QUADRAT SURVEY, 1991

	PHOTO QUADRAT NUMBER				
STATION A: Transect 1	ACC4	ACC3	ACC2	ACC1	ABC4
Corals					
Porites lobata	16	8	2	15	1
P. compressa	1			1	
Pocillopora meandrina		2	3	5	6
Sand	2		39		15
Rubble	13		23	19	
Hard Substratum	69	89	33	79	59
Mean Coral Coverage Transect 1 = 12%					
STATION A: Transect 2	ACC3	AAC4	ABC1	ABC2	ABC3
Algae					
Corallina sp.	0.4				
Porolithon onkodes			3		
Unidentified Red Sponge			0.3		
Corals					
Porites lobata	19	3	49	20	14
P. compressa			2	2	0.3
Pocillopora meandrina		4	3	3	
Sand	2	1			1
Hard Substratum	78.6	92	42.7	75	84.7
Mean Coral Coverage Transect 2 = 24%					
STATION B: Transect 3	AAA1	AAA2	AAA3	AAA4	AAB1
Unidentified Red Sponge	1			1	0.3
Corals					
Porites lobata		0.3	3	1	

Pocillopora meandrina	5	5	1	4	
Fungia scutaria					0.5
Sand	6	2	1	8	0.3
Rubble	1	10		17	
Hard Substratum	87	82.7	96	69	98.9

Mean Coral Coverage Transect 3 = 4%

STATION B: Transect 4	ACC4	ACC3	ACC2	ACC1	ABC4
Unidentified Red Sponge	0.1	0.3	1	0.3	1
Corals					
Porites lobata	0.1	3	1	1	1
P. compressa		3	0.3		
Pocillopora meandrina			1	4	5
Sand	4		6	8	3
Rubble	79.8	25		14	
Hard Substratum	16	68.7	90.7	72.7	90

Mean Coral Coverage Transect 4 = 4%

STATION C : Transect 5	CCC1	CCC2	CCC3	CCC4	CCA1
Algae					
Porolithon onkodes	4	14	22	31	17
Soft Corals					
Palythoa tuberculosa	0.2	1			
Corals					
Porites lobata	0.3	0.1	0.3		0.4
P. compressa	3	1	1	1	1
Pocillopora meandrina					1
Rubble				10	
Hard Substratum	92.5	83.9	76.7	58	80.6

Mean Coral Coverage Transect 5 = 2%

STATION C: Transect 6	CCB2	CCB1	CCA4	CCA3	CCA2
Algae					
Porolithon onkodes	16	32	4	28	16
Corals					
Porites lobata	15	1		7	8
P. compressa	1				
Sand			11		6
Rubble			56		
Hard Substratum	68	67	29	65	70

Mean Coral Coverage Transect 6 = 6%

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

TABLE 3.

SUM
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MADE AT

TABLE 8. SUMMARY OF PHYSICAL MEASUREMENTS MADE AT EACH OF THREE LOCATIONS IN THE VICINITY OF TRANSECT PAIRS, 6 DECEMBER 1991

LOCATION AND TIME	
Kewalo Landfill	

APPENDIX TABLE A. RESULTS OF QUANTITATIVE VISUAL CENSUSES
CONDUCTED AT SIX LOCATIONS OFFSHORE OF
SAND ISLAND, O‘AHU, 5–6 DECEMBER 1991

	TRANSECT NUMBER					
FAMILY AND SPECIES	1	2	3	4	5	6
MURAENIDAE0						
Gymnothorax flavimarginatus	1					
G. meleagris			1			
G. eurostus						1
Uropteryginus tigrinus	1					
HOLOCENTRIDAE						
Myripristes amaenus						15
AULOSTOMIDAE						
Aulostomus chinensis	1					1
FISTULARIIDAE						
Fistularia commersoni			1			
SCORPAENIDAE						
Scorpaenopsis diabolus	1			1		
SERRANIDAE						
Cephalophosis argus						1
APOGONIDAE						
Apogon kallopterus		13				
SPARIDAE						
Monotaxis grandoculis						2
MULLIDAE						
Mulloides flavolineatus		37				
M. vanicolensis					11	4
Parupeneus pleurostigma	8	1	1			
P. multifasciatus	32	5	23	6	11	3
CHAETODONTIDAE						
Forcipliger flavissimus						2
Chaetodon multicinctus	4	2	1	2		2
C. ornatissimus		2				
POMACANTHIDAE						
Centropyge potteri		2	2		2	8
POMACENTRIDAE						
Dascyllus albisella			10			10
Plectroglyphidodon imparipennis					1	1
Chromis vanderbilti	77	52	52	10		
C. hanui	1	3			3	6
Stegastes fasciolatus					2	2

APPENDIX TABLE A.—*Continued*

	TRANSECT NUMBER					
FAMILY AND SPECIES	1	2	3	4	5	6
CIRRHITIDAE						
Paracirrhitus arcatus	3		1	2	1	
Cirrhitops fasciatus		1			1	
Cirrhitus pinnulatus					1	
LABRIDAE						
Labroides phthirophagus			1			1
Bodianus bilunulatus	1		2		1	
Cheilinus bimaculatus		4	1	1		
Pseudocheilinus octotaenia		6				
P. tetrataenia	1					
Thalassoma duperrey	52	28			15	21
T. ballieui					1	2
Comphosus varius					3	3
Coris gaimard	1	1	1			1
Pseudojuloides cerasinus	13	19	13	32		
Stethojulis balteata					1	1
Macropharyngodon geoffroy	3	2				
SCARIDAE						
Calotomus carolinus	6		1			
Scarus perspicillatus	1		2		3	2
S. sordidus	3				2	14
S. psittacus	3				4	
BLENNIIDAE						
Exallis brevis					1	
ACANTHURIDAE						
Acanthurus achilles					2	
A. nigrofuscus	27	17	19	4	34	37
A. nigroris	5				60	
A. olivaceus	4					
A. dussumieri	1					
Ctenochaetus strigosus		1	1	1		43
Zebrasoma flavescens	4				1	4
Naso lituratus	1	7				
N. hexacanthus		29				
ZANCLIDAE						
Zanclus cornutus		2			1	2
BALISTIDAE						
Melichthys niger					2	3
M. vidua	1					
Sufflamen bursa	1	2	2	5	6	2
MONACANTHIDAE						

Pervagor spilosoma	1	1			1	
Cantherhines dumerili			1			

APPENDIX TABLE A.—*Continued*

	TRANSECT NUMBER					
FAMILY AND SPECIES	1	2	3	4	5	6
OSTRACIIDAE						
Ostracion meleagris	1	1				
CANTHIGASTERIDAE						
Canthigaster jactator		1	1	2	3	8
C. cornata	1		1	2		
C. rivulata					2	
TETRAODONTIDAE						
Arothron hispidus		2				
Total No. of Species	31	26	22	12	28	29
Total No. of Individuals	260	240	138	68	176	202
Biomass (g/m^2)	148	221	72	20	101	183

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.

APPENDIX TABLE B. RESULTS OF QUANTITATIVE VISUAL CENSUSES CONDUCTED AT SIX LOCATIONS OFFSHORE OF SAND ISLAND, O‘AHU, 27–29 DECEMBER 1990

	TRANSECT NUMBER					
FAMILY AND SPECIES	1	2	3	4	5	6
MURAENIDAE						
Gymnothorax petelli				1		
G. flavimarginatus	1	1			1	
G. meleagris				1		
G. eurostus	1					
HOLOCENTRIDAE						
Myripristes amaenus						20
AULOSTOMIDAE						
Aulostomus chinensis		1				
SERRANIDAE						
Cephalophosis argus						1
APOGONIDAE						
Apogon kallopterus		18				3
CARANGIDAE						
Seriola dumerili		3				
Caranx orthogrammus	1	3				
SPARIDAE						
Monotaxis grandoculis						18
MULLIDAE						
Mulloides flavolineatus	55	34			1	
Parupeneus cyclostomus					2	3
P. pleurostigma	6	7	3		1	1
P. multifasciatus	28	38	52	16	5	9
CHAETODONTIDAE						
Forcipliger flavissimus	1	4			1	1
Chaetodon multicinctus	6				2	
POMACANTHIDAE						
Centropyge potteri		5	1		1	9
POMACENTRIDAE						
Dascyllus albisella			10			5
Plectroglyphidodon imparipennis				2	2	
Chromis vanderbilti	67	28	111	57		
C. ovalis	5					
C. hanui	1	18	9			9
Stegastes fasciolatus					2	7
CIRRHITIDAE						

Paracirrhitus arcatus	1	1	1	2		
Cirrhitops fasciatus	1	1				

APPENDIX TABLE B.—*Continued*

	TRANSECT NUMBER					
FAMILY AND SPECIES	1	2	3	4	5	6
LABRIDAE						
Labroides phthirophagus						2
Bodianus bilunulatus	1		2		1	1
Cheilinus rhodochrous	3					
C. bimaculatus		21	6	10	1	
Pseudocheilinus octotaenia	17	11		1		1
P. tetrataenia	4	8				
Thalassoma duperrey	26	43	42	5	20	31
T. ballieui					1	2
Comphosus varius					4	1
Coris venusta			1			1
C. gaimard		1	1			1
Pseudojuloides cerasinus	19	14	14	14		
Stethojulis balteata	1				1	
Macropharyngodon geoffroy		1	1		1	2
Anampses chrysocephalus		3				
SCARIDAE						
Calotomus carolinus	3	1				
Scarus perspicillatus	3	1	3			
S. sordidus					15	6
S. psittacus	10		2			
S. rubroviolaceus	1	1				
BLENNIIDAE						
Exallis brevis					1	
Cirripectus variolosus					1	
ACANTHURIDAE						
Acanthurus nigrofuscus	49	50	37	9	40	36
A. nigroris	17	33	8		7	4
A. olivaceus	3	5	1			
A. dussumieri	3	1		1		2
Ctenochaetus strigosus	7	3			74	74
Zebrasoma flavescens	9	2				7
Naso brevirostris	4	44				
N. hexacanthus	36	69				
N. lituratus		1				
N. unicornis	2					
ZANCLIDAE						
Zanclus cornutus	1				1	
BALISTIDAE						
Melichthys niger					1	3
M. vidua	2					
Sufflamen bursa						
		4	1	2	4	3

MONACANTHIDAE						
Pervagor spilosoma		1				1
Cantherhines dumerili			1	1		
C. sandwichensis			1		1	

APPENDIX TABLE B.—*Continued*

FAMILY AND SPECIES	TRANSECT NUMBER 1	2	3	4	5	6
OSTRACIIDAE						
Ostracion meleagris					1	
CANTHIGASTERIDAE						
Canthigaster jactator	3	1	1	2	4	3
C. cornata			1	2		
TETRAODONTIDAE						
Arothron hispidus	1					
Total No. of Species	38	37	24	16	29	31
Total No. of Individuals	455	481	310	126	197	267
Biomass (g/m^2)	763	824	91	30	129	293

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.