AN ANALYSIS OF THE FISH AND MACROBENTHOS ALONG THE SAND ISLAND DEEP OCEAN OUTFALL, O'AHU, HAWAI'I, USING REMOTE VIDEO IV—1993

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PROJECT REPORT PR-94-12

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ABSTRACT

Because the diffuser of the Sand Island deep ocean outfall lies below safe diving depths, a remotely controlled video camera system was used to determine the status of the fish and diurnally exposed macrobenthos resident to the diffuser. The use of a remotely operated vehicle is stipulated in the National Pollutant Discharge Elimination System 301(h) waiver permit for the Sand Island Wastewater Treatment Plant. Video reconnaissance was completed over the entire 1 036 m length of the outfall diffuser. Five visual "transects," which "sampled" approximately 41% of the total diffuser length, were established on the diffuser pipe. Video sampling of the diffuser marine communities was carried out in 1990, 1991, 1992, and 1993. Only a few species of diurnally exposed macroinvertebrates are evident on the videotapes of the diffuser; the numbers are insufficient for any meaningful analysis. In 1993, 22 fish species (279 individuals) having an estimated biomass ranging from 6 to 39 g/m^2 (mean 21 g/m^2) were censused; in 1991, 27 species (1,785 individuals) having a biomass ranging from 8 to 106 g/m^2 (mean 42 g/m^2) were counted; and in 1992, 30 fish species (2,936 individuals) having an estimated biomass ranging from 39 to 77 g/m^2 (mean 53 g/m^2) were censused. Because the 1990 video census covered only the terminal 183 m of the diffuser, whereas the later surveys were spread out along the entire diffuser length, a direct comparison cannot be made between the 1990 data and the data for subsequent years. In 1990, one "new" fish species was encountered for every 22.9 m^2 of substratum sampled and one fish was seen for every 5.6 m^2; in 1991, it was one new species for every 13.1 m^2 and one fish for every 0.7 m^2; and in 1992, it was one new species for every 7.4 m^2 and one fish for every 0.4 m^2. The 1993 census noted one new fish species for every 38.5 m^2 of substratum sampled and one fish for every 3.0 m^2. In the 1991–93 period, measures of the fish community (number of species, number of individuals, and biomass) increased from 1991 to 1992 but decreased in 1993. From a statistical perspective, the change in the mean number of species per transect and the mean number of individual fishes per transect is significant (Kruskal-Wallis ANOVA); changes in the biomass of fishes over this time are not significant. These changes in the fish community are attributed to changes in resolution of the videotape from which the data are derived. Poorer camera resolution results in lower counts; camera resolution is affected by local wind and currents interacting with the camera, tether, and support vessel as well as by water visibility. Controlling these sources of variation inherent with the use of the remotely operated video system is difficult if not impossible. Until an alternative can be found, the remotely controlled video system is the only low-cost means available to view the marine communities on the diffuser. Until a more accurate means of visual assessment is available, the biological data generated by the remotely operated video camera should be viewed as qualitative, with little statistical rigor.

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INTRODUCTION

In recent years controversy has arisen regarding the impact that sewage effluent from the Sand Island Wastewater Treatment Plant may have on marine communities resident to the receiving waters. The outfall was constructed in 1975, and screened sewage has been discharged since 1976. The ocean portion of the outfall is comprised of 2 780 m of 2.1-m-diameter reinforced concrete pipe that terminates in a 1 036-m-long diffuser. The diffuser is made up of reinforced concrete pipe of three diameters: 490 m of 2.1-m-diameter pipe, 271 m of 1.7-m-diameter pipe, and 275 m of 1.2-m-diameter pipe at the terminus. Along its length, the diffuser, which lies in water from 68 to 73 m in depth, has 282 ports that range from 7.6 to 9 cm in diameter. The diffuser rests on a gravel pad and has some ballast rock placed at the junctures between sections. Fishes and macroinvertebrates have taken up residence along most of the length of the deep ocean outfall. This study has been undertaken in an attempt to semiquantitatively ascertain the impacts that may be occurring to the communities resident to the discharge port areas of the outfall. This report presents a synopsis of the data from the fourth annual sampling effort carried out on 5 August 1993 and comparatively analyzes these data with information collected annually since 1991.

MATERIALS AND METHODS

A remotely controlled video camera system was used to conduct the census because the fish and diurnally exposed macroinvertebrate communities of interest to this study reside in waters below safe diving depths. In addition, the system was used because the waiver permit issued by the U.S. Environmental Protection Agency/Hawaii Department of Health requires the use of a remotely operated vehicle. There are a number of drawbacks as well as positive aspects to using a video camera system to visually census fishes and diurnally exposed macroinvertebrates. The drawbacks include problems with camera resolution, making species and size identifications difficult, and the problem of adequately controlling the camera to focus-in on rapidly fleeing fishes, adding further difficulty to identification problems. On the positive side, a permanent record of the organisms in the path of the camera is obtained. An additional benefit to using a video system is that it eliminates the need for diving to great depths.

There are some well-known problems with using visual census methods to assess coral reef fish populations, regardless of whether a camera or diver is in the water conducting the census. One of these is the simple frightening of wary fishes on the approach of the diver or camera. Another is the underestimation of cryptic species such as moray eels (family

Muraenidae) and nocturnal species such as squirrelfishes (family Holocentridae) and bigeyes or ʻāweoweo (family Priacanthidae). This problem is compounded in areas of high relief and coral coverage that affords numerous shelter sites. Species lists and abundance estimates are more accurate for areas of low relief, although some fishes with cryptic habits or protective coloration, such as scorpionfishes, or nohu (family Scorpaenidae) and flatfishes (family Bothidae), might still be missed. Another problem is the reduced effectiveness of the visual census technique in turbid water. This is compounded by the difficulty of counting fishes that move quickly or are very numerous. Additionally, bias related to the experience of the census taker should be considered in making comparisons between surveys. Despite these problems, the visual census technique carried out by divers is probably the most accurate, nondestructive assessment method currently available for counting diurnally active fishes (Brock 1982). Use of a remotely controlled video system to obtain census data compounds many of the above problems, but it is probably one of the most cost-effective methods available for assessing fish communities at depths below safe diving limits.

Other than exposed sessile species (corals in shallow water and some sponges in deeper water), most tropical marine invertebrates are cryptic, remaining under shelter until darkness when they emerge to feed. Only a few motile macroinvertebrates remain fully exposed during the day; among these are some holothurian (sea cucumber) and echinoid (sea urchin) species. Problems with species identification preclude the enumeration of most of the diurnally exposed invertebrates. Identification of holothurians is based on a microscopic examination of skin spicule configuration, and spicules are also used for the identification of sponges. Thus, in this study, the identification and enumeration of exposed macroinvertebrates are confined to large arthropods (spiny lobsters) and sea urchins; as for species of holothurians present along the Sand Island diffuser pipe, educated "guesses" are made.

This study utilized a remote controlled video system to visually assess the fish and macroinvertebrate populations resident to the diffuser pipe. The video "transect" was undertaken by the Oceanographic Team of the Department of Wastewater Management, City and County of Honolulu. In general, the video camera traveled from 0.5 to 1.5 m above the diffuser pipe, occasionally moving to the right or left side (and down) to survey the substratum alongside the pipe. The camera usually viewed a path from about 1.5 to 3 m in width. For purposes of data analysis, we assumed that the camera path was approximately 2 m in width and attempted to count only fishes seen in this path. At times, the camera would tilt up (towards the horizon), allowing a viewing ahead down the pipe. Visibility under these circumstances ranged from about 0.5 m (in a discharge plume) to about 8 m, which is approximately the length of one pipe section. In the 1993 survey, the camera roughly followed the same path, but on occasion it rose to about 4 m above the pipe. In doing so, a wider field of view was attained, but with the small average size of fish present this meant a decrease in resolution with greater height above the pipe, resulting in a decrease in apparent abundance of fishes (see below). Because the camera grossly underestimates the number of fish and invertebrates, we counted everything in the arbitrary 2-m-wide path, regardless of whether it was encountered directly below the camera (as when viewing from above) or several meters ahead (as when the camera is in a horizontal position).

The fish census involved not only the counting of populations but also the estimating of lengths of all fishes for later use in calculating standing crop. The standing crop of all fishes was estimated by use of linear regression techniques (Ricker 1975; Brock and Norris 1989). Species-specific regression coefficients have been developed over the last 30 years by the author and others at the University of Hawaii, the Naval Undersea Center (see Evans 1974), and the Hawaii Division of Aquatic Resources from weight and body length measurements of captured fishes; for many species, sample sizes were in excess of a hundred individuals.

RESULTS

Video "transects" of the fish communities resident to the Sand Island diffuser pipe were carried out on four occasions: 7 November 1990, 22 August 1991, 28 August 1992, and 5 August 1993. Only the final 183 m of the 1 036-m-long diffuser pipe was surveyed in November 1990. In the three most recent surveys, the camera commenced just shoreward of the first discharge port on the diffuser and "sampled" the fish and macrobenthos for the entire diffuser length. The 1991 survey tape was viewed several times to determine where representative transects could best be established. Five transect sites selected as being representative sections of the diffuser pipe were sampled using the visual census technique. These transects were located using known points on the pipe and counting sections of pipe from those points. The five transect sites were again sampled in 1992 and 1993, thus allowing for data comparison between years.

The location of each transect is shown in Figure 1. The transects range from 44 to 110 m in length; thus, in total, approximately 848 m^2 of substratum were sampled in this survey. The results of all fish censuses are presented in Table 1, and the data for each transect are discussed below. In tallying the number of species seen on a given transect, all fishes that could not be positively assigned to a given species were lumped into groups such as "labrid sp."); in the tally of species, each of these groups was counted as a single species, even though more than one species may have been in the group. The diurnally exposed macroinvertebrates that were

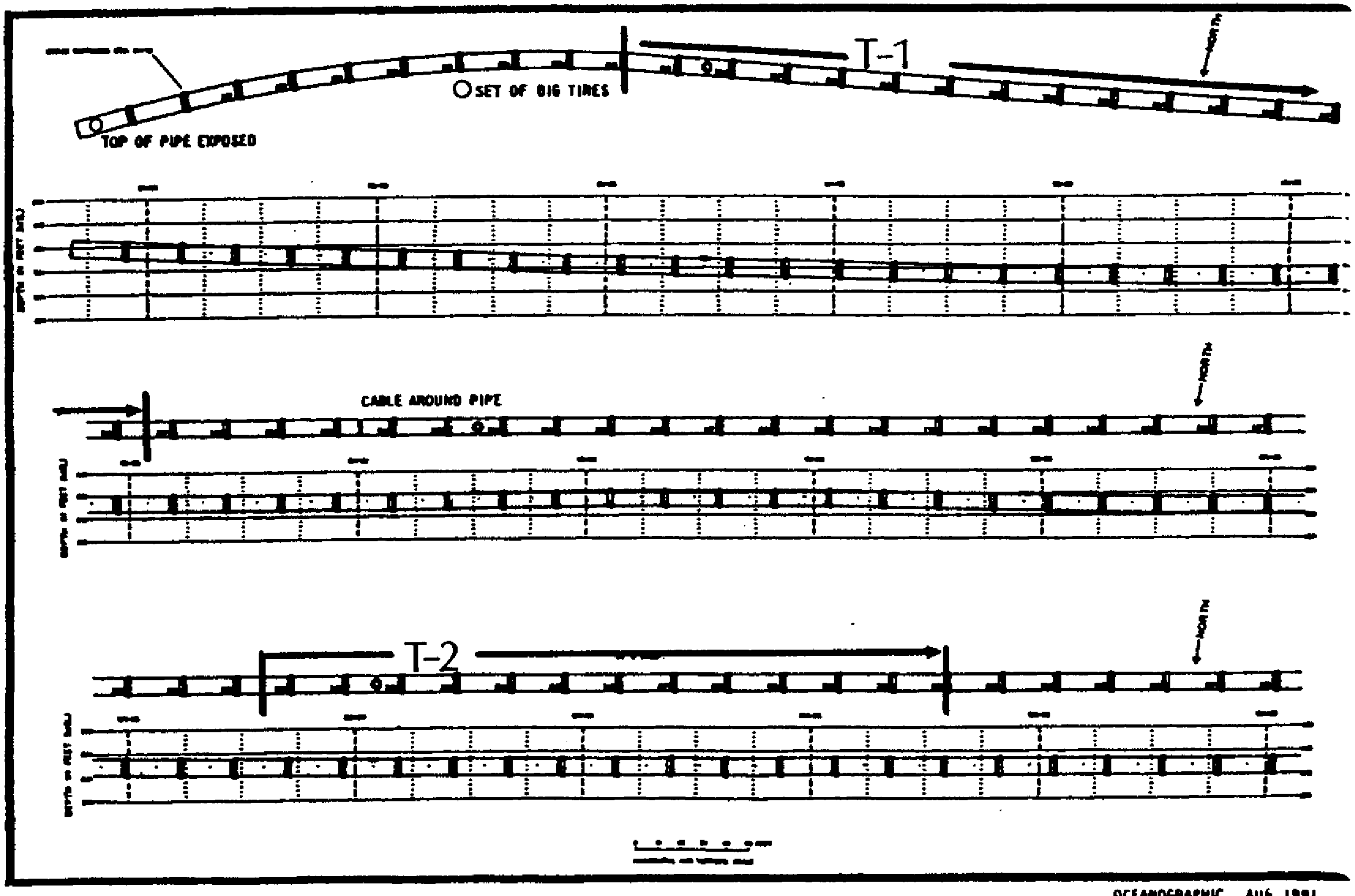

Figure courtesy of the Oceanographic Team, Department of Wastewater Management, City and County of Honolulu.

FIGURE 1. Schematic of the 1 036-m-long Sand Island deep ocean outfall diffuser pipe showing the approximate locations of the five transects established in August 1991 and monitored annually using a remotely controlled video recording system. Transects are numbered, and the length of diffuser pipe covered by each is shown with an arrow.

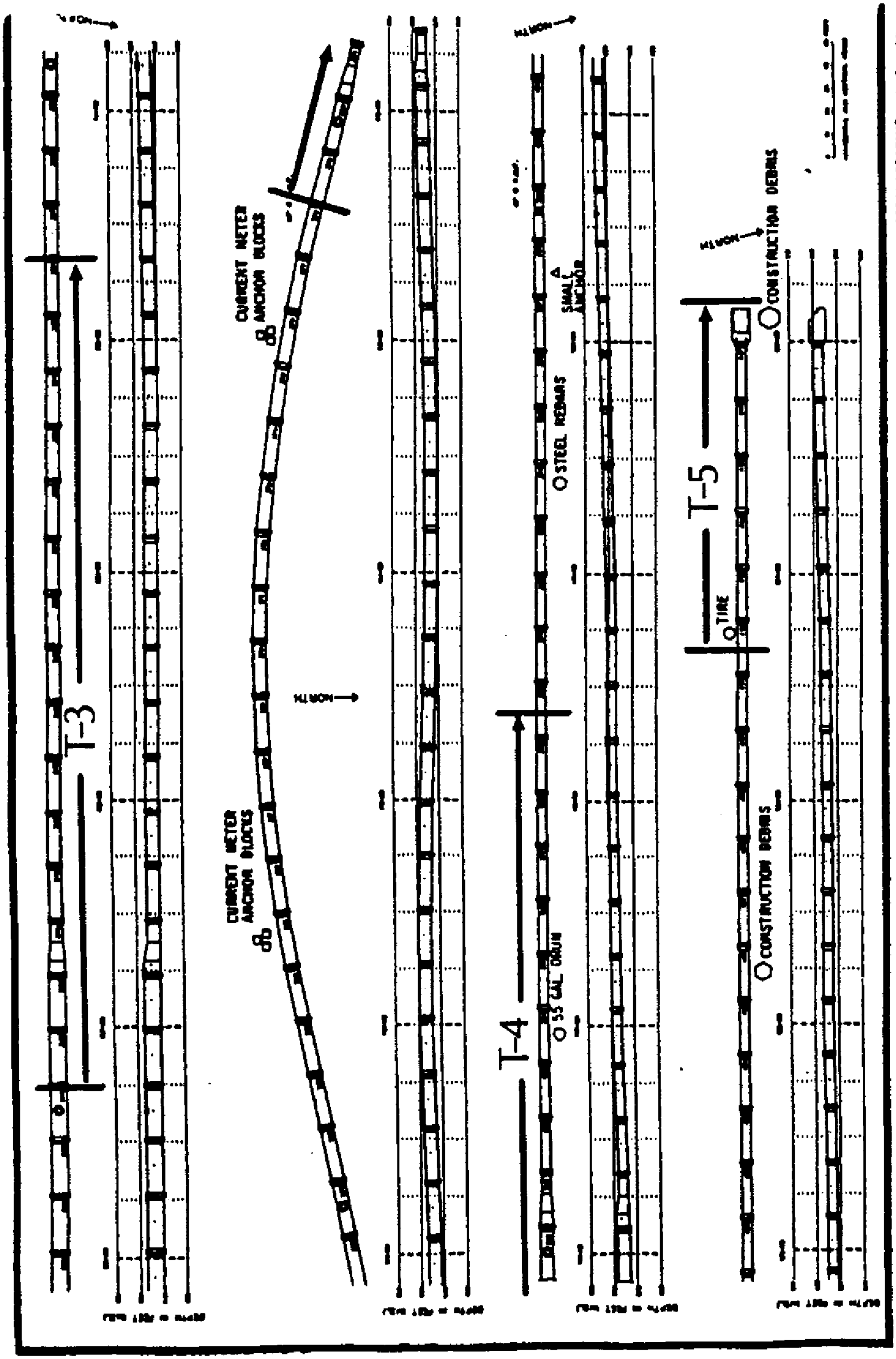

FIGURE 1. —Continued

TABLE 1. Species of fishes censused on five transects along the 1 036-m-long diffuser pipe of the Sand Island deep ocean outfall as delineated using a remotely controlled video camera system on 5 August 1993. Areas sampled on the five transects varied: 190 m^2 for Transect 1, 182 m^2 for Transect 2, 220 m^2 for Transect 3, 168 m^2 for Transect 4, and 88 m^2 for Transect 5. The number of individuals of each species censused are given in the body of the table. Totals for numbers of species and individuals and an estimate of the biomass for each transect are given at the foot of the table.

Species	Transect Number				
	1	2	3	4	5
SERRANIDAE					
Pseudanthias thompsoni	—	2	7	3	8
LUTJANIDAE					
Lutjanus kasmira	—	—	14	—	—
MULLIDAE					
Parupeneus multifasciatus	—	4	1	—	—
CHAETODONTIDAE					
Chaetodon sp.	1	—	—	—	1
Heniochus diphreutes	—	—	—	—	1
POMACENTRIDAE					
Chromis hanui	6	—	14	—	—
Chromis sp.	8	24	44	—	3
Pomacentrid sp.	—	—	5	—	—
LABRIDAE					
Pseudojuloides cerasinus (?)	1	—	—	—	—
Thalassoma sp.	—	2	2	—	—
Labrid sp.	18	15	34	9	10
ACANTHURIDAE					
Acanthurus xanthopterus	—	1	—	1	2
Acanthurus sp.	—	—	2	1	—
Ctenochaetus strigosus (?)	1	—	—	—	—
Naso unicornis (?)	—	—	1	—	—
ZANCLIDAE					
Zanclus cornutus	—	—	—	3	7
BALISTIDAE					
Sufflamen frenatus	1	1	2	4	3
Rhinecanthus aculeatus (?)	1	—	—	—	—
MONACANTHIDAE					
Cantherhines dumerilii	1	—	—	—	—
TETRAODONTIDAE					
Arothron hispidus	2	1	—	1	—
CANTHIGASTERIDAE					
Canthigaster jactator	2	1	—	—	—
Canthigaster coronata	1	—	—	1	1
Total No. of Species	11	10	11	8	9
Total No. of Individuals	42	52	126	23	36
Biomass (g/m^2)	6	12	11	39	39

tallied in each transect area are given in Table 2, and the invertebrate census data from previous annual surveys are presented in Table 3 for comparative purposes.

Transect 1 commenced 58 m down from the beginning of the diffuser pipe and continued for approximately 95 m along the pipe toward the terminus (Figure 1). This transect sampled 13.5 sections of the 2.1-m-diameter diffuser pipe. The depth at the top of the diffuser pipe at the start of the transect was approximately 68.5 m and about 70.1 m at the end. Eleven species of fish (42 individuals) were noted in this transect, and the biomass was estimated to be 6 g/m^2. This amounts to one new species encountered for every 17.3 m^2 of substratum sampled and one individual fish seen for every 4.5 m^2. Of the species that could be identified, the most abundant on this transect were the damselfishes (*Chromis hanui* and *Chromis* sp., probably *C. agilis*). Unidentified wrasses were also common on this transect; 43% of the fishes counted fell into this category. As for standing crop, the stripebelly puffer or kēkē (*Arothron hispidus*) accounted for 61% of the total. Four macroinvertebrate species (five individuals) were censused on this transect (Table 2). The most visually abundant species on this and the other four transects was the black sea cucumber, *Holothuria atra*. Of note was a single spiny lobster or ula (*Panulirus marginatus*) estimated to weigh 0.7 kg.

Transect 2 commenced 355 m down from the beginning of the diffuser pipe in about 71 m of water and ending 91 m down the pipe from that point (Figure 1) in approximately 71.3 m of water (depth to the top of pipe). This transect sampled 12.5 sections of the 2.1-m-diameter portion of the diffuser pipe. Ten species of fishes were censused (Table 1); this translates to one new species seen for every 18.2 m^2 of substratum sampled. In total, 52 individual fishes were counted, and one new fish was seen for every 3.5 m^2 of substratum sampled. Again, the most common fish species seen was *Chromis* sp. (46% of the total). Unidentified wrasses comprised 29% of the total number of fishes seen. Important species by weight was the single large yellowfin surgeonfish or pualu (*Acanthurus xanthopterus*—45% of the total weight) and a single *Arothron hispidus* (30% of the total weight). The biomass of fishes on Transect 2 was estimated to be 45 g/m^2. Three species of macroinvertebrates (4 individuals) were seen on this transect (Table 2).

Seventy-three meters from the end of Transect 2, Transect 3 was established (see Figure 1). The water depth at the beginning of the transect was 71.3 m to the top of the pipe; at the end at 110 m away, it was in 71.9 m of water. Transect 3 sampled 2.5 sections of the 2.1-m-diameter portion of the diffuser pipe and 12.5 sections of the 1.7-m-diameter portion. Fourteen species of fishes were seen on this census, and one new fish species was seen for every 15.7 m^2 of substratum sampled. The number of individual fishes encountered on this transect was 126, and one new fish was seen for every 1.7 m^2 of substratum sampled. The most abundant fish species seen on this transect appeared to be *Chromis* sp. (35% of the total)

TABLE 2. Summary of the diurnally exposed macroinvertebrates censused in five video transects carried out on the Sand Island diffuser on 5 August 1993. The number of individuals of each species censused are given in the body of the table. Totals for numbers of species and individuals for each transect are given at the foot of the table.

Species	Transect Number 1	2	3	4	5
Phylum Arthropoda					
Panulirus marginatus	1	—	—	—	—
Phylum Echinodermata					
Tripneustes gratilla	—	—	1	1	—
Chondrocidaris gigantea	—	1	—	—	—
Culcita novaeguineae	1	—	1	—	—
Holothuria atra	2	2	21	23	7
Bohadschia vitiensis (?)	1	1	2	3	—
Total No. of Species	4	3	4	3	1
Total No. of Individuals	5	4	25	27	7

TABLE 3. Species of diurnally exposed macroinvertebrates censused on five transects along the 1 036-m-long diffuser pipe of the Sand Island deep ocean outfall as delineated using a remotely controlled video camera system on 22 August 1991 and 28 August 1992. Areas sampled on the five transects varied: 190 m^2 for Transect 1, 182 m^2 for Transect 2, 220 m^2 for Transect 3, 168 m^2 for Transect 4, and 88 m^2 for Transect 5. The number of individuals of each species censused are given in the body of the table. Totals for numbers of species and individuals for each transect are given at the foot of the table.

Species	1991 Transect Number					1992 Transect Number				
	1	2	3	4	5	1	2	3	4	5
Phylum Arthropoda										
Panulirus marginatus	—	—	—	—	—	—	2	—	—	—
Phylum Echinodermata										
Holothuria atra	2	2	32	12	1	—	—	14	11	4
Bohadschia vitiensis	—	—	1	—	—	2	—	7	—	—
Culcita novaeguineae	—	—	—	—	—	—	1	—	—	—
Diadema setosum	7	1	—	—	—	—	—	—	—	—
Tripneustes gratilla	—	—	—	—	3	—	—	—	—	—
Total No. of Species	2	2	2	—	2	1	2	2	1	1
Total No. of Individuals	9	3	33	12	4	2	3	21	11	4

and unidentified wrasses (labrid sp.—27% of the total). The standing crop of fishes was estimated to be 11 g/m^2, 30% of which was comprised of unidentified wrasses (labrid sp.) and 32% of two bridled triggerfishes or humuhumu mimi (*Sufflamen frenatus*). Table 2 presents a summary of the macroinvertebrates encountered on Transect 3; four species (25 individuals) were counted, the most abundant of which was *Holothuria atra*.

Transect 4 was established 161 m from the end of Transect 3 toward the diffuser terminus (Figure 1). It commenced at a depth of about 70.7 m (depth to the top of the pipe) and ended at a depth of 70.1 m. Transect 4 sampled about 84 m of the diffuser pipe, covering 2.5 sections of the 1.7-m-diameter portion of the pipe and 9 sections of the 1.2-m-diameter portion. In total, eight species of fishes (23 individuals) were seen at this station. Equating these figures to the area sampled results in one new fish species seen for every 21.0 m^2 and one fish encountered for every 7.3 m^2. The most abundant fish on Transect 4 was the unidentified wrasse (labrid sp.), which comprised 39% of the total number of fishes seen. The standing crop of fishes at Transect 4 was estimated to be 39 g/m^2, and the species contributing most heavily was a single *Acanthurus xanthopterus* (30% of the total weight), a single *Arothron hispidus* (20% of the total weight) and two *Sufflamen frenatus* (17% of the total weight). Three species of diurnally exposed macroinvertebrates (27 individuals) were encountered on this transect (Table 2).

Transect 5 covered the final 44 m of the diffuser pipe and the terminus. This transect sampled 5.5 sections of pipe and the diffuser terminus. It commenced at a depth of about 71 m (depth to the top of the pipe) and ended at a depth of approximately 69.5 m at the top of the diffuser terminus. Nine species of fishes (36 individuals) were encountered in the census. As for area sampled, one new species of fish was seen for every 9.8 m^2 and one new fish for every 2.4 m^2. The most abundant species seen included the brightly colored sea bass (*Pseudanthias thompsoni*—22% of the total), the moorish idol or kihikihi (*Zanclus cornutus*—19% of the total), and the unidentified wrasse (labrid sp.—28% of the total). The standing crop of fishes on Transect 5 was estimated to be 39 g/m^2, and the species comprising the greatest proportion include *Acanthurus xanthopterus* (45% of the total weight) and *Sufflamen frenatus* (29% of the total weight). Only one macroinvertebrate species (*Holothuria atra*) was seen on this transect (Table 2).

The results of the five transects carried out in 1993 using the video camera are summarized in Table 4. The visual fish census transects from the video shot in August 1991 and August 1992 covered the same five sections of the diffuser pipe as the 1993 census; thus data for the three years can be comparatively analyzed. The 1991 and 1992 census data are presented in Tables 5 and 6, and data for all three years are summarized in Table 7. In general, the 1992 data showed higher numbers of species, numbers of individual fish, and estimated

TABLE 4. Summary of the characteristics of five transects carried out at various points along the 1 036-m-long Sand Island deep ocean outfall diffuser, with data from the fish censuses carried out at each transect in August 1993. Grand means are presented in the right column.

Parameter	Transect Number					Grand Mean
	1	2	3	4	5	
Transect Length (m)	95	91	110	84	44	85
Area Sampled (m^2)	190	182	220	168	88	170
No. of Species	11	10	11	8	9	10
No. of Individuals	42	52	126	23	36	56
No./m^2 Sampled per New Species	17.3	18.2	15.7	21.0	9.8	16.4
No./m^2 Sampled per Individual	4.5	3.5	1.7	7.3	2.4	3.9
Biomass (g/m^2)	6	12	11	39	39	21

biomass than the 1991 data; in contrast, the 1993 data showed consistently lower figures. The 1992 increase over the 1991 survey data may be due to (1) better control of the remotely operated video camera in viewing both sides of the diffuser pipe or (2) improved ability to identify fishes recorded with a video camera with the passage of time. From a review of the tapes for 1991, 1992, and 1993, it is suggested that maximum visibility was about the same (8 m) for all years but coverage by the camera was better in 1992 than in 1991. The control of the camera (steadiness and area coverage) in 1993 appeared to be less than in 1992, and the resolution in the 1993 videotape was considerably less. Average visibility in 1993 was about 3 m, less than in previous surveys. The net result is an apparent decrease in fish species, numbers, and biomass in the 1993 data.

A summary of the parameters measured in the fish community along the Sand Island diffuser for the three sample dates (August 1991, August 1992, and August 1993) is given in Table 7. Statistically significant differences were found in the mean number of fish species encountered on a transect among the three years (Kruskal-Wallis ANOVA, d.f. = 2, $p > 0.007$; see Siegel 1956). The nonparametric Student-Newman-Keuls multiple range test on ranked values of each variable (SAS Institute, Inc. 1985) was used to delineate statistically significant differences for the mean number of fish species per transect among the three years. Only the mean number of fish species for 1992 differed significantly from that in 1991 and 1993 (Table 8). The same analyses were performed for the mean number of individual fishes censused on a transect. Again, the Kruskal-Wallis ANOVA pointed out that a statistically significant difference exists in the mean number of individual fishes per transect among the

TABLE 5. Species of fishes censused on five transects along the 1 036-m-long diffuser pipe of the Sand Island deep ocean outfall as delineated using a remotely controlled video camera system on 28 August 1992. Areas sampled on the five transects varied: 190 m^2 for Transect 1, 182 m^2 for Transect 2, 220 m^2 for Transect 3, 168 m^2 for Transect 4, and 88 m^2 for Transect 5. The number of individuals of each species censused are given in the body of the table. Totals for numbers of species and individuals and an estimate of the biomass for each transect are given at the foot of the table. (Data from Brock 1993)

Species	Transect Number				
	1	2	3	4	5
MURAENIDAE					
Gymnothorax flavimarginatus	—	1	1	—	—
Gymnothorax sp.	—	—	1	1	—
AULOSTOMIDAE					
Aulostomus chinensis	—	—	1	—	—
PRIACANTHIDAE					
Priacanthus sp.?	—	—	—	—	1
SERRANIDAE					
Pseudanthias thompsoni	—	24	158	41	148
LUTJANIDAE					
Lutjanus kasmira	—	261	—	—	—
Lutjanus fulvus	1	2	2	—	—
Lutjanus sp.?	—	—	722	153	375
MULLIDAE					
Parupeneus multifasciatus	11	24	32	5	—
CHAETODONTIDAE					
Chaetodon multicinctus (?)	4	1	—	—	—
C. kleinii (?)	—	2	—	—	—
Chaetodon sp.	—	3	1	—	—
POMACANTHIDAE					
Holacanthus arcuatus	—	1	1	—	—
Centropyge (?) sp.	1	2	16	2	3
POMACENTRIDAE					
Chromis hanui	52	31	28	19	8
Chromis sp.	76	126	91	55	11
Pomacentrid sp.	11	3	—	—	—
LABRIDAE					
Bodianus bilunulatus	—	—	1	—	1
Thalassoma duperrey (?)	23	17	8	—	—
Pseudojuloides cerasinus	—	3	15	5	—
Gomphosus varius	3	—	—	1	—
Macropharyngodon geoffroy	1	—	3	—	—
Halichoeres ornatissimus (?)	1	1	1	—	—
Labrid sp.	111	83	56	30	8
ACANTHURIDAE					
Acanthurus dussumieri	7	1	1	—	—
ZANCLIDAE					
Zanclus cornutus	—	—	—	1	7
BALISTIDAE					
Sufflamen frenatus	—	—	1	—	1
Sufflamen bursa (?)	—	—	1	—	—
MONACANTHIDAE					
Cantherhines dumerilii	3	5	2	11	2
TETRAODONTIDAE					
Arothron hispidus	3	—	1	1	1
CANTHIGASTERIDAE					
Canthigaster jactator (?)	—	2	—	—	—
Total No. of Species	15	20	23	13	12
Total No. of Individuals	308	593	1144	325	566
Biomass (g/m^2)	39	45	58	44	77

TABLE 6. Species of fishes censused on five transects along the 1 036-m-long diffuser pipe of the Sand Island deep ocean outfall as delineated using a remotely controlled video camera system on 22 August 1991. Areas sampled on the five transects varied: 190 m^2 for Transect 1, 182 m^2 for Transect 2, 220 m^2 for Transect 3, 168 m^2 for Transect 4, and 88 m^2 for Transect 5. The number of individuals of each species censused are given in the body of the table. Totals for numbers of species and individuals and an estimate of the biomass for each transect are given at the foot of the table. (Data from Brock 1992b)

Species	Transect Number				
	1	2	3	4	5
MURAENIDAE					
Gymnothorax flavimarginatus	—	—	—	—	1
SERRANIDAE					
Pseudanthias thompsoni	—	18	44	18	87
APOGONIDAE					
Apogon kallopterus (?)	—	—	1	—	—
LUTJANIDAE					
Lutjanus kasmira	—	—	690	—	—
MULLIDAE					
Parupeneus multifasciatus	1	4	10	3	1
CHAETODONTIDAE					
Chaetodon multicinctus	—	1	—	—	—
C. kleinii (?)	—	3	—	—	—
Chaetodon sp.	5	3	—	—	—
Heniochus acuminatus (?)	—	—	—	1	—
POMACANTHIDAE					
Holacanthus arcuatus	—	1	—	—	1
POMACENTRIDAE					
Chromis hanui	41	—	—	23	—
C. verater (?)	—	—	1	—	—
Chromis sp.	31	118	91	30	64
LABRIDAE					
Bodianus bilunulatus	—	—	1	1	3
Thalassoma duperrey (?)	1	—	—	—	—
Thalassoma sp.	—	—	1	—	—
Pseudojuloides cerasinus	4	11	19	—	—
Labrid sp.	69	50	175	62	41
ACANTHURIDAE					
Acanthurus dussumieri	5	—	—	—	1
A. xanthopterus	2	—	—	—	—
Acanthurus sp.	—	4	3	—	—
ZANCLIDAE					
Zanclus cornutus	—	—	—	5	5
BALISTIDAE					
Sufflamen frenatus	1	—	—	—	2
MONACANTHIDAE					
Cantherhines dumerilii	7	2	6	2	1
TETRAODONTIDAE					
Arothron hispidus	2	—	2	1	—
A. meleagris (?)	—	1	—	—	—
CANTHIGASTERIDAE					
Canthigaster jactator (?)	—	1	—	—	—
C. coronata	—	—	1	1	—
Total No. of Species	12	13	14	11	11
Total No. of Individuals	169	217	1045	147	207
Biomass (g/m^2)	32	8	55	10	106

TABLE 7. Comparative summary of the fish community development measured over three years at five locations along the 1 036-m-long Sand Island deep ocean outfall diffuser. Means for parameters measured on each transect are given in the body of the table. Data are drawn from Tables 1, 5, and 6, and grand means for the five transects are given at the foot of the table.

Transect Number	No. of Species			No. of Individuals			Biomass (g/m^2)		
	1991	1992	1993	1991	1992	1993	1991	1992	1993
1	12	15	11	169	308	42	32	39	6
2	13	20	10	217	593	52	8	45	12
3	14	23	11	1,045	1,144	126	55	58	11
4	11	13	8	147	325	23	10	44	39
5	11	12	9	207	566	36	106	77	39
Grand Mean	12	17	10	357	587	56	42	53	21

TABLE 8. Summary of the nonparametric Student-Newman-Keuls multiple range test on ranked values of parameters measured in the fish community at five permanent transects along the 1 036-m-long Sand Island diffuser censused in August of 1991, 1992, and 1993. In the body of the table are given means on a per transect basis. Horizontal lines connect means that do not differ significantly; breaks in the line indicate significant differences ($p \geq 0.05$).

Parameter	1992	1991	1993
Mean No. of Species per Transect	17	12	10
Mean No. of Individuals per Transect	587	357	56
Biomass (g/m^2)	53	42	21

three years (d.f. = 2, $p > 0.009$). Using the Student-Newman-Keuls multiple range test, it was noted that the means for 1991 and 1992 are related and also that the means for 1991 and 1993 are related; the overlapping 1991 data suggest that the mean number of individual fishes per transect is only significantly different between 1992 and 1993 (Table 8). No statistically significant differences were found in the mean standing crop of fishes encountered on a transect among the three sample dates (Kruskal-Wallis ANOVA, d.f. = 2, $p > 0.1$, N.S.; see also Table 8).

The 1990 videotape only recorded the fishes present on the final 183 m of the diffuser (Brock 1992a); thus the data are not directly comparable to the 1991–93 transect information. In the 1990 study, Brock (1992a) found 16 species of fishes and one new species for every 22.9 m^2 of substratum sampled, and 67 individual fishes and one new fish for every 5.6 m^2. The standing crop of fishes was estimated to be 17 g/m^2. Based on the criteria used (i.e., biomass and number of square meters sampled to encounter a new species or an individual fish), the fish communities along the diffuser pipe were found to increase from 1990 to 1991.

DISCUSSION

Since 1991, the estimated biomass of fishes ranged from 6 g/m^2 (Transect-1, 1993) to 106 g/m^2 (Transect 5, 1991). The overall mean standing crop (all years) is 39 g/m^2: in 1991 it was 42 g/m^2; in 1992, 53 g/m^2; and in 1993, 21 g/m^2. The census of Transect 5 in 1991 resulted in a high biomass estimate (106 g/m^2); this was due to a large resident yellowmargin moray eel or puhi paka (*Gymnothorax flavimarginatus*) and two tableboss or a'awa (*Bodianus bilunulatus*) that wandered through the path of the video camera. If these three fishes are removed from the biomass estimate, the standing crop for 1991 becomes 24 g/m^2. The grand mean estimate of the biomass would then be 33 g/m^2 (all years combined).

Goldman and Talbot (1975) suggested that a reasonable maximum biomass of coral reef fish is about 200 g/m^2. Space and cover are important agents governing the distribution of coral reef fishes (Sale 1977). Similarly, the standing crop of fishes on a reef is correlated with the degree of vertical relief. 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. The large variation seen in standing crop of fishes on coral reefs is tied to the structural diversity of the habitat (Risk 1972). Some authors (Risk 1972; 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) view reef structure as an important factor in determining the species composition of coral reef fish communities. Thus some evidence suggests that both the biomass and species composition are influenced by the complexity of the local topography.

The substratum in the vicinity of the Sand Island outfall diffuser appears to be a sandy plain. Sand habitats typically support a low diversity of fish species and biomass, i.e., standing crops ranging from 0.5 to 20 g/m^2 (Brock 1954; Brock et al. 1979; Brock and Norris 1989). The diffuser pipe situated on a gravel pad with some ballast stone placed at the ends of most pipe sections provides additional local topographical structure, which has probably influenced the development of the fish community. Because of the graded sizes used, the ballast stone and gravel pad provide only small-scale shelter. Small-scale shelter favors species that are either small as adults or juveniles of larger species. The average size of the fishes censused in this survey supports this contention. Additionally, many of the larger fishes seen (especially *Acanthurus xanthopterus*) were in the vicinity of known areas of topographical relief, such as the set of large tires near the start of the diffuser pipe, the discarded 55-gallon drum, and the construction debris. The accuracy of censusing is less with smaller fishes.

The data from 1991 to present suggest that there is considerable variation in the fish and invertebrate counts over time. The identification of some species of fishes in this study was not difficult because of their size (such as *Acanthurus xanthopterus* and *Bodianus bilunulatus*) or color (such as *Zanclus cornutus*). In past years some species such as the bluelined snapper or ta'ape (*Lutjanus kasmira*) occurred in such high abundance that species identification was not difficult. Despite this, a number of fishes have consistently been difficult or impossible to identify because of (1) poor camera resolution, (2) rapid movement of the individual fishes to cover, (3) small size, or (4) having the fishes on the peripheral field of view. Some of these fishes were small damselfishes (probably *Chromis hanui* or *C. agilis*), small *Lutjanus* sp. (probably *Lutjanus kasmira*), and small wrasses (family Labridae, possibly *Cheilinus bimaculatus*, *Pseudocheilinus* spp., *Thalassoma* spp., or *Pseudojuloides cerasinus*). As for abundance, these unidentified fishes are important, but they generally contribute little to the biomass estimates because of their small size.

The counts for the parameters measured in the 1993 fish census appear to be lower than those taken in 1992. As noted above, the camera resolution was much poorer in 1993 than in 1992 and is probably the reason for the decrease in the apparent abundance of fishes on the diffuser. Manipulation of the remotely operated and tethered video camera is difficult, especially when considering that more than 60 m of electrical cable is between the camera and the operator on the surface vessel. Not only does the wind create difficulties with keeping the surface vessel on station, but currents may interact with the cable and camera below. These factors serve to move the camera away from the area of interest, making accurate censusing of fishes and invertebrates on the resulting videotape very difficult at best. These problems, coupled with highly variable turbidity due to the interaction of material discharged from the diffuser ports with local currents, result in highly variable visibility that serves to add variability to the counts.

Controlling these sources of variation inherent with the use of the remotely controlled video system is difficult if not impossible. The remotely controlled video camera used for the annual inspection by Department of Wastewater Management personnel probably provides sufficient resolution and information with respect to the physical status of the outfall and diffuser, but it appears to be inadequate for monitoring the status of fish and macrobenthos on the diffuser. Until an alternative can be found, the remotely controlled video system is the only low-cost means available to view the marine communities on the diffuser. Until a more accurate means of visual assessment is available, the biological data generated by the remotely controlled video camera should be viewed as qualitative, with little statistical rigor.

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