COMMUNITY STRUCTURE OF FISH AND MACROBENTHOS AT SELECTED SITES IN THE VICINITY OF THE MOKAPU OCEAN OUTFALL, O‘AHU, HAWAI‘I, 1998

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ABSTRACT

This report provides the results of the first quantitative survey of the coral reef communities in the vicinity of the Mokapu Ocean Outfall in Kailua Bay, Oʻahu, Hawaiʻi. This survey, conducted in April and July 1998, focuses on benthic and fish community structure and is designed to detect community changes that may be mediated by the release of treated sewage through the outfall. The Kailua Regional Wastewater Treatment Plant (WWTP), which has been operational since 1977, releases a little more than 13 mgd of secondary treated sewage through a 1.55-km-long discharge pipe at a depth of 32 m. If impacts are occurring to marine communities from a point-source discharge, their effects will be most evident in proximity to the source and less obvious with distance from the source. The sampling strategy used in this study focuses on quantifying the degree of development of marine communities adjacent to and at distances from the discharge source. This strategy should allow delineation of impacts—if they are occurring.

The results of this first survey indicate that the marine communities in the study area are diverse, with well-developed fish and coral components. This is particularly evident on the Mokapu Ocean Outfall diffuser (Transect T-1) where a high-biomass, diverse fish community occurs. This well-developed fish community is related to the shelter created by the diffuser pipe and basalt armor rock, as well as to the release of organic particles in the treated effluent which serve as a food resource for some fish species. The development of corals as measured in terms of live coverage in the diffuser pipe community is about half that found at the more distant sampling sites. However, a second sampling site (Transect T-2) located parallel to and 15 m away from the diffuser has coral coverage very similar to that found elsewhere in Kailua Bay. These data suggest that if the operation of the Kailua Regional WWTP is having an impact on marine communities, it is very limited in scope and scale.

INTRODUCTION

Purpose

Wastewaters of mainly domestic origin are pumped and secondary treated prior to discharge through the Mokapu Ocean Outfall diffuser at a rate of approximately 14.5 million gallons per day (0.64 m^3/s), 5,083 ft (1.55 km) offshore, at a depth of 105 ft (32 m) offshore of Mo(¯,o)kapu Peninsula. Sources that feed into the diffuser include the Kailua Regional Wastewater Treatment Plant (WWTP) (13.0 mgd or 0.57 m^3/s) and Kaneohe Marine Corps Air Station WWTP (1.5 mgd or 0.07 m^3/s). The discharge pipe is 48 inches (1.2 m) in diameter and 4,120 ft (1.26 km) in length, and the diffuser portion is 963 ft (0.29 km) in length. The diffuser has 80 discharge ports spaced 12 feet (3.7 m) apart, alternating from one side of the pipe to the other. These ports are located at the springline (midline) of the discharge pipe. The first 30 ports are not open because of the less than maximum flow presently being discharged through the diffuser. The remaining 50 ports are operational, with the 20 most-shoreward ports being 4.5 inches (11.4 cm) in diameter, the next 15 being 5 inches (12.7 cm) in diameter, and the final 15 being 5.5 inches (14.0 cm) in diameter. The diffuser terminates with a 5.5-inch-diameter port and a half-circle port that is 8 inches (20.3 cm) in diameter.

Prior to the development of this plant and outfall, sewage from the Kailua area received secondary treatment and was discharged into Kailua Bay via a relatively short outfall offshore of Kapoho Point. The discharge depth was less than 12 m.

In recent years controversy has arisen regarding the impact that sewage effluent discharged from the Mokapu Ocean Outfall may have on inshore coral reef species. Because of these concerns, the City and County of Honolulu contracted the University of Hawai‘i Water Resources Research Center to determine the status of the marine resources in the vicinity of the discharge in an effort to quantitatively ascertain if any impacts are occurring to the coral reef biota. This report presents the findings of the first field survey conducted in April and July 1998.

Strategy

Marine environmental surveys are usually performed to evaluate the feasibility of, and ecosystem response to, specific proposed activities. Appropriate survey methodologies reflect the nature of the proposed action(s). An action that may have an acute impact (such as channel dredging) requires a survey designed to determine the route of least harm and the projected rate and degree of ecosystem recovery. Impacts that are more chronic or progressive require different strategies for measurement. Management of chronic stress to a marine ecosystem requires identification of system perturbations that exceed boundaries of natural fluctuations. Thus a thorough understanding of normal ecosystem variability is required to separate the impact signal from background “noise.” Infrequent natural events may add considerably to the variability or background noise measured in a marine community.

Rare storm events not withstanding, the potential impacts occurring to the Kailua Bay marine ecosystem are most probably those associated with chronic or progressive stresses. Because of the proximity of urbanization, marine communities in Kailua Bay are subjected to an array of impacts not encountered in Hawai‘i coral communities that front undeveloped coastlines. Thus a sampling strategy must attempt to separate impacts due to the discharge of wastewater treatment plant effluent on coral reef communities from a host of nonpoint perturbations occurring in the waters of Kailua Bay.

Almost 42,000 people live in Kailua town (Statistics and Data Support Branch, State of Hawaii, 1997). Growth of this windward community began in the mid-1950s with improvements to the Pali Highway, making the commute between Kailua and Honolulu much faster. In 1977 the Kailua Regional WWTP, with a design capacity of 15.25 mgd (0.67 m^3/s), began operation to handle the wastewaters of the growing Kailua population. In the outlying areas of Kailua (such as Lanikai), sewage continued to be handled by cesspools. Cesspools and urban use of fertilizers, among other factors, contribute toward providing opportunities for nonpoint-source materials to enter the sea.

The Mokapu Ocean Outfall discharge into Kailua Bay may be considered in terms of gradients. There are numerous “gradients” owing to point-source and nonpoint-source (such as Kawainui Canal and Ka‘elepulu Stream) inputs into Kailua Bay from the urbanization of much of the watershed. 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 of Kailua Bay are those that have evolved under the influence of these ongoing perturbations.

As noted above, if impacts are occurring to the coral reef communities in Kailua Bay owing to sewage effluent discharged from the outfall offshore of Mo(¯,o)kapu Peninsula, they are probably chronic in nature and would probably be manifested as slow shifts in the structure of the communities so affected. Gradients of “stress” or “impact” should be evident with distance from the 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 in marine communities presents a number of problems, many of which are related to the scale on which one wishes to quantitatively enumerate organism abundance. Marine communities in Kailua Bay may be spatially defined in a range on the order of a few hundred square centimeters (such as the community living in a *Pocillopora meandrina* coral head) to many hectares (such as areas which are covered by major biotopes). Because considerable interest focuses on visually dominant corals, diurnally exposed macroinvertebrates, and fishes, we designed a sampling program to delineate changes that may be occurring in communities at this scale.

Three stations were selected for the monitoring of benthic and fish community response to possible sewage impacts. Their approximate locations are shown in Figure 1. Station A is located at the diffuser in water ranging from 29.6 to 32.0 m in depth. It was established to sample the communities resident to the diffuser as well as directly adjacent to it. The location of this station is at the lower depth limit for safe diving, where considerable time must be spent underwater gathering data. Station B is located about 2.7 km south-southwest of the diffuser and 400 m south of Mo(¯,o)ko(¯,o)lea Rock at a depth of 20 m (approximately 1.8 km from shore). Station C is located halfway between Mo(¯,o)ko(¯,o)lea Rock and the shore of Kailua Bay (1.7 km inshore of Mo(¯,o)ko(¯,o)lea Rock) in water ranging from 5.2 to 6.7 m in depth.

At Stations A and B two 20-m transect lines each were permanently established using metal stakes and plastic-coated no. 14 copper wire. At Station C only one 20-m transect line was established using the same procedure. The transects at Stations B and C have an orientation that is approximately parallel to shore. At Station A one transect was positioned on top of the diffuser pipe and the second on the natural substratum parallel to the diffuser pipe but about 15 m to the north. The two transects at Station B sample approximately the same benthic communities, thus providing some replication. On each transect are five permanently marked locations (0 m, 5 m, 10 m, 15 m, and 20 m) for making cover estimates of benthic community components using a 1 m ∞ 1 m quadrat. The quadrat is 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 are often related to small-scale topographical relief over short linear distances. A long transect may bisect a number of topographical features (e.g., coral mounds, sand flats, and algal beds), thus sampling more than one community and obscuring distinctive features of individual communities. To alleviate this problem, a short transect (20 m in length), which has proved to be adequate for sampling many Hawai‘i benthic communities (see Brock 1982; Brock and Norris 1989), is used.

Information is collected at each transect location using methods including a visual assessment of fishes, a quadrat survey of the benthos for cover estimates of sessile forms (e.g., algae, corals, and colonial invertebrates), and a visual assessment of diurnally exposed motile macroinvertebrates. Fish censuses are conducted over a 4 m ∞ 20 m corridor (the permanent transect line). All fishes within this area to the water's surface are counted. A single diver equipped with scuba, slate, and pencil enters the water, then counts and notes all fishes in the prescribed area (method modified from Brock 1954). Besides counting the individuals of all fishes seen, the length of each is estimated for later use in the determination 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 Hawai‘i, the Naval Undersea Center (see Evans 1974), and the Hawai‘i Division of Aquatic Resources using weight and body measurements of captured fishes; for many species the coefficients have been developed using sample sizes in excess of a hundred individuals. To reduce the bias caused by the flight of wary fishes, the census taker enters the water, locates the transect site, and commences with the census of fishes. The same individual (the author) performs all fish censuses to reduce bias related to the experience or inexperience of the census taker.

Besides divers frightening wary fishes, other problems with the visual census technique include underestimating cryptic species such as moray eels (family Muraenidae) and nocturnal species such as squirrelfishes (family Holocentridae) and bigeyes or ‘o(¯,a)weoweo (family Priacanthidae). This problem is compounded in areas of high relief and coral coverage that afford 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 is probably the most accurate, nondestructive assessment method currently available for counting diurnally active fishes (Brock 1982).

A number of methods are utilized to quantitatively assess benthic communities at each station, including the placing of 1 m ∞ 1 m quadrats at marked locations on each transect for repeated measurements. The quadrats are used to estimate coverage of corals and other sessile forms. Cover estimates are all recorded as percent cover. Diurnally exposed motile macroinvertebrates greater than 2 cm in some dimension are censused in the same 4 m ∞ 20 m corridor used for the fish counts.

Macrothalloid algae encountered in the 1 m ∞ 1 m quadrats are quantitatively recorded as percent cover. Emphasis is placed on those species that are visually dominant, and no attempt is made to quantitatively assess the multitude of microalgal species that constitute the “algal turf” so characteristic of many coral reef habitats.

During fieldwork, an effort is made to note the presence of any green sea turtles (a threatened species) within or near the study sites.

RESULTS

Field sampling was undertaken on 27 April 1998 at Stations B and C and on 27 and 31 July 1998 at Station A. Sampling at Station A (the diffuser) required more field time because of the greater depth. Figure 1 shows the approximate locations of the three stations.

Station A

Station A is located at the Mokapu Ocean Outfall diffuser offshore of Mo(¯,o)kapu Point. The diffuser is located at a depth of 32 m in an area primarily comprised of sand with occasional patches of emergent hard substratum. In areas where this substratum has sufficient elevation above the sand/rubble bottom, corals are present. One such hard substratum “patch” is located just north of the diffuser. This patch is roughly oval in shape, with the short dimension (~50 m wide) having a north–south orientation and coming within 10 m of the diffuser pipe and with the long (~70 m) dimension being roughly parallel to the diffuser pipe. Transects T-1 and T-2 are located at this station.

Transect T-1 is situated on and down the midline of the diffuser pipe and is located about midway along the diffuser. The water depth here is 29.6 m, and the substratum is a mix of basalt armor rock having graded sizes between 30 and 70 cm and the exposed concrete surface of the diffuser. The armor rock or capstones cover the junctions between the segments of the diffuser as well as much of the diffuser pipe, creating more cover for fishes and invertebrates. The areas of exposed concrete surface occur near the middle of each pipe section where two diffuser ports (one on either side near the springline) are located. Transect T-2 is located on the emergent hard substratum about 15 m north of the diffuser and approximately parallel to it.

Transect T-1

The results of the survey carried out at Transect T-1 is presented in Table 1. Two encrusting coralline algal species, *Porolithon onkodes* and *Peyssonellia rubra* (mean coverage of 19.2%), were present; other species encountered in the quadrat survey include the stinging hydroid *Halocordyle disticha* (mean coverage of 0.2%) and the bryozoan *Reteporellina denticulata* (mean coverage of 0.5%). Also seen in the quadrats were two coral species, *Porites lobata* and *P. compressa* (mean coverage of 16.1%). Macroinvertebrates seen at this transect include the polychaete *Loimia medusa* and four sea urchin species (the green urchin *Echinometra mathaei*, the long-spined black urchin *Echinothrix diadema*, the banded urchin *Echinothrix calamaris*, and the slate pencil urchin *Heterocentrotus mammillatus*). Thirty-four species of fishes (1,481 individuals) were censused (Appendix). The most common species seen include the brick soldierfish or menpachi (*Myripristis amaenus*—5% of the total) the bluelined snapper or ta‘ape (*Lutjanus kasmira*—20.3% of the total), the milletseed butterfly fish or lauwiliwili (*Chaetodon miliaris*—37.1% of the total), the oval damselfish *Chromis ovalis* (6.8% of the total), the sergeant major or mamo (*Abudefduf abdominalis*—3.9% of the total), the goldring surgeonfish or kole (*Ctenochaetus strigosus*—6.6% of the total), and the sleek unicornfish or kala holo (*Naso hexacanthus*—6.8% of the total). The standing crop of fishes was estimated at 1,124 g/m^2, and the species contributing most heavily include *Myripristis amaenus* and *Chaetodon miliaris* (each making up 12% of the total) and *Lutjanus kasmira* (comprising 46% of the total).

Transect T-2

The results of the survey carried out at Transect T-2 are presented in Table 2. The quadrat survey noted the bryozoan *Reteporellina denticulata* with a mean coverage of 1.5% and four coral species (*Porites lobata, Pocillopora meandrina*, *Montipora verrucosa*, and *M. patula*) having a mean coverage of 40.3%. The macroinvertebrate census noted the Christmas tree worm *Spirobranchus giganteus corniculatus*, the helmet shell *Cassis cornuta*, the green sea urchin *Echinometra mathaei*, and the brown sea cucumber *Holothuria verrucosa*. Twenty-eight fish species (184 individuals) were censused in the 4 m ∞ 20 m transect area (Appendix). The most abundant species were the palenose parrotfish or uhu (*Scarus psittacus*) and the damselfish *Chromis hanui* (each making up 22.8% of the total) and the damselfish *Chromis agilis* (comprising 10.9% of the total). The standing crop of fishes at Transect T-2 was estimated at 62 g/m^2. Species contributing most heavily to this standing crop include the lined coris or mo(¯,a)lamalama (*Coris ballieui*—10.1% of the total), the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*—10.5% of the total), and *Scarus psittacus* (23.1% of the total).

Station B

Station B is located approximately 400 m south of Mo(¯,o)ko(¯,o)lea Rock at a depth of 20 m. The substratum is a mix of limestone and live coral that forms a large elongate knoll with the major axis parallel to shore. This knoll is close to 100 m in width and is at least 200 m in length. It is surrounded by sand and rubble. The two transects (T-3 and T-4) established at Station B are located close to the shoreward side of the large knoll, and both approximately follow the long axis of the knoll (i.e., both are parallel to shore).

Transect T-3

The results of the quantitative survey carried out at Transect T-3 are given in Table 3. The quadrat survey noted two encrusting coralline algal species (*Porolithon onkodes* and *Hydrolithon reinboldii*) having a mean coverage of 12.2% and seven coral species (*Porites lobata*, *P. compressa*, *Pavona varians*, *P. duerdeni*, *Montipora verrucosa*, *M. patula*, and *M. flabellata*) with a mean coverage of 40.6%. The macroinvertebrate census noted the Christmas tree worm *Spirobranchus giganteus corniculatus*, the rock oyster *Spondylus tenebrosus*, the black sea urchin *Tripneustes gratilla*, and the starfish *Linckia diplax*. Twenty-eight species of fishes (212 individuals) were censused on this transect (Appendix). The most abundant fish species were the bluelined snapper or ta‘ape (*Lutjanus kasmira*—12.3% of the total), the brown surgeonfish or mo(¯,a)‘i‘i‘i (*Acanthurus nigrofuscus*—16.0% of the total), and the goldring surgeonfish or kole (*Ctenochaetus strigosus*—24.1% of the total). The standing crop of fishes at Transect T-3 was estimated at 140 g/m^2. Species contributing most heavily to this standing crop include *Lutjanus kasmira* (13.3% of the total), the bulletnose parrotfish or uhu (*Scarus sordidus*—14.2% of the total), and *Ctenochaetus strigosus* (17.1% of the total).

Transect T-4

Transect T-4, located just southeast of Transect T-3, serves as a replicate for Station B. Table 4 presents the results of the survey carried out at Transect T-4. The quadrat survey noted the same algal and coral species found at Transect T-3. The two coralline algal species (*Hydrolithon reinboldii* and *Porolithon onkodes*) had a mean coverage of 10.8%, and the seven coral species (*Porites lobata*, *P. compressa*, *Pavona varians*, *P. duerdeni*, *Montipora verrucosa*, *M. patula*, and *M. flabellata*) had a mean coverage of 50.4%. The macroinvertebrate census noted three species: the Christmas tree worm *Spirobranchus giganteus corniculatus*, the rock oyster *Spondylus tenebrosus*, and the long-spined black sea urchin *Echinothrix diadema*. The fish census noted 206 individuals spread among 23 species. The most common fish species were the black plankton-feeding surgeonfish *Acanthurus thompsoni* (14.1% of the total), the goldring surgeonfish or kole (*Ctenochaetus strigosus*—48.1% of the total), and the yellow tang or lau‘ipala (*Zebrasoma flavescens*—8.3% of the total). The standing crop of fishes was estimated at 127 g/m^2, with the most important contributors being the bulletnose parrotfish or uhu (*Scarus sordidus*—20.2% of the total), *Ctenochaetus strigosus* (33.6% of the total), and *Zebrasoma flavescens* (7.3% of the total).

Station C

Situated about half the distance between Kailua Beach and Mo(¯,o)ko(¯,o)lea Rock is Station C, where sampling was carried out at a single shallow transect (T-5). Water depth at this station ranges from 5.2 to 6.7 m, and the substratum is limestone. This limestone slopes seaward, and numerous small channels or grooves cut into it. These small channels are ramose, with a general orientation perpendicular to shore. Spaced from 2 to 20 m apart, the channels are from 1 to 25 m in length and up to 4 m in width, with a maximum depth of 0.8 m. Also present in the limestone are larger depressions having a sand and rubble substratum. These depressions, which are up to 30 m in diameter and spaced from 30 to 80 m apart, have a maximum depth of 2 m below the surrounding bottom. The combined effect of these depressions and small channels is a heterogeneous topography with considerable cover present. On the limestone is a diverse coral community, but because this area apparently receives considerable wave impact, many corals have prostrate growth forms and thus do not contribute much to the local topographical complexity.

Table 5 presents the results of the quantitative survey carried out in the shallow, topographically complex habitat at Transect T-5. Encountered in the quadrat survey were two algal species (*Turbinaria ornata* and *Desmia hornemannii*) with a mean coverage of 0.2%, the soft coral *Palythoa tuberculosa* having a mean coverage of 0.6%, and eight coral species (*Porites lobata*, *P. compressa*, *Pocillopora meandrina*, *P. damicornis*, *Montipora verrucosa*, *M. patula*, *M. verrilli*, and *Pavona duerdeni*) with a mean coverage of 53.7%. The census of macroinvertebrates noted five species, including the rock oyster *Spondylus tenebrosus*, the hebrew cone *Conus ebreus*, the rock boring sea urchin *Echinostrephus aciculatum*, the green sea urchin *Echinometra mathaei*, and the starfish *Linckia multiflora*. The fish census encountered 32 species (151 individuals) having an estimated biomass of 138 g/m^2. The most common fishes were the saddleback wrasse or ho(i,¯)no(¯,a)lea lauwili (*Thalassoma duperrey*—21.2% of the total), the brown surgeonfish or mo(¯,a)‘i‘i‘i (*Acanthurus nigrofuscus*—22.5% of the total), and the orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*—19.2% of the total). Important contributors to the standing crop of fishes include *Acanthurus olivaceus* (49.0% of the total), *Thalassoma duperrey* (9.3% of the total), and *Acanthurus nigrofuscus* (7.3% of the total).

Biological Parameters

Table 6 presents a summary of the biological parameters measured at the five transect sites examined in this study. Other than for coral coverage and the degree of development in the fish community at Transect T-1 (on the diffuser pipe), the data for these parameters are quite similar among the five transect sites. Coral coverage on the diffuser was about one-half of that measured at other locations, but the biomass and number of individual fish were considerably higher than at the other transect sites. The better development in the fish community is probably related to the significantly greater cover afforded by the basalt armor rock on the diffuser, as well as to the food resource present (particulate materials from the discharge). The lower coral coverage seen on the diffuser was not seen at Transect T-2, which is located within 15 m of the discharge. Instead, coral coverage seen at Transect T-2 is similar to that seen at the more distant transect sites, suggesting that the discharge is having little negative impact on corals in the immediate vicinity of the diffuser.

From a commercial fisheries standpoint, a small number of important species were encountered on the transects. Around the diffuser were seen the bluelined snapper or ta‘ape (*Lutjanus kasmira*) and the brick soldierfish or menpachi (*Myripristis amaenus*), and at the two transects just south of Mo(¯,o)ko(¯,o)lea Rock were seen the yellowstripe goatfish or weke ‘o(¯,a) (*Mulloidichthys flavolineatus*) and *Lutjanus kasmira*.

Green Sea Turtle Observations

On 27 April 1998 at about 1110 hours, a single green sea turtle (*Chelonia mydas*) with an approximate 70-cm straight-line carapace length was seen near Transect T-2. No other green turtles were seen during the course of this fieldwork; however, on other occasions green turtles were commonly seen from shore just seaward of the Kawainui Canal mouth and Kapoho Point in Kailua Bay (personal observations). As many as ten adult and subadult individuals have been seen surfacing for air at a single time, suggesting that an appropriate resting habitat as well as forage (algae) are present in the area.

DISCUSSION

The transect locations selected are representative of the marine communities in the general area in which the stations are situated. This was ascertained by carrying out reconnaissance surveys of the surrounding areas prior to site selection. At a minimum, these qualitative surveys covered several hectares around each of the sites—except for the diffuser site, where the transect (T-1) was established in the middle portion of the diffuser.

The working hypothesis is that if impacts are occurring to the coral reef communities as a result of the release of secondary treated sewage effluent through the diffuser (situated offshore of Mo(¯,o)kapu Point), these impacts should be evident as a gradient, decreasing with distance from the source. Thus impacts should be most obvious at the diffuser (Transect T-1) but also apparent at Transect T-2, which is no more than 15 m away from the diffuser. With distance from this source, impacts should decrease and be less evident. In general, currents appear to be tidally influenced, running approximately from north to south and occasionally reversing. Therefore, marine communities south of the diffuser (at Transects T-3 and T-4 more than 2.7 km away) should show less evidence of disturbance, as should the marine communities at Transect T-5, which is inshore and southwest of the discharge.

The parameters measured in this study show little, if any, evidence of negative impact that can be attributed to the discharge of secondary treated effluent. Coral cover at Transect T-1 is about one-half of that encountered at the other stations, but within 15 m of the diffuser (at Transect T-2) it is close to the coverage found at the more distant sites, suggesting that if the effluent is having an impact on coral coverage, it is very limited in scope and scale. In contrast, the number of individual fish as well as their estimated standing crop are considerably elevated at the diffuser compared to the other sampling sites. This exceptionally high abundance and standing crop are probably related to the cover afforded by the basalt armor rock as well as the continual discharge of fine particulate organic materials. The treated sewage effluent is a source of food for some particulate/plankton-feeding species such as the milletseed butterfly fish or lauwiliwili (*Chaetodon miliaris*), which is very common at this transect site (see Figure 2). These materials are probably also consumed by the goldring surgeonfish or kole (*Ctenochaetus strigosus*), a detritivore that feeds on the surrounding substrate. Other planktivorous species in relatively high abundance, such as the sleek unicornfish or kala holo (*Naso hexacanthus*) and the oval damselfish *Chromis ovalis*, feed in the water column above the diffuser and probably utilize the shelter created by the pipe and armor rock. Some species that are nocturnally active also use the shelter created by the diffuser during the day. This group of fishes includes the brick soldierfish or menpachi (*Myripristis amaenus*) and the bluelined snapper or ta‘ape (*Lutjanus kasmira*), both of which are very common at the diffuser site.

The diets of many common Hawai‘i reef fish are reasonably well-known, as discussed in Hiatt and Strasburg (1960), Jones (1968), Hobson (1974), and Parrish et al. (1984, 1985). However, the utilization of particulate materials from sewage discharges has not been previously documented. The only species seen in the field actively consuming the particles emitted with the discharge are the milletseed butterfly fish or lauwiliwili (*Chaetodon miliaris*) and, on an earlier occasion, the bigeye scad or akule (*Selar crumenophthalmus*).

Damage occasionally occurs to benthic and fish communities when storm waves impinge on shallow habitats. The resulting destruction is caused by scouring and breakup of corals and is frequently patchy, leading to a mosaic of destruction (personal observations; Walsh 1983). One of the most important parameters used in determining the structure of Hawaiʻi coral communities is occasional storm events that generate high surf (Dollar 1982). Numerous studies have shown that storm-generated surf may keep coral reefs in a nonequilibrium or subclimactic state (Grigg and Maragos 1974; Connell 1978; Woodley et al. 1981; Grigg 1983). The large expanses of near-featureless lava or limestone substratum present around much of the Hawaiian islands at depths of less than 30 m attest to the force and frequency of these events (Brock and Norris 1989). These same wave forces also impinge upon and impact fish communities (Walsh 1983). Moreover, since Hawaiʻi corals are relatively slow growing, recovery from the impact of storm waves can be relatively slow, taking many years before evidence of the impact is erased. The relatively high coral coverage found at most of the sampling sites in this study suggest that these communities have not been subjected to any unusually large wave events in the recent past.

Relative to many other locations in the Hawaiian islands, the fish community is well developed at the Mo(¯,o)kapu diffuser. The high standing crop estimate is much greater than for most coral reefs; the maximum fish standing crop encountered on natural coral reefs is about 200 g/m^2 (Goldman and Talbot 1975; Brock et al. 1979). Two explanations for the high biomass of fishes at the Mo(¯,o)kapu diffuser are (1) the shelter created by the diffuser, armor rock, and coral growth on this pipe locally enhances the fish community and (2) chance encounters with roving predators or planktivorous and/or other schooling species may occur during the census.

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 Hawaiʻi reefs, estimated the standing crop of fishes to range from 4 g/m^2 on sand flats to 186 g/m^2 in an area of considerable vertical relief. If structural complexity or topographical relief is important to coral reef fish communities, then the addition of materials to increase this relief in otherwise barren areas may serve to locally enhance the biomass of fish. The additional topographical relief is usually in the form of artificial reefs, but any underwater structure (such as a deployed sewer line) will have a similar effect. The diffuser pipe is set above the seafloor, creating considerable local topographical relief. 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, schools of planktivorous fishes (the sleek unicornfish or kala holo [*Naso hexacanthus*], the milletseed butterfly fish or lauwiliwili [*Chaetodon miliaris*], and the sergeant major or mamo [*Abudefduf abdominalis*]), or other schooling species (the yellowstripe goatfish or weke‘o(¯,a) [*Mulloidichthys flavolineatus*]) may greatly increase the counts and biomass at a particular transect. The presence of the sewage discharge pipe serves to focus numerous predators and schooling fishes in the vicinity of this site; hence, an encounter with these fishes during a census will result in high biomass estimates. For example, *Chaetodon miliaris* and *Naso hexacanthus* account for 44% of the numbers counted and 21% of the estimated biomass in the census carried out on the diffuser.

The five transects selected for this study show a considerable range in community development that is probably related to historical impacts. Separating the impact of secondary-treated effluent released at depth from a multitude of other ongoing and historical impacts that have occurred in and to the shallow marine communities of Kailua Bay is difficult at best. However, the siting of the permanent transects to capitalize on presumed gradients of impact created by a variety of land-derived sources, as well as the repeated future sampling at these transects, should allow delineation of any changes attributable to the discharge of sewage effluent from the Mokapu Ocean Outfall.

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TABLE 1. Summary of Biological Observations made at Transect T-1 on the Mokapu Ocean Outfall Diffuser on 27 July 1998. (Sampling began at the main stake marking this transect and continued in a seaward direction.)

		Percent Cover				
I. Quadrat Survey		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Algae						
Porolithon onkodes		12.0	4.0	15.0	3.0	9.0
Peyssonellia rubra (?)		9.0	15.0	8.0	7.0	14.0
Hydrozoans						
Halocordyle disticha					1.0	
Bryozoans						
Reteporellina denticulata				1.1	1.5	
Corals						
Porites lobata		39.0		7.0	17.0	17.0
Porites compressa		0.3				
Rubble			12.0			
Hard Substratum		39.7	69.0	68.9	70.5	60.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				
Phylum Annelida					
Loimia medusa	1				
Phylum Echinodermata					
Echinometra mathaei	3				
Echinothrix diadema	27				
Echinothrix calamaris	6				
Heterocentrotus mammillatus	2				

III. Fish Census (4 m ∞ 20 m)					
34 Species					
1,481 Individuals					
Estimated Standing Crop = 1,124 g/m^2					

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth is 29.6 m; mean coral coverage is 16.1% (quadrat method).

TABLE 2. Summary of Biological Observations made at Transect T-2, 15 m North of and Parallel to the Mokapu Ocean Outfall Diffuser Pipe on Natural Substratum, on 31 July 1998. (Sampling began at the main stake marking this transect and continued in a seaward direction.)

I. Quadrat Survey	Percent Cover Quadrat Distance Along Transect				
	0 m	5 m	10 m	15 m	20 m
Bryozoans					
Reteporellina denticulata	1.2	1.1	0.9	1.5	2.8
Corals					
Porites lobata	13.5	6.5	2.0		6.0
Pocillopora meandrina	0.6			0.8	1.0
Montipora verrucosa	19.0	3.0	9.0	12.0	15.0
Montipora patula	12.0	31.0	57.0	13.0	
Sand	12.0	12.0	7.0	6.0	6.0
Rubble	9.0	23.0	18.0	28.7	9.0
Hard Substratum	32.7	23.4	6.1	38.0	60.2

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals
Phylum Annelida	
Spirobranchus giganteus corniculatus	12
Phylum Mollusca	
Cassis cornuta	1
Phylum Echinodermata	
Echinometra mathaei	1
Holothuria verrucosa	1

III. Fish Census (4 m ∞ 20 m)
28 Species
184 Individuals
Estimated Standing Crop = 62 g/m^2

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth is 32.0 m; mean coral coverage is 40.3% (quadrat method).

TABLE 3. Summary of Biological Observations made at Transect T-3 (Station B) South of Mo(¯,o)ko(¯,o)lea Rock in Kailua Bay on 27 April 1998. (Sampling began at the main stake marking this transect and continued in a northwest direction.)

		Percent Cover				
I. Quadrat Survey		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m
Algae						
Hydrolithon reinboldii			6.0	5.0	5.0	4.0
Porolithon onkodes		6.0	15.0	12.0	2.0	6.0
Corals						
Porites lobata		0.6	39.0			
Porites compressa		1.5				
Pavona varians		7.0	5.0	14.0	4.5	2.0
Pavona duerdeni		11.0		8.0	14.5	12.0
Montipora verrucosa		20.0	0.2	1.0	2.0	5.0
Montipora patula		11.0	15.0	8.0	13.5	2.0
Montipora flabellata					6.0	
Hard Substratum		37.5	19.8	52.0	52.5	69.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals
Phylum Annelida	
Spirobranchus giganteus corniculatus	9
Phylum Mollusca	
Spondylus tenebrosus	1
Phylum Echinodermata	
Tripneustes gratilla	1
Linckia diplax	1

III. Fish Census (4 m ∞ 20 m)
28 Species
212 Individuals
Estimated Standing Crop = 140 g/m^2

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth is 20.0 m; mean coral coverage is 40.6% (quadrat method).

TABLE 4. Summary of Biological Observations made at Transect T-4 (Station B) South of Mo(¯,o)ko(¯,o)lea Rock in Kailua Bay on 27 April 1998. (Sampling began at the main stake marking this transect and continued in a southeast direction.)

		Percent Cover				
I. Quadrat Survey		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m

Algae					
Hydrolithon reinboldii			4.0		14.0
Porolithon onkodes	8.0	6.0	3.0	13.0	6.0
Corals					
Porites lobata	75.0	6.0	2.0	22.0	
Porites compressa		12.0	3.0		
Pavona varians		15.0	9.0	3.0	8.0
Pavona duerdeni		2.5		5.0	13.0
Montipora verrucosa	8.0		21.0	8.0	2.0
Montipora patula	3.0	3.0	23.0	4.0	2.0
Montipora flabellata		2.5			
Hard Substratum	6.0	59.0	35.0	45.0	55.0

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				

Phylum Annelida	
Spirobranchus giganteus corniculatus	13
Phylum Mollusca	
Spondylus tenebrosus	1
Phylum Echinodermata	
Echinothrix diadema	1

III. Fish Census (4 m ∞ 20 m)					

23 Species					
206 Individuals					
Estimated Standing Crop = 127 g/m^2					

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth is 20.0 m; mean coral coverage is 50.4% (quadrat method).

TABLE 5. Summary of Biological Observations made at Transect T-5 Inshore of Mo(¯,o)ko(¯,o)lea Rock in Kailua Bay on 27 April 1998. (Sampling began at the main stake marking this transect and continued in a northeast direction.)

		Percent Cover				
I. Quadrat Survey		Quadrat Distance Along Transect				
		0 m	5 m	10 m	15 m	20 m

Algae					
Turbinaria ornata	0.1	0.5		0.3	0.2
Desmia hornemannii					0.1
Soft Corals					
Palythoa tuberculosa		1.5		1.3	0.2
Corals					
Porites lobata	43.0		9.0	17.0	2.0
Porites compressa				1.0	0.8
Pocillopora meandrina	1.0	3.5	3.0	0.2	4.0
Pocillopora damicornis	1.0				
Montipora verrucosa	11.0	17.0	1.0	13.0	11.0
Montipora patula	6.0	14.0	62.0	27.0	9.0
Montipora verrilli	7.0	4.0			
Pavona duerdeni				1.0	
Sand				1.0	
Rubble	2.0				
Hard Substratum	28.9	59.5	25.0	38.2	72.7

II. Macroinvertebrate Census (4 m ∞ 20 m)	No. of Individuals				

Phylum Mollusca	
Spondylus tenebrosus	1
Conus ebreus	1
Phylum Echinodermata	
Echinostrephus aciculatum	1
Echinometra mathaei	1
Linckia multiflora	1

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

151 Individuals					
Estimated Standing Crop = 138 g/m^2					

NOTE: Results of the 5-m^2 quadrat sampling of the benthic community are presented in Part I as percent cover, counts of diurnally exposed macroinvertebrates are given in Part II, and a summary of the fish census is given in Part III. Water depth ranges from 5.2 to 6.7 m; mean coral coverage is 53.7% (quadrat method).

TABLE 6. Summary of Biological Parameters Measured at the Five Transect Locations in the 1998 Survey

Parameter	Transect				
	T-1	T-2	T-3	T-4	T-5
No. of Algal Species	2	0	2	2	2
% Algal Cover	19.2	0	12.2	10.8	0.2
No. of Coral Species	2	4	7	7	8
% Coral Cover	16.1	40.3	40.6	50.4	53.7
No. of Invertebrate Species	5	4	4	3	5
No. of Invertebrate Individuals	39	15	12	15	5
No. of Fish Species	34	28	28	23	32
No. of Fish Individuals	1,481	184	212	206	151
Fish Biomass (g/m^2)	1,124	62	140	127	138

NOTE: Each transect samples 80 m^2 of substratum for fishes and invertebrates other than corals. Coral and algal data (given in percent cover) are from 5 m^2 of substratum sampled on each transect.

APPENDIX. Results of the Quantitative Visual Fish Censuses Conducted at Five Locations in Kailua Bay, O‘ahu, Hawai‘i, in 1998

FAMILY and Species	Transect				
	T-1	T-2	T-3	T-4	T-5
HOLOCENTRIDAE					
Adioryx xantherythrus	17				
Myripristis amaenus	74				
Flammeo sammara	5				
AULOSTOMIDAE					
Aulostomus chinensis		1			
SERRANIDAE					
Cephalopholis argus	1		1		1
LUTJANIDAE					
Lutjanus kasmira	300		26		
MULLIDAE					
Mulloidichthys flavolineatus			4		
Parupeneus multifasciatus	10	4	1	1	2
CHAETODONTIDAE					
Forcipiger flavissimus	2			1	4
Chaetodon fremblii	1			1	
Chaetodon kleinii	19				
Chaetodon unimaculatus			4	2	2
Chaetodon ornatissimus	2		4	2	2
Chaetodon quadrimaculatus					1
Chaetodon multicinctus	2	6	4		2
Chaetodon miliaris	550				
POMACANTHIDAE					
Holacanthus arcuatus		1			
Centropyge potteri	7	5	2	3	
POMACENTRIDAE					
Dascyllus albisella	32				
Abudefduf abdominalis	58				
Plectroglyphidodon johnstonianus		1	7	5	1
Plectroglyphidodon imparipennis					4

Chromis vanderbilti		7			3
Chromis ovalis	100				
Chromis verator	45		7		
Chromis hanui		42	21	9	
Chromis agilis		20			
Stegastes fasciolatus			1		1
CIRRHITIDAE					
Paracirrhites arcatus				1	1
Paracirrhites forsteri		1			
Cirrhitops fasciatus		1			
LABRIDAE					
Cheilio inermis			1	1	1
Labroides phthirophagus	2				
Bodianus bilunulatus		1	2		1
Pseudocheilinus octotaenia		4			
Novaculichthys taeniourus					1
Thalassoma duperrey	9	8	7	2	32

APPENDIX—*Continued*

FAMILY and Species	Transect				
	T-1	T-2	T-3	T-4	T-5
Thalassoma ballieui	3			1	1
Gomphosus varius	2				
Coris gaimard		1			1
Coris ballieui		6			
Pseudojuloides cerasinus		2			
Stethojulis balteata				1	1
Macropharyngodon geoffroy			1		
Anampses chrysocephalus		5			
Halichoeres ornatissimus	1	1			
SCARIDAE					
Calotomus carolinus					1
Scarus sordidus	3		11	3	1
Scarus psittacus		42			8
BLENNIIDAE					
Exallis brevis			1		
ACANTHURIDAE					

Acanthurus triostegus					4
Acanthurus leucoparieus					1
Acanthurus nigrofuscus		9	34	12	34
Acanthurus nigroris	9	6	1		
Acanthurus thompsoni	15			29	
Acanthurus olivaceus		2			29
Acanthurus dussumieri	1				3
Acanthurus glaucopareius			5	11	
Ctenochaetus strigosus	98		51	99	
Zebrasoma flavescens	1	1	6	17	
Naso lituratus	1		1	2	
Naso unicornis					1
Naso hexacanthus	100				
Zanclus cornutus	4				2
BALISTIDAE					
Rhinecanthus rectangulus					3
Melichthys niger			3	1	
Melichthys vidua		1	1		
Sufflamen bursa	2	4	2	1	
MONACANTHIDAE					
Cantherhines sandwichiensis				1	
OSTRACIIDAE					
Ostracion meleagris	1	1			
TETRAODONTIDAE					
Canthigaster jactator	4	1	3		1
Canthigaster rivulata					1

Total No. of Species	34	28	28	23	32
Total No. of Individuals	1,481	184	212	206	151
Estimated Standing Crop (g/m^2)	1,124	62	140	127	138

NOTE: Each entry in the body of the table represents the total number of individuals of each species seen; totals are presented at the foot of the table, along with an estimate of the standing crop of fishes present at each location. All censuses were carried out by the author.