AN ANALYSIS OF THE FISH AND MACROBENTHOS ALONG THE SAND ISLAND OCEAN OUTFALL USING REMOTE VIDEO: V. 1994 DATA

Richard E. Brock

PROJECT REPORT PR-95-06

January 1995

WATER RESOURCES RESEARCH CENTER
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PREPARED FOR
Department of Wastewater Management
City and County of Honolulu
Project Report
for
"The Assessment of the Impact of Ocean Outfalls on the Marine Environment off Oahu, Hawaii"
Project No.: C59390
Project Period: 21 February 1990–31 December 1994
Principal Investigator: Roger S. Fujioka

WATER RESOURCES RESEARCH CENTER
University of Hawai'i at Mānoa
Honolulu, Hawai'i 96822

ABSTRACT

Because the diffuser of the Sand Island 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 1036 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, 1993, and 1994. 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 1994, 33 fish species (1,473 individuals) having an estimated biomass ranging from 16 to 46 g/m^2 (mean 35 g/m^2) were censused; in 1993, 22 species (279 individuals) having a standing crop ranging from 6 to 39 g/m^2 (mean 21 g/m^2) were encountered; in 1992, 30 fish species (2,936 individual fish) having an estimated standing crop ranging from 39 to 77 g/m^2 (mean 53 g/m^2) were censused, and 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. 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 sampled and one fish for every 0.7 m^2; in 1992, it was one new species for every 7.4 m^2 and one fish for every 0.4 m^2; and in 1993, it was one new species for every 38.5 m^2 and one fish for every 3.0 m^2. The 1994 census noted one new fish species for every 10.2 m^2 of substratum sampled and one fish for every 0.7 m^2. In the 1991–94 period, measures of the fish community (number of species, number of individuals, and biomass) increased from 1991 to 1992, decreased in 1993, and increased again in 1994. From a statistical perspective, changes in the mean number of species per transect and the mean number of individual fishes per transect are significant (Kruskal–Wallis ANOVA); changes in the biomass of fishes over the same period are not significant. These changes in the fish community are attributed to changes in the general viewplane in 1994 from earlier years as well as to a change in the 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

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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.

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 2780 m of 2.1-m-diameter reinforced concrete pipe that terminates in a 1036-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 fifth annual sampling effort carried out on 10 August 1994 and comparatively analyzes these data with information collected annually since 1991.

MATERIALS AND METHODS

A remotely controlled video camera 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 'āweoweo (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 remotely 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 the first three annual surveys, the video camera generally 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 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 we attempted to count only fishes seen in this path. At times, the camera would tilt up (toward 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 fourth (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.

The path of the camera in the most recent (1994) survey was quite different. In this case, the camera remained along one (inshore) side of the pipe while traveling toward the outfall terminus, and on reaching the terminus, the camera was moved to the opposite (offshore) side, for its travel back to the beginning of the diffuser. The censuses for the 1994 survey were carried out at each of the five transect sites on the offshore side of the diffuser only, to make data between surveys comparable.

The camera grossly underestimates the number of fish and invertebrates, thus everything seen in an arbitrary 2-m-wide path was counted, 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 five occasions: 7 November 1990, 22 August 1991, 28 August 1992, 5 August 1993, and 10 August 1994. The November 1990 survey only covered the final 183 m of the 1036-m-long diffuser pipe. In the more 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 by counting sections of pipe from those points. The five transect sites were again sampled in subsequent surveys, 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 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. Fourteen species of fish (225 individuals) were noted in this transect, and the biomass was estimated at 16 g/m^2. This amounts to one new species encountered for every 13.6 m^2 of substratum sampled and one individual fish seen for every 0.8 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. hanui* and/or *C. agilis*). The smalltail wrasse (*Pseudojuloides cerasinus*) was also common on this transect. In terms of standing crop, five stripebelly puffers or kēkē (*Arothron hispidus*) accounted for 58% of the total. Two macroinvertebrate species (two individuals) were censused on this transect, and the most visually abundant species on the other transects was the black sea cucumber *Holothuria atra* (Table 2). Of note was a single spiny lobster or ʻula (*Panulirus marginatus*) estimated to weigh 0.5 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 the pipe). This transect sampled 12.5 sections of the 2.1-m-diameter portion of the diffuser pipe. Sixteen species of fishes were censused (Table 1); this translates to one new species seen for every 11.4 m^2 of substratum sampled. In total, 194 individual fishes were counted, and one new fish was seen for every 0.9 m^2 of substratum sampled. Again, the most common fish species seen was the damselfish (*Chromis* sp.—46% of the total). Unidentified wrasses comprised 11% of the total number of fishes seen. Important species by weight were three large broomtail filefish or ʻōʻili lepa (*Alutera scripta*—57% of the total weight) and four stripebelly puffers or kēkē (*Arothron hispidus*—24% of the total weight). The biomass of fishes on Transect 2 was estimated at 46 g/m^2. One macroinvertebrate species (a single *Chondrocidaris gigantea*) was seen on this transect (Table 2).

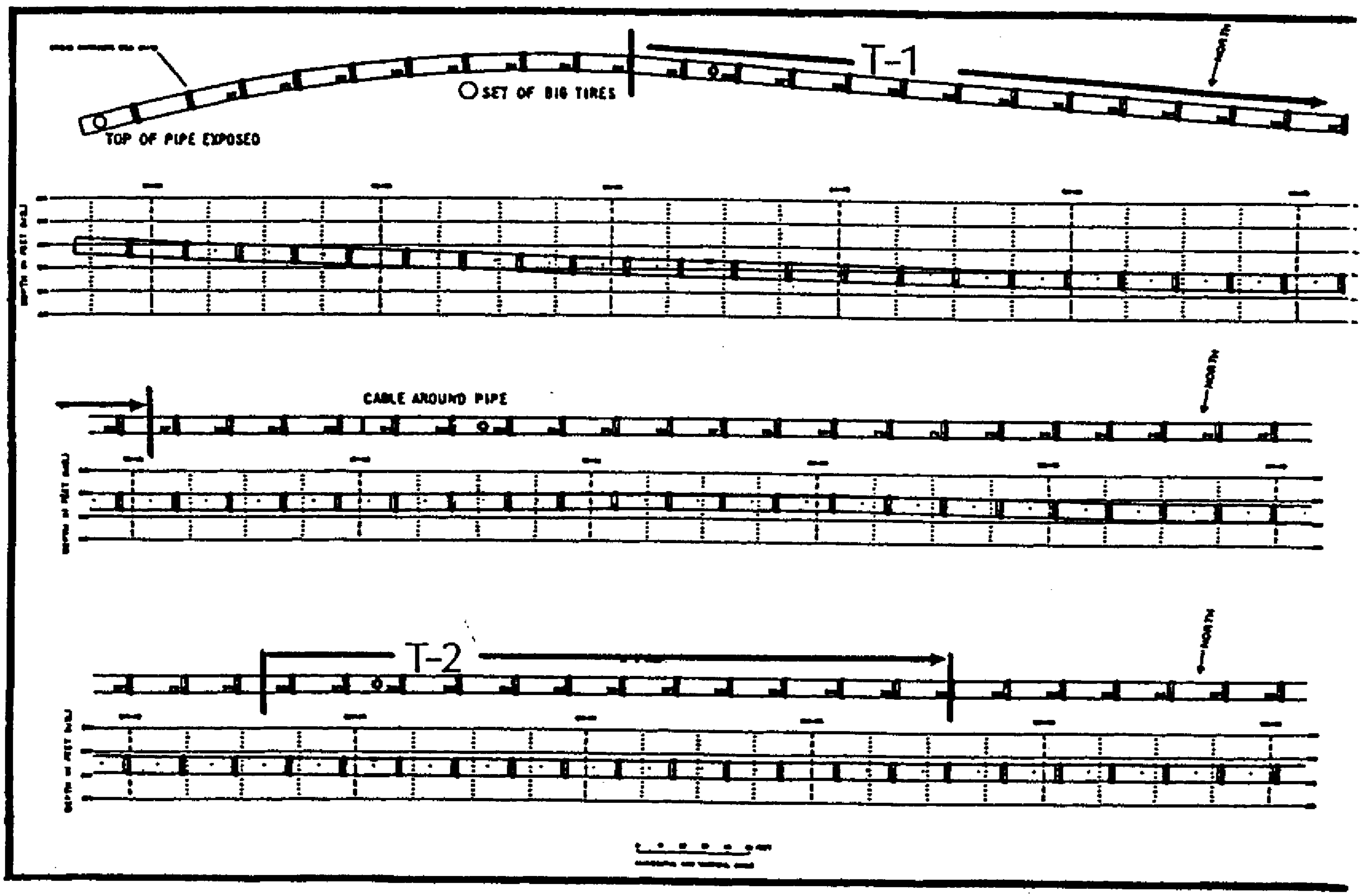

Figure courtesy of the Oceanographic Team, Department of Wastewater Management, City and County of Honolulu.

FIGURE 1. Schematic of 1036-m-long Sand Island 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.

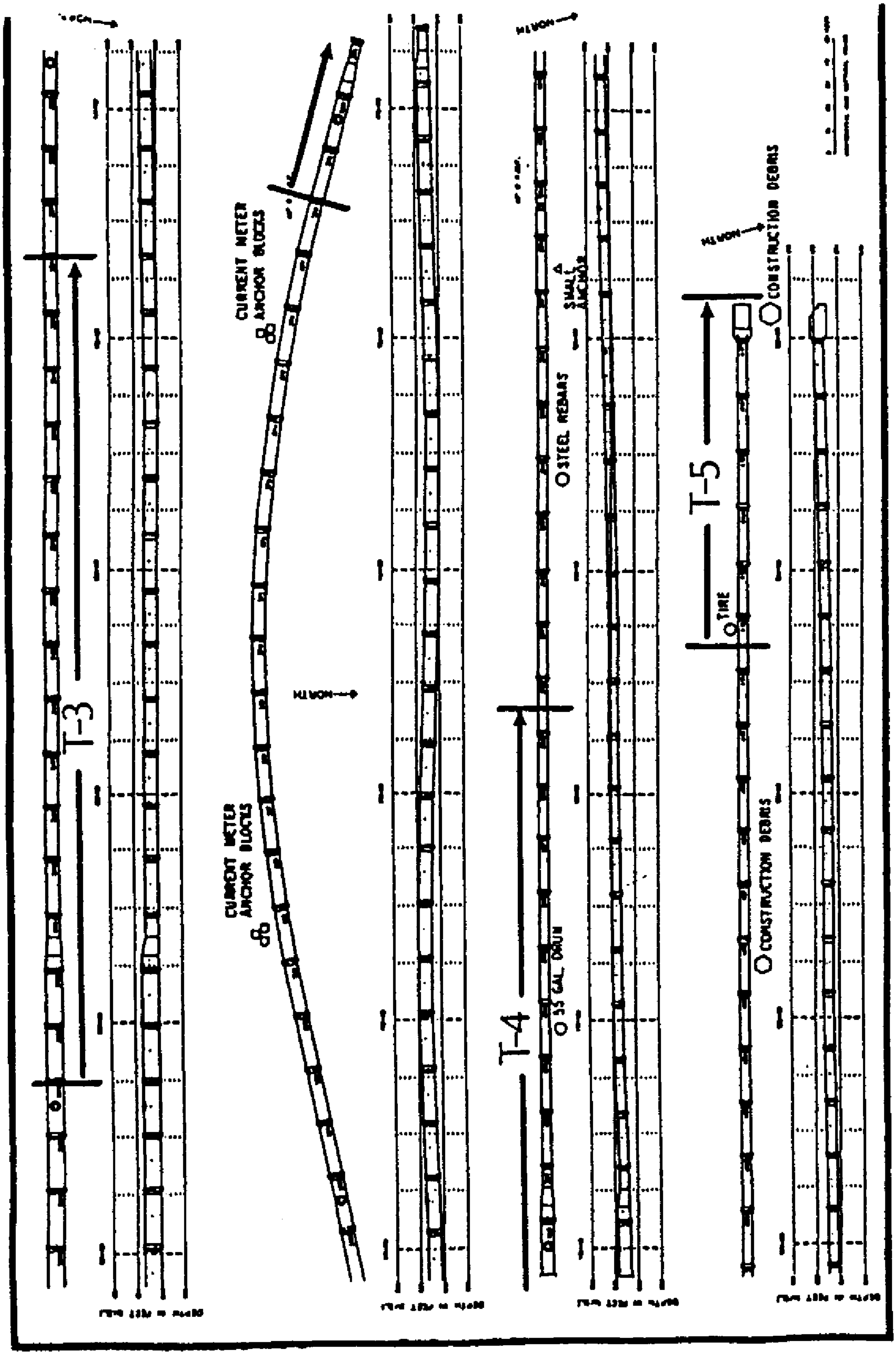

FIGURE 1. —Continued

TABLE 1. Family and species of fishes censused on five transects along the 1036-m-long diffuser pipe of the Sand Island Ocean Outfall as delineated using a remotely controlled video camera system on 10 August 1994. 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 numbers 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 biomass for each transect are given at the foot of the table.

FAMILY and Species	Transect				
	1	2	3	4	5
MURAENIDAE					
Gymnothorax sp.	2	1	4	2	1
AULOSTOMIDAE					
Aulostomus chinensis			2		
SERRANIDAE					
Pseudanthias sp.	6	18	91	35	103
APOGONIDAE					
Apogon kallopterus		4	17		
CARANGIDAE					
Caranx melampygus			3	1	
LUTJANIDAE					
Lutjanus kasmira	2		72		20
MULLIDAE					
Parupeneus multifasciatus	6	3	5	1	
Mulloidichthys vanicolensis			2		
CHAETODONTIDAE					
Chaetodon kleinii			1		
Chaetodon miliaris			2		2
POMACANTHIDAE					
Centropyge fisheri	3	3	5	2	2
POMACENTRIDAE					
Chromis hanui	18	16	64	14	4
Chromis agilis				9	7
Chromis sp.	141	90	339	77	22
Pomacentrid sp.	6	19	4	4	1
Plectroglyphidodon johnstonianus (?)		1			
LABRIDAE					
Pseudojuloides cerasinus (?)	18	5	15	12	2
Bodianus bilunulatus					1
Anampses chrysocephalus			1		
Halichoeres ornatissimus			3		
Labrid sp.	15	22	50	18	8
ACANTHURIDAE					
Acanthurus sp.			3		
Naso unicornis (?)			1		
Naso brevirostris	1				
ZANCLIDAE					
Zanclus cornutus					1
BALISTIDAE					
Sufflamen fraenatus	1			1	
Sufflamen fuscus (?)			2		
MONACANTHIDAE					
Cantherhines dumerilii		3	2	6	3
Alutera scripta		3		1	
TETRAODONTIDAE					
Arothron hispidus	5	4	2	1	
CANTHIGASTERIDAE					
Canthigaster jactator		1	1		
Canthigaster coronata	1	1		2	
Total No. of Species	14	16	24	16	14
Total No. of Individuals	225	194	691	186	177
Biomass (g/m^2)	16	46	42	43	28

TABLE 2. Summary of the diurnally exposed macroinvertebrates censused on five video transects carried out along the 1036-m-long diffuser pipe of the Sand Island Ocean Outfall on 10 August 1994. The numbers 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.

PHYLUM and Species	Transect				
	1	2	3	4	5
ARTHROPODA					
Panulirus marginatus	1		1		
ECHINODERMATA					
Chondrocidaris gigantea	1	1			
Holothuria atra			4	16	10
Bohadschia vitiensis (?)			1		
Total No. of Species	2	1	3	1	1
Total No. of Individuals	2	1	6	16	10

TABLE 3. Summary of diurnally exposed macroinvertebrates censused on five transects along the 1036-m-long diffuser pipe of the Sand Island Ocean Outfall as delineated using a remotely controlled video camera system in August of 1991, 1992, and 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 numbers of individuals of each species 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.

PHYLUM and Species	1991 Transect					1992 Transect					1993 Transect				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
ARTHROPODA															
Panulirus marginatus								2			1				
ECHINODERMATA															
Tripneustes gratilla					3								1	1	
Chondrocidaris gigantea												1			
Culcita novaeguineae							1				1		1		
Diadema setosum	7	1													
Holothuria atra	2	2	32	12	1			14	11	4	2	2	21	23	7
Bohadschia vitiensis (?)			1			2		7			1	1	2	3	
Total No. of Species	2	2	2	1	2	1	2	2	1	1	4	3	4	3	1
Total No. of Individuals	9	3	33	12	4	2	3	21	11	4	5	4	25	27	7

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. Twenty-four species of fishes were counted, and one new fish species was seen for every 9.2 m^2 of substratum sampled. The number of individual fishes encountered on this transect was 691, and one new fish was seen for every 0.3 m^2 of substratum sampled. The most abundant fish species on this transect appeared to be *Chromis* sp. (49% of the total) and *Chromis hanui* (9% of the total). The standing crop of fishes was estimated at 42 g/m^2, 37% of which was comprised of three blue trevally or ʻōmilu (*Caranx melampygus*) and 10% of two bridled triggerfishes or humuhumu mimi (*Sufflamen fraenatus*). Table 2 presents a summary of the macroinvertebrates encountered on Transect 3; three species (six individuals) were counted, including a single 0.5-kg spiny lobster (*Panulirus marginatus*).

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, 16 species of fishes (186 individuals) were seen at this station. Equating these figures to the area sampled results in one new fish species seen for every 10.5 m^2 and one fish encountered for every 0.9 m^2. The most abundant fish on Transect 4 was *Chromis* sp., which comprised 41% of the total number of fishes seen, and the brightly colored sea bass (*Pseudanthias* sp.), which made up 19% of the total. The standing crop of fishes at Transect 4 was estimated at 43 g/m^2, and the species contributing most heavily were a single *Caranx melampygus* (19% of the total) and a single *Alutera scripta* (33% of the total). Only one macroinvertebrate species (*Holothuria atra*) was seen 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. Fourteen species of fishes (177 individuals) were encountered during the census. As for area sampled, one new species of fish was seen for every 6.3 m^2 and one new fish for every 0.5 m^2. The most abundant species seen included *Pseudanthias* sp. (22% of the total) and *Chromis* sp. (12% of the total). The standing crop of fishes on Transect 5 was estimated at 28 g/m^2, and the species comprising the greatest proportion were *Pseudanthias* sp. (46% of the total) and the barred filefish or ʻōʻili (*Cantherhines dumerilii*—28% of the total). Only one macroinvertebrate species (the black sea cucumber *Holothuria atra*) was seen on this transect (Table 2).

The results of the five transects carried out in 1994 using the video camera are summarized in Table 4. The visual fish census transects from the video shot in August of 1991, 1992, and 1993 covered the same five sections of the diffuser pipe as in the present survey; thus data for the four years can be comparatively analyzed. The 1991, 1992, and 1993 data are presented in Tables 5, 6, and 7, respectively, and data for all four years are summarized in Table 8. In general, the 1992 and 1994 census data showed higher numbers of species, numbers of individual fish, and estimated biomass than the 1991 or 1993 data. These differences may be due to (1) better control of the remotely operated camera in viewing the substratum or (2) improved ability to identify fishes recorded with a video camera with the passage of time. From a review of all tapes for 1991, 1992, 1993, and 1994, it is suggested that maximum visibility was about the same (8 m) for all years but coverage by the camera was better in 1992 and 1994. The control of the camera (steadiness and area coverage) in 1993 appeared to be less than in other years, 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 and individuals in the 1993 data.

As noted above, Table 8 presents a summary of the parameters measured in the fish community along the Sand Island diffuser for the four sampling dates. Statistically significant differences were found for the mean number of fish species encountered on a transect among the four years (Kruskal–Wallis ANOVA, d.f. = 3, $p > 0.003$; 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 four years. These results are presented in Table 9; only the mean number of fish species for 1993 differed significantly from the other three years. 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 four years (d.f. = 3, $p > 0.004$). Using the Student–Newman–Keuls multiple range test, it was noted that only the means for 1992 and 1993 differed significantly from one another; the overlapping data from 1991 and 1994 suggest that the mean number of individual fish per transect in those years are related (Table 9). No statistically significant differences were found in the mean standing crop of fishes encountered on a transect among the four sampling dates (Kruskal–Wallis ANOVA, d.f. = 3, $p > 0.11$, not significant; see also Table 9).

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 through 1994 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

TABLE 4. Summary of the characteristics of five transects carried out at various points along the 1036-m-long Sand Island Ocean Outfall diffuser, with data from the fish censuses carried out at each transect in August 1994. Grand means are presented in the right column.

Parameter	Transect 1	2	3	4	5	Grand Mean
Transect Length (m)	95	91	110	84	44	85
Area Sampled (m^2)	190	182	220	168	88	170
No. of Species	14	16	24	16	14	17
No. of Individuals	225	194	691	186	177	295
No./m^2 Sampled Per New Species	13.6	11.4	9.2	10.5	6.3	10.2
No./m^2 Sampled Per Individual	0.8	0.9	0.3	0.9	0.5	0.7
Biomass (g/m^2)	16	46	42	43	28	35

5.6 m^2. The standing crop of fishes was estimated at 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 standing crop of fishes ranged from 6 (Transect 1, 1993) to 106 g/m^2 (Transect 5, 1991). The overall mean standing crop (all years) is 38 g/m^2: in 1991, it was 42 g/m^2; in 1992, 53 g/m^2; in 1993, 21 g/m^2; and in 1994, 35 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 ʻaʻawa (*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

TABLE 5. Family and species of fishes censused on five transects along the 1036-m-long diffuser pipe of the Sand Island 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 numbers of individuals of each species are given in the body of the table. Totals for numbers of species and individuals and an estimate of biomass for each transect are given at the foot of the table. (Data from Brock 1992b)

FAMILY and Species	Transect				
	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			
Chaetodon kleinii (?)		3			
Chaetodon sp.	5	3			
Heniochus acuminatus (?)				1	
POMACANTHIDAE					
Holocanthus arcuatus		1			1
POMACENTRIDAE					
Chromis hanui	41			23	
Chromis verator (?)			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 unidentified	69	50	175	62	41
ACANTHURIDAE					
Acanthurus dussumieri	5				1
Acanthurus xanthopterus	2				
Acanthurus sp.		4	3		
ZANCLIDAE					
Zanclus cornutus				5	5
BALISTIDAE					
Sufflamen fraenatus	1				2
MONACANTHIDAE					
Cantherhines dumerilii	7	2	6	2	1
TETRAODONTIDAE					
Arothron hispidus	2		2	1	
Arothron meleagris (?)		1			
CANTHIGASTERIDAE					
Canthigaster jactator (?)		1			
Canthigaster coronata			1	1	
Total No. of Species	12	13	14	11	11
Total No. of Individuals	169	217	1,045	147	207
Biomass (g/m^2)	32	8	55	10	106

TABLE 6. Family and species of fishes censused on five transects along the 1036-m-long diffuser pipe of the Sand Island 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 numbers of individuals of each species are given in the body of the table. Totals for numbers of species and individuals and an estimate of biomass for each transect are given at the foot of the table. (Data from Brock 1993a)

FAMILY and Species	Transect				
	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			
Chaetodon kleinii (?)		2			
Chaetodon sp.		3	1		
POMACANTHIDAE					
Holocanthus 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 unidentified	111	83	56	30	8
ACANTHURIDAE					
Acanthurus dussumieri	7	1	1		
ZANCLIDAE					
Zanclus cornutus				1	7
BALISTIDAE					
Sufflamen fraenatus			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	1,144	325	566
Biomass (g/m^2)	39	45	58	44	77

TABLE 7. Family and species of fishes censused on five transects along the 1036-m-long diffuser pipe of the Sand Island 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 numbers of individuals of each species are given in the body of the table. Totals for numbers of species and individuals and an estimate of biomass for each transect are given at the foot of the table. (Data from Brock 1993b)

FAMILY and Species	Transect				
	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 fraenatus	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

TABLE 8. Comparative summary of fish community development measured over four years at five locations along the 1036-m-long Sand Island Ocean Outfall diffuser. Data are drawn from Tables 1, 5, 6, and 7, and grand means for the five transects are given at the foot of the table.

Transect	No. of Species				No. of Individuals				Biomass (g/m²)			
	1991	1992	1993	1994	1991	1992	1993	1994	1991	1992	1993	1994
1	12	15	11	14	169	308	42	225	32	39	6	16
2	13	20	10	16	217	593	52	194	8	45	12	46
3	14	23	11	24	1,045	1,144	126	691	55	58	11	42
4	11	13	8	16	147	325	23	186	10	44	39	43
5	11	12	9	14	207	566	36	177	106	77	39	28
Grand Mean	12	17	10	17	357	587	56	295	42	53	21	35

TABLE 9. 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 1036-m-long Sand Island diffuser censused in August of 1991, 1992, 1993, and 1994. The means on a per transect basis are given in the body of the table. Horizontal lines connect means that do not differ significantly; breaks in the line show significant differences ($p \geq 0.05$).

Parameter		Year and Means			
Mean No. of Species Per Transect	Year	1994	1992	1991	1993
	Mean	17	17	12	10
Mean No. of Individuals Per Transect	Year	1992	1991	1994	1993
	Mean	587	387	295	56
Biomass (g/m²)	Year	1992	1991	1994	1993
	Mean	53	42	35	21

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., biomass 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 small 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 invertebrates counts over time. The identification of some species of fishes in this study was not difficult because of their size (such as adult *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) their rapid movement to cover, (3) their small size, or (4) their being 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 1994 fish census appear to be higher than those for 1993. The change in operation of the camera in 1994 to view the fish community along each side of the diffuser rather than continually crossing over the pipe from side to side as done in previous years may account for some of the increase. The better camera resolution in

1994, compared with 1993, is probably another reason for the increase in the apparent abundance of fishes on the diffuser. Overall, the variability in fish counts over the years is influenced by many other factors. Manipulation of the remotely operated and tethered video camera is difficult, especially when considering that more than 60 m of electrical cable are 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 the 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 operated 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.

REFERENCES CITED

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

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

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

Brock, R.E. 1992a. An analysis of the fish communities along the Sand Island deep ocean outfall using remote video. I. 1990 data. Special Rep. 04.02:92, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii. 6 pp.

Brock, R.E. 1992b. An analysis of the fish communities along the Sand Island deep ocean outfall using remote video. II. 1991 data. Special Rep. 04.08:92, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii. 14 pp.

Brock, R.E. 1993a. An analysis of the fish communities along the Sand Island deep ocean outfall using remote video III. 1992 data. Special Rep. 01.15:93, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii. 15 pp.

Brock, R.E. 1993b. An analysis of the fish and macrobenthos along the Sand Island deep ocean outfall, O'ahu, Hawai'i, using remote video IV—1993. Proj. Rep. PR-94-12, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii. 17 pp.

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

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

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

Eckert, G.J. 1985. Settlement of coral reef fishes to different natural substrata and at different depths. In *Proceedings of the 5th International Coral Reef Congress,* vol. 5, Tahiti, 385–390.

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

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

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

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

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

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

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

SAS Institute, Inc. 1985. SAS user's guide: Statistics, version 5 edition. SAS Institute, Inc. 956 pp.

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

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

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

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