COMMUNITY STRUCTURE OF FISH AND MACROBENTHOS AT SELECTED SITES FRONTING SAND ISLAND, O‘AHU, IN RELATION TO THE SAND ISLAND DEEP OCEAN OUTFALL, DECEMBER 1990 SURVEY

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ABSTRACT

This report is the first of an annual monitoring of shallow marine communities inshore of the Sand Island deep ocean outfall. This quantitative monitoring was carried out on 27–29 December 1990; the effort focuses on benthic and fish community structure and is designed to detect changes in these communities. Marine communities offshore of Honolulu have been subject to considerable perturbation over the last 100 years. Raw sewage was dumped in shallow water until 1978; point and non-point pollution from both urban sources and industry continue. All of these disturbances may serve to obscure any impacts which may be caused by the deep ocean outfall. The marine communities show a considerable range in development that is probably related to past (historical) impacts. Siting of stations to capitalize on presumed gradients of impact from a variety of land-derived sources should allow delineation of changes attributable to 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.

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 more 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 is the primary commercial port for the State of Hawaii and has been so 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 done up to the present time. Up until about 1960 dredging spoils were dropped just outside of the harbor; generally to the east of the Honolulu

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 may 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, we designed a sampling program 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 previously used by Dollar (1979). Site locations and the rationale for their selection are given below:

Station A (Kewalo Landfill) was utilized as a control area lying east of the present deep ocean outfall in about 16 m of water (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 is emergent limestone at this station, but coral coverage is low (>1%).

Station C (Reef Runway) was 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 was close to Brock's (1986) station that was monitored quarterly in 1977–1978 (AECOS, Inc. 1979) and again in 1986. It is 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 oriented perpendicular to shore. Two transects were established at each location to provide some replication. At each station, both transects sample 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.

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., across coral mounds, sand flats, and algal beds) and thus sample more than one community thereby obscuring 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, 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 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; 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 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 the 1 ∞ 1 m quadrats were used for an "in the field" appraisal of coverage. Diurnally exposed motile macroinvertebrates greater than 2 cm in any dimension were counted in the same 4 ∞ 20 m corridor used in the fish counts.

If macrothalloid algae were encountered in the 1 ∞ 1 m quadrats, they were quatitatively 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.

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 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 rough sketches showing the orientation of the permanent photographic quadrats on each transect line.

Malfunction of a new Nikonos V camera caused the loss of all photographic quadrat data for all stations in the 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 has been subsequently repaired. To avoid a reccurrence 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 this first annual effort.

The results are presented below by station.

Station A – East Control Station

This station was 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 were 35 m apart, out of visual range of one another. Visibility at this station was usually in the range of 15 to 20 m.

A summary of the data collected at Transect 1 is presented in Table 1. In the quadrat survey, four 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 polychaete, the Christmas tree worm (*Spirobrachus giganteus corniculatus*); and three echinoderms, the sea cucumber (*Holothuria atra*), black sea urchin (*Tripneustes gratilla*), and the wana (*Echinothrix diadema*). The results of the fish census carried out at Transect 1 are given in Appendix Table A. In total, 38 species of fishes (455 individuals) were encountered in the 4 ∞ 20 m census area. The most common fishes on this transect included goatfishes or moano (*Parupeneus multifasciatus*) and weke (*Mulloides flavolineatus*); a damselfish (*Chromis vanderbilti*); a wrasse or hinalea lauwili (*Thalassoma duperrey*); and surgeonfishes or ma‘i‘i‘i (*Acanthurus nigrofuscus*) and kala holo (*Naso hexacanthus*). The estimated standing-crop of fishes at Transect 1 was 763 g/m^2. Species contributing heavily to this high biomass include the goatfish or weke (*Mulloides flavolineatus*), and the plankton feeding surgeonfish or kala hole (*Naso hexacanthus*).

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 of depth. Table 2 presents a summary of the biological information collected at this site. The quadrat survey noted one macroalgal species (*Actinotrichia fragilis*) and five coral species (*Porites lobata, P. compressa, P. evermanni*, *Pocillopora meandrina,* and *Montipora verrucosa*) having an average coverage of 30.4 percent. The largest contributor to this coverage was *Porites lobata*. The invertebrate census counted one cone shell (*Conus imperialis*); two polychaete species, the Christmas tree worm (*Spirobranchus giganteus corniculatus*) and the feather duster worm (*Sabellastarte sanctijopsephi*); and two sea urchins (*Tripneustes gratilla* and *Echinothrix diadema*). The results of the fish census are presented in Appendix Table A. Thirty-seven fish species were identified (481 individuals) on this transect, the most abundant species included: goatfishes or weke (*Mulloides flavolineatus*) and moano (*Parupeneus multifasciatus*); damselfish (*Chromis vanderbilti*); wrasses or hinalea lauwili (*Thalassoma duperrey* and *Cheilinus bimaculatus*); as well as surgeonfishes or ma‘i‘i‘i (*Acanthurus nigrofuscus*), maiko (*A. nigroris*), kala holo (*Naso hexacanthus*)*,* and kala lolo (*N. brevirostris*).

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 was parallel to Transect 3 but was shoreward of this and approximately 8 m to the west. Visibility at this station ranged from 6 to 10 m. The lack of appropriate hard substratum necessitated establishment of 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 was oriented perpendicular to shore on the limestone substratum in water from 14.6 to 15 m in depth. Table 3 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 four coral species (*Porites lobata*, *Pocillopora meandrina*, *Montipora verrucosa* and *Fungia scutaria*). The corals had an estimated mean coverage of 3.8 percent and *Pocillopora meandrina* provided the greatest coverage. The invertebrate census noted one rock oyster (*Spondylus tenebrosus*), a starfish (*Linckia diplax*) and four sea urchin species (*Echinostrephus aciculatum*, *Echinometra mathaei, Echinothrix diadema* and *E. calamaris*). The fish census (App. Table A) found 24 species, 310 individuals, and an estimated standing crop of 91 g/m^2. The most abundant fishes at Transect 3 included the goatfish or moano (*Parupeneus multifasciatus*), damselfish (*Chromis vanderbilti*), wrasse or hinalea lauwili (*Thalassoma duperrey*), and the surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*). The fish species contributing heavily to the biomass on Transect 3 included the goatfish or moano (*Parupeneus multifasciatus*), the wrasse or hinalea lauwili (*Thalassoma durperrey*), the surgeonfish or ma‘i‘i‘i (*Acanthurus nigrofuscus*), and the filefish or ‘o‘ili (*Cantherhines dumerili*).

Transect 4 was also located in the vicinity of the Kalihi Entrance Channel. As with the previous transect, Transect 4 was located on limestone substratum at a depth ranging from 13.7 to 14 m. Table 4 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 patula*). Coral coverage was estimated to be 3.4 percent and both *Porites lobata* as well as *Pocillopora meandrina* were the major contributors to this coverage. The invertebrate census noted one juvenile octopus or he‘e (*Octopus cyanea*) and five sea urchin species (i.e., the boring urchin [*Echinostrephus aciculatum*], the black urchin [*Tripneustes gratilla*], the green urchin [*Echinometra mathaei*], and the long spined urchins or wana [*Echinothrix diadema* and *E. calamaris*]). The fish census noted 126 individual fishes among 16 species (Appendix Table A). The most common fishes present on this transect include the goatfish or moano (*Parupeneus multifasciatus*), damselfish (*Chromis vanderbilti*), and wrasses (*Cheilinus bimaculatus* and *Pseudojuloides* *cerasinus*). The standing crop of fishes on Transect 4 was estimated to be 30 g/m^2 and the important contributors to this biomass include the moray eel or puhi‘oni‘o (*Gymnothorax meleagris*) and the filefish or ‘o‘ili (*Cantherhines dumerili*).

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 was located between 760 and 840 m seaward of the runway in water ranging from 9.1 to 11.6 m in depth. The substratum of this area was 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 the direction of usual wave impact. The spurs were from 5 to 40 m in width, 30 to 80 m in length, and 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 the visibility did not exceed 10 m.

Both transects were established on spurs or ridges of limestone. Transect 5 was established on a limestone ridge in a depth from 9.1 to 11 m. Table 5 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 1.8 percent. The invertebrate census found two sea urchin species, *Tripneustes gratilla* and *Echinometra mathaei*. The fish census (Appendix Table A) counted 197 individuals amongst 29 species. The most common species included the wrasse or hinalea lauwili (*Thalassoma duperrey*) and surgeonfishes (ma‘i‘i‘i [*Acanthurus nigrofuscus*] and kole [*Ctenochaetus strigosus*]). The standing crop of fishes on Transect 5 was estimated to be 129 g/m^2. The important contributors to this standing crop were kole (*Ctenochaetus strigosus*) and a puhi paka (*Gymnothorax flavomarginatus*).

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 to 11.6 m. A summary of the biological observations made on Transect 6 is given in Table 6. 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 9.5 percent. The census of macroinvertebrates noted just two species: one drupe shell (*Drupa speciosa*) and several green sea urchins (*Echinometra mathaei*). The fish census found 267 individuals belonging to 31 species in the 4 ∞ 20 m census area. The most abundant fishes on Transect 6 included squirrelfish or mempachi (*Myripristes amaenus*), saddleback wrasse or hinalea lauwili (*Thalassoma duperrey*), and the surgeonfishes ma‘i‘i‘i (*Acanthurus nigrofuscus*) as well as the kole (*Ctenochaetus strigosus*). The standing crop of fishes on this transect was estimated to be 293 g/m^2; the largest contributors to this biomass included the emperor or mu (*Monotaxis grandoculis*), squirrelfish or mempachi (*Myripristes amaenus*), and surgeonfish or kole (*Ctenochaetus strigosus*). Also present at this site were at least three green sea turtles that all had resting areas within 100 m of Transect 6. One turtle with an estimated carapace length of 70 cm had a resting site within 4 m of this transect; the other two had estimated carapace lengths of 50 and 60 cm. None of the these turtles appeared to have tags or obvious tumors present.

The biological data for all transects is summarized as means by station in Table 7. On inspection it is apparent that for the criteria measured in this study (i.e., number of coral species, percent cover, number of macroinvertebrate species, number of fish species, number of individual fish and biomass of fishes) that the Kewalo Landfill site was the most diverse, followed by the Reef Runway. The least diverse appeared to be the Kalihi Entrance Channel site; it is interesting to note that this site was heavily impacted by the old shallow water 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 or weke (*Mulloides flavolineatus*), emperor or mu (*Monotaxis grandoculis*), squirrelfish or mempachi (*Myripristes amaenus*), amberjack or kahala (*Seriola dumerili*), and the jack or papio (*Caranx orthogrammus*).

DISCUSSION

This document presents the data for the first year (single sample event) and thus comparative temporal analysis cannot yet be undertaken. Since their delineation in December 1990, the six transect sites 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 sites. At a minimum, these qualititative surveys 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 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 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 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 (Table 7).

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 ellipsoid shape of the zone of influence was attributed to the predominant westerly direction of current flow.

The Kewalo Landfill station was located 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 on 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 are situated close to an old, non-operational 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 occurred in probably 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 is well to the east of the present deep ocean outfall (presumably out of the zone of influence).

Relative to many other locations in the Hawaiian Islands, the fish community is well developed at the Kewalo Landfill station. The high standing crop estimate (mean = 794 g/m^2) is much greater than that 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; these are (1) the shelter created by the old sewer pipe locally enhances 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; 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 increase 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 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, *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*, mamo, *Abudefduf abdominalis*) may greatly increase the counts and biomass at 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 an encounter with these fishes during a census will result in a high biomass estimate. 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. 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*) and papio (*Caranx orthogrammus*) contributed 21 percent to the biomass estimate for that transect.

In conclusion, this first sampling effort suggests that the selected stations show a considerable range in community development that is probably related to past (historical) impacts. Separating the impact of primary treated effluent released at depth from a multitude of other ongoing and historical impacts that have occurred 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 Honolulu deep ocean outfall.

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TABLE 1. SUMMARY OF BIOLOGICAL OBSERVATIONS MADE AT TRANSECT 1, OFFSHORE OF

A. QUADRAT SURVEY
Soft Corals
Anthelia edmondsoni
Palythoa tuberculosa
Corals
Porites lobata
P. compressa
Poncillopora meandrina
Montipora flabellata
M. verrucosa
Sand
Rubble