A SURVEY OF SELECTED CORAL AND FISH ASSEMBLAGES NEAR THE WAIANAE OCEAN OUTFALL, O‘AHU, HAWAI‘I, 1998

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ABSTRACT

In 1998, coral growth and fish abundance were monitored at stations located at and in the vicinity of the Waianae Ocean Outfall. Comparisons of results with fish surveys done in previous years showed no significant differences in the species composition or relative abundances of fish populations at Station W-2 (the sunken ship *Mahi*), which is located 1.2 km south of the diffuser. Fish abundance and species richness at Station W-3, which is located at the diffuser, increased from 1990 to 1995, decreased in 1996, and increased again in 1997 and 1998. At Station WW, an inshore station located 0.8 km from shore, fish were abundant and speciose on the armor rock covering the pipeline. The fish species seen inshore are comparable to fish species seen in similar (boulder) natural biotopes around Hawai‘i. There were no significant differences in total mean coral cover at selected quadrats from 1994 to 1998 at Station W-2. However, when comparing 1991 data with 1998 data, there was a significant increase (4.6%) in total mean coral cover at this station. At the diffuser, corals were seen growing on the diffuser pipe and on the riser discharge ports. In 1986, when the diffuser began operation at a discharge rate of 1.5 mgd (0.07 m^3/s), no corals were seen at this location. At inshore station WW corals off the pipeline were sparsely distributed but were numerous and thriving on the armor rock over the pipeline. The inshore transect (Alpha), off the armor rock, was moderately covered (less than 30%) with the alga *Dictyopteris plagiogramma*. This seaweed was also abundant at this location in 1995, 1996, and 1997. The water was clear at all stations surveyed (15 to 20 m horizontal visibility), and the surrounding sediments were clean and white. No significant deleterious effect due to outfall operation and discharge were seen on the biological community at the stations surveyed. The increase in fish diversity and abundance at the diffuser in 1998 may be due to natural fluctuations in abundance or to environmental conditions suitable to fish populations living there. To distinguish between outfall effects and natural fish population fluctuation patterns, several years of consecutive monitoring must be performed.

INTRODUCTION

The City and County of Honolulu's conservation district use permit for installation of a wastewater outfall pipe at Wai‘anae, O‘ahu, Hawai‘i, was approved subject to several conditions (Board of Land and Natural Resources letter to the City, 11/15/83; ref. no. CPO-844, file no. OA-4/11/83-1541). Among the conditions was the requirement that, in the vicinity of the outfall diffuser, fishery stocks be censused annually after the first year of discharge and benthic organisms be monitored photographically annually.

The Waianae Wastewater Treatment Plant (WWTP) is a secondary treatment system which discharges approximately 3.2 million gallons per day (0.14 m^3/s) of mainly domestic wastewater through an outfall 6,000 feet (1.8 km) offshore at a diffuser depth of approximately 110 feet (33 m). The diffuser is 531 feet (161.8 m) long and discharges at approximately 1.5 feet (0.5 m) above the seafloor through vertical risers.

In the summer of 1998, researchers from the University of Hawai‘i and oceanographic personnel from the City and County of Honolulu Department of Wastewater Management collaborated in a scuba survey of the marine community near the Waianae Ocean Outfall. This reports summarizes the results of that survey and comparatively analyzes the 1998 data with data collected in previous years.

MATERIALS AND METHODS

Specific locations of the three sampling stations are provided in Figure 1. General information about the stations and their locations are given below.

Station W-2 is located 1.2 km south of the zone of initial dilution (ZID) on the deck of the sunken ship *Mahi* at a depth of approximately 30 m. The area is one of the prime sites to which local dive shops take their tourist customers. It is known for its clear water and abundance of marine life.

Station W-3 is located at the middle of the diffuser at a depth of approximately 30 m. The 42-inch (1.06-m) diameter diffuser pipe is buried in the sediment and covered with tremie concrete. Discharge is through risers projecting vertically from the pipe. Surrounding sediments consist of coarse carbonate sands.

Station WW is located 1 km offshore on the effluent pipeline at a depth of approximately 8 m. Two transects—one approximately 20 m north of the pipeline (Transect Alpha) and the other on the pipeline (Transect Beta)—were set up at this station. The outfall pipe is covered with tremie concrete and surrounded by large armor rock boulders. Transect Alpha lies on flat limestone substratum and Transect Beta on the armor rock covering the pipeline. Both transects are approximately 20 m long and run perpendicular to shore. With authorization from the Hawaiʻi Department of Land and Natural Resources (DLNR), Station WW became a permanent station in 1994; it was established to monitor, temporally, any inshore movement of effluent discharged from the outfall. Transect Alpha was monitored in 1990 and 1991, although its monitoring was not then a requirement of DLNR. It was not monitored in 1992 or 1993 because of destruction of transects by Hurricane Iniki in September 1992. A new Transect Alpha was established in 1994.

In late April 1995, the CCH Oceanographic Team found the 2-inch (5.08-cm) diameter transect wire at Transect Alpha to be damaged and large sections moved or altogether gone from the area. It is not certain whether this was due to natural causes (wave action) or other causes (vandalism, anchor dragging). The transect wire was replaced on 8 and 9 May 1995 by the CCH team.

There is no spatial control station in this study; the stations selected are all located at different depths and differ in bottom type and relief. At the chosen stations, relief is provided by artificial structures (i.e., the diffuser, sunken ship, and armor rock). Because of the uniqueness of each station, comparisons cannot be made among stations for coral and fish abundance and species richness. Only year-to-year comparisons of survey data obtained at the same station can be made.

Normally at the diffuser isobath (33 m) and near the hull of the sunken ship *Mahi* (depth of 33 m) off the Waiʻanae coast, the bottom is mostly sand with some rubble. Usually no coral are present, and few fishes reside at this depth. However, artificial reefs in the area can attract fishes and provide substrata for coral growth. At Stations W-2 and W-3, artificial structures (a sunken ship and the outfall structure) provide habitats for fish as well as surfaces and relief for coral settlement, colonization, and growth. At Station WW (depth of 8 m) armor rock covering the pipeline provides relief in areas where normally flat limestone with 1% to 2% coral cover exists.

At all stations fish counts were made along permanent transects by divers equipped with scuba (Brock 1982). Fishes were counted along the transect as the diver swam upline looking 3 m to the right and then downline looking 3 m to the right. At Station W-2 divers counted fishes along a permanent transect, 30 m long ∞ 6 m wide (Figure 2), down the centerline of the ship's deck. At Station W-3 fish counts were made along a transect located at the terminal 30 m of the diffuser (Figure 3). At Station WW fishes were counted along the two transects (20 m long ∞ 9 m wide each) (Figure 4).

Fish species composition at all stations was compared with past surveys using Cochran's nonparametric Q-test for species presence or absence (Green 1979). The Q value is tested against the chi-square critical value for years minus one degree of freedom and p = 0.05. Green recommends this test because it precludes meeting the assumptions of homogeneous variances of abundances and normal distribution of the data. The test addresses the null hypothesis "no differences in species composition among survey years." Species composition is a better estimator of temporal stability in fish communities than relative abundance, since there may be large natural fluctuations in fish abundances from year to year and season to season.

A Bray–Curtis index was also used to measure dissimilarity of fish species composition. For Station W-2, the 1998 fish community composition, abundance, and number of species were compared with survey results from earlier years. For Station W-3 comparisons of fish presence or absence (Cochran's Q-test) and dissimilarity were made for 1992 through 1998. In 1991 there was some fish activity at Station W-3, but no fish were seen swimming on the transect. For Station WW comparisons of fish species composition were made for 1990, 1991, and 1994 through 1998. Since errors can occur because of differences in technique and capability among observers, the same diver–observer (the author) performs the fish counts annually.

Estimates of coral cover on selected permanent quadrats were made using bottom photography and the subsequent projection of photos on a grid. Coral cover was estimated by total grid cover relative to the total area of the quadrat. For all stations the presence of all macroinvertebrates seen were recorded. Coral covers between 1997 and 1998 and between 1991 and 1998 were compared (Station W-2) using a paired t-test to determine if significant differences in total coral cover exist (Sokal and Rohlf 1995). The use of inferential statistical analysis may not be valid when comparing data for the same location over time because the assumption of independent sampling may be violated. The abundance of an organism at time t1 may influence the abundance at time t2. This problem of independence is not a factor when using the paired t-test. This test is not sensitive to moderate deviations from normality, is not affected by assumptions of homogeneous variances because only one variable is involved, and eliminates a maximum number of sources of extraneous variation by making pairs similar with respect to as many variables as possible (Daniel 1987). If the data are seriously skewed from normality, a nonparametric paired sign test may be used instead.

RESULTS

Station W-2

Fishes were very abundant at Station W-2 in 1998 (total = 238). Thirty-six species were represented. Fish abundance, by species, for 1991 through 1998 is shown in Table 1. With

the exception of 1987 and 1989, fish abundance and species richness have been monitored every year since 1986; however, results are reported for only the past eight consecutive years (1991 through 1998; Figures 5 and 6). Figures and tables in this study only report data from 1991 to present; however, in the discussion of results some reference is made to pre-1991 data where it is pertinent for comparisons with data from 1991 and later. Total fish abundance at the *Mahi* was higher in 1998 than in all previous years. Fish abundance was low in 1991 and 1992, when compared with pre-1991 and post-1993 years. Fish species richness increased from 1991 to 1993, decreased slightly in 1994, increased again in 1995 and 1996, decreased slightly in 1997, and increased again by eight species in 1998 (Figure 6). The bluelined snapper or ta‘ape (*Lutjanus kasmira*) was relatively abundant in all years surveyed. Prior to 1988 large numbers of both *L. kasmira* and the fantail filefish or ‘o(o,¯)‘ili ‘uwo(i,ˉ) ‘uwo(i,ˉ) (*Pervagor spilosoma*) were present (e.g., in 1986, together they represented more than 50% of the total fish abundance). From 1993 no filefish were seen, and *L. kasmira* represented only 13% of the total abundance in 1993, 31% in 1994, 19% in 1995 and 1996, 16% in 1997 and 12% in 1998 (Table 1). Surgeonfishes (pualu) were abundant in 1998, especially the species *Naso hexacanthus*, *Zebrasoma flavescens*, and *Naso unicornis*. The surgeonfish *Acanthurus blochii* (or *A. nigroris*) was abundant in 1995, 1996, and 1997; only two individuals were recorded for 1998. The identification of this fish, listed as
Acanthurus sp. in Table 1, is questionable since most specimens were juveniles and, although they had a white ring around their tail, several surgeonfish species can have this pattern (Hoover 1993).

Other fishes seen near the *Mahi* but not on the transects were eight eagle rays (genus *Aetobatus*), six jacks or ulua (*Caranx* sp.), schools of weke (*Mulloidichthys flavolineatus*), emperor fish or mu (*Monotaxis grandoculis*), and the pennantfish *Heniochus diphreutes.* The eagle rays have been seen in each survey since 1992.

There were no significant differences in presence or absence of fish species from 1991 to 1998 (Q = 1.8, 4 df, $p > 0.05$). Similarity among years in species composition was high (similarity index = 0.66 to 0.72). Any similarity index over 0.5 is considered to be significant (Green 1979).

No statistical significant differences in mean coral cover at selected quadrats were found between 1997 and 1998 (t-test, $p = 0.05$, Table 2). Coral cover at selected quadrats have been compared using data for subsequent years since 1991 (Russo 1994, 1995, 1996, 1997), and no significant changes in mean coral cover between the year of survey and the previous year have been found. There was significantly more coral cover in 1998 than in 1991. At some quadrats coral cover increased and at others it decreased over the years of study, but total mean cover steadily increased until 1997 and then decreased slightly in 1998 (Figure 7). Coral cover was high on the deck of the *Mahi*; the deck platform is an ideal place for the settlement and subsequent colonization of corals (Figures 8 and 9). For the 10 selected permanent quadrats, mean coral cover in 1998 ranged from 18.9% to 62.6%. For all years, dominant coral species recorded were *Pocillopora meandrina* (14% to 62%) and *Porites compressa* (1% to 9%). Other coral genera seen were *Montipora*, *Pavona*, and *Tubastrea*, but these were rare and small (less than 5.0 to 9.5 cm in diameter).

Other organisms seen at this station were the seastar (crown-of-thorns) *Acanthaster planci,* the bryozoan *Triphyllozoan* sp., red and yellow sponges, the coralline alga *Lithothamnion* sp., the seastar *Culcita* sp., and the long-spined black sea urchin or wana (*Echinothrix diadema*).

Station W-3

On the diffuser transect at Station W-3, a total of 157 fishes representing 20 species were counted in 1998, whereas 100 fishes representing 15 species were counted in 1997 (Table 3). There was an increase in fish abundance from 1997 to 1998, due mainly to increases in the numbers of the butterfly fish *Chaetodon kleinii* and the orangebar surgeonfish *Acanthurus olivaceus.* Russo (1992) recorded 24 fishes representing 6 species in 1986. In 1988 and 1991 no fishes were seen on the transect, but they were seen swimming in the area. In 1987 and 1989 this station was not monitored. Figures 10 and 11 show fish abundance and species richness for 1992 to 1998. Fish abundance increased from 1992 to 1994, decreased in 1996, and increased again in 1997 and 1998. The number of fish species increased from 1992 to 1995, decreased in 1996, and increased again in 1997 and 1998.

Fish species composition in 1998 was significantly different ($p < 0.05$; Q-test) from the composition in 1992. The Bray–Curtis similarity index was 0.41. Species composition in 1998 was similar to that in 1996 (SI = 0.61) and to that in 1997 (SI = 0.77). Approximately three times as many species were seen in 1998 as in 1992. Butterfly fishes were not seen in 1992 but were common in 1994 through 1998, especially the species *Chaetodon kleinii*. The fantail filefish or ‘O(o,¯)‘ili ‘uwO(i,¯)‘uwO(i,¯) (*Pervagor spilosoma*) was seen in 1992 but was absent in 1993 through 1998.

As in 1993 through 1996, corals of the genus *Pocillopora* (10 to 15 cm in diameter) were seen growing on the concrete cover of the outfall and on the riser ports (8 to 10 cm in diameter) during the 1997 and 1998 surveys (Figures 12 and 13). Cover, as in 1993 through 1997, still ranged from 1% to 2% of the substratum along a 6-m-wide strip on the diffuser. The most dominant species of corals were *Pocillopora meandrina*, *Porites lobata*, and *Montipora verrucosa*. In 1986, the year the outfall was completed and in service below full discharge capacity (1.5 mgd [0.07 m^3/s]), no corals were seen growing on the diffuser or in its vicinity. Only after 1991 were corals seen colonizing the diffuser substratum. In 1991 the sewage discharge rate was approximately 2 mgd (0.09 m^3/s); it increased to 2.9 mgd (0.13 m^3/s) in 1994 and to 3.4 mgd (0.15 m^3/s) in 1996. The average discharge rate of 3.3 mgd (0.14 m^3/s) for the summer of 1998 was approximately the same as the 1997 rate.

Other macroinvertebrates recorded in 1998 were six long-spined black sea urchins (*Echinothrix diadema*), four black sea urchins (*Tripneustes gratilla*), and three black sea cucumbers (*Holothuria atra*).

Station WW

Station WW was monitored for scientific interest and was not authorized by DLNR as a permanent sampling station until 1994. The station was not monitored in 1992 or 1993 because of the effects of Hurricane Iniki, which changed the substratum characteristics and destroyed the permanent transects emplaced in 1990. New transects were set up at Station WW in 1994. The location of Transect Alpha is the same as that of the transect set up in 1990 to monitor inshore movement of effluent.

At Station WW there was a steady decrease in total fish abundance (Transects Alpha and Beta combined) from 1994 to 1997 (Figure 14). There was an increase in total fish abundance in 1998 over the 1997 counts (Table 4). Fish diversity remained fairly constant from 1996 through 1998 (Figure 15). For the two transects combined, 256 fishes representing 28 species were recorded in 1998.

At Transect Beta, abundance of fish decreased from 1994 (523 individuals) to 1995 (297 individuals), increased slightly in 1996 (303 individuals), decreased in 1997 (180 individuals), and increased again in 1998 (240) (Table 4). The decrease in numbers of individuals from 1994 to 1995 was due to a large drop in counts of the bluelined snapper *Lutjanus kasmira*, which normally congregate in large schools, and the convict tang *Acanthurus triostegus*. Increases in abundance in 1998 were mainly due to higher counts of the orangebar surgeonfish *Acanthurus olivaceus* and the soldierfish or menpachi (*Myripristis berndti*). There were two more fish species seen in 1998 than in 1997.

Many more fish individuals and species were recorded at Transect Beta than at Transect Alpha. Fishes appear to aggregate over artificial substrata, which provides ample hard structure for the colonization of corals (Figure 16). At Transect Alpha, in 1997, the bottom was covered (80%) with the alga *Dictyopteris plagiogramma*, and there was very little relief. The total cover of this alga decreased in 1998 to approximately 30% (Figure 17). This seaweed was first seen in 1995, when it was recorded at 40% cover.

Corals were seen colonizing on the armor rock and a 2-inch cable that was discarded or moved close to Transect Alpha during Hurricane Iniki in 1992. Few corals were seen in this area (less than 1% coverage) in 1998. At Transect Beta the long-spined black sea urchin *Echinothrix diadema* (five individuals) and the black sea urchin *Tripneustes gratilla* (eight individuals) were seen.

DISCUSSION

Off the Wai'anae coast, coral cover is normally low (1% to 2% of bottom area) and is dominated by two coral species, *Pocillopora meandrina* and *Porites lobata* (Reed et al. 1977). This dominance existed long before the modified Wai'anae outfall pipeline began discharge in January 1986. The old outfall pipe, which discharged effluent into water less than 20 m deep, was modified and extended to discharge into the 33-m isobath approximately 1.8 km offshore.

At Station W-2 on the ship *Mahi*, abundance and diversity of fishes remained high over all the survey years. No significant decrease in fish stocks or coral cover has occurred at this station, which has been monitored since 1986; nor has there been any significant difference in fish community structure or diversity over the years.

At Station W-3, fishes were fairly abundant and corals were seen colonizing the areas near the diffuser and on the diffuser riser ports themselves. The surrounding sediments were clean and white. In 1986 through 1988 corals were not seen at this station. In 1993 through 1998 coral heads (approximately 10 to 20 cm in diameter) of *Pocillopora meandrina* and *Porites lobata* were becoming established (Russo 1993, 1994, 1995, 1996, 1997).

At the diffuser station (W-3) there was a sharp increase in fish abundance and diversity in 1998 when compared with 1997. A reason for the decrease in fish species at this station in 1996, followed by an increase in 1997 and 1998, may be because of the switch from primary to secondary wastewater treatment in 1996. It may have taken several years for the fish community to adjust to the shift in particulate load. If effluent loads are not excessive, some particulate matter may be utilized by water-column-feeding fishes (Hobson 1984; Pastorak and Bilyard 1985). The particulate load is decreased under secondary wastewater treatment. However, secondary-treated effluents (nitrate rich) can be utilized by phytoplankton more rapidly than primary-treated sewage (ammonia rich). This readily available nutrient load may allow the plankton component to increase rapidly and thereby provide food resources for fishes. Increases in the number of planktivorous butterfly fishes *Chaetodon kleinii* and

C. miliaris seem to support this idea. However, more years of study are needed to verify this hypothesis.

At Station WW, many fishes were counted over the pipeline and armor rock (Transect Beta), whereas fewer were seen over the flat, algal-dominated limestone bottom (Transect Alpha). Low fish abundance was seen at this station over all the years of study, probably due to the lack of relief of the bottom.

That bottom relief is important in structuring fish communities is evidenced by the much greater abundance and diversity of fishes seen at Transect Beta, which has an appreciable structure of armor rock. Fishes at Transect Alpha may be attracted to the armor rock at Transect Beta, as evidenced by the large number of fishes seen on the latter transect. Large numbers of the soldierfish or menpachi (*Myripristis berndti*), the black damselfish or ‘O(a,¯)lo‘ilo‘i (*Dascyllus albisella*), the yellowstripe goatfish or weke (*Mulloidichthys flavolineatus*), and other common fish species were seen swimming over the rocks at Transect Beta. The bluelined snapper or ta‘ape (*Lutjanus kasmira*) was still abundant at Transect Beta in 1998 but in less numbers than recorded in earlier years.

Lutjanus kasmira was introduced to Hawai‘i from the Marquesas Islands in 1958 (Randall 1987). Since then it has dramatically increased in abundance and has spread throughout the entire Hawaiian archipelago. Local fishermen suspect that *L. kasmira* may eat the juveniles of locally important fish species since 40% of its diet is fish (Tabata 1981). However, there is little conclusive evidence to support this. Oda and Parrish (1981) found some evidence of holocentrid fish (genus *Myripristis*) remains in the guts of *L. kasmira* but not in sufficient quantity to justify its classification as a major fish predator of locally important fishes. *L. kasmira* is an active, generalized carnivore that feeds mainly on crabs and juvenile fishes (Oda and Parrish 1981). However, there seems to be no significant overlap in diet to warrant a conclusion of intense competition for food with locally important fish species such as *Parupeneus porphyreus* or *Mulloidichthys flavolineatus*. The ecological niche of *L. kasmira* is still not completely understood, and more information is needed to conclusively determine why it has increased greatly in abundance since 1958 while, coincidentally, other fish species important to the local fishermen have declined. One other important factor, the possibility of overfishing, must still be addressed before cause-and-effect relationships can be made about the impact of *L. kasmira* on Hawai‘i fish community dynamics (Grigg 1994).

The armor rock surrounding the outfall pipe provides ample habitat space for hiding and mating, ample surface for the colonization of food sources, and a reference point above the substratum for aggregation and maintenance of schools. Artificial structures placed in an area normally devoid of bottom relief can attract large numbers of fish and provide surfaces for coral and other sessile organism attachment.

In 1975, total fish abundance at a transect located approximately 1 km offshore from the Waianae WWTP near the pipeline was 18 individuals representing 6 species (number adjusted to a 30 m ∞ 6 m transect area) (Reed et al. 1977). At Transect Alpha of Station WW, which is close (less than 50 m) to the above-mentioned transect, 16 individual fishes representing 6 species were recorded in 1998. Aggregations of fish species comparable to those found in similar biotopes around the Hawaiian islands were seen over the armor rock (Transect Beta) at Station WW during the 1994 through 1998 surveys. For example, Hobson's (1984) record of aggregations over "boulder" regions includes schools of yellowstripe goatfish or weke (*Mulloidichthys flavolineatus*), orangebar surgeonfish or na‘ena‘e (*Acanthurus olivaceus*), menpachi or ‘o(¯,u)‘o(¯,u) (*Myripristis berndti*), and saddleback wrasse or ho(¯,i)no(¯,a)lea lauwili (*Thalassoma duperrey*). These same species and many others were photographed over the armor rock at Station WW in 1998.

In 1998 there was no observable indication that the Wai‘anae sewer outfall effluent was adversely affecting the fish, coral, or macroinvertebrates at selected stations in the vicinity of the discharge. Since studies before 1986 were not conducted at the same deeper stations but in an area closer to shore (depth of 8 m), a before-and-after-discharge comparison at Stations W-2 and W-3 cannot be made. However, generally, the dominant fishes and coral species seen from 1986 through 1998 were essentially the same as those seen in earlier discharge years and before the outfall was modified (Reed et al. 1977). Sediments at all stations were clean, and horizontal visibility was good (15 to 20 m). The three parameters of fish abundance, diversity, and species composition at the sunken ship *Mahi* did not vary greatly from year to year. Numbers and species of fishes seen in the late 1970s were similar to those seen from 1986 through 1998. When compared with extensive surveys done by Hobson (1984), fish species richness, species composition, and abundance at the stations surveyed were similar to those found in other typical subtidal biotopes in Hawai‘i. Fishes normally intolerant of moderate sewage pollution (e.g., *Dascyllus albisella* [‘O(a,¯)lo‘ilo‘i] and *Chaetodon multicinctus* [kO(i,¯)kO(a,¯)kapu]), along with many coral heads, were seen at Station W-2. The growth of coral and the ship structure itself may be attracting large numbers of fish. At Station W-3, corals were growing on the diffuser ports and seemed to be thriving where none were seen prior to 1991. Fishes associated with corals became more abundant after 1991. At Station WW (the inshore station), fish populations were abundant and diverse, as well as representative of similar biotopes (Hobson 1984) found in Hawai‘i. Fish species number at Station WW and at the diffuser station (W-3) was greater in 1998 than in 1997.

Near Station WW coral coverage is generally low—a condition typical of shallow, flat, low-relief bottoms in this area (Reed et al. 1977). However, corals were thriving on the armor rock at the inshore pipeline, probably because of artificial topographical relief. This study showed that, since the beginning of biomonitoring in 1986, no significant deleterious effects have occurred on the fish and coral communities at the stations surveyed.

REFERENCES CITED

Brock, R.E. 1982. A critique of visual census methods for assessing coral reef populations. *Bull. Mar. Sci.* 32:24–35.

Daniel, W.W. 1987. *Biostatistics: A foundation for analysis in the health sciences.* New York: Wiley and Sons.

Green, R.H. 1979. *Sampling design and statistical methods for environmental biologists.* New York: Wiley-Interscience. 314 pp.

Grigg, R.W. 1994. Effects of sewage discharge, fishing pressure and habitat complexity on coral reef ecosystems and reef fishes in Hawaii. *Mar. Ecol. Prog. Ser.* 103:25–34.

Hobson, E.S. 1984. The structure of reef fish communities in the Hawaiian archipelago. In *Proc. N.W. Hawaiian Island Symp.*, MR-84-01, University of Hawaii Sea Grant College Program, Honolulu, pp. 57–70.

Hoover, J.P. 1993. *Hawaii's fishes: A guide for snorkelers, divers, and aquarists.* Honolulu: Mutual Publ. 178 pp.

Oda, D.K., and J.D. Parrish. 1981. Ecology of commercial snappers and groupers introduced to Hawaiian waters. *Proc. 4th Int. Coral Reef Symp.*, vol. I, Manila, Philippines.

Pastorak, R.A. and G.R. Bilyard. 1985. Effects of sewage pollution on coral reef communities. *Mar. Ecol. Prog. Ser.* 21:175–189.

Randall, J. 1987. Introductions of marine fishes to the Hawaiian islands. *Bull. Mar. Sci.* 4(2):490–502.

Reed, S.A., E.A. Kay, and A.R. Russo. 1977. Survey of benthic coral reef ecosystems, fish populations, and micromollusks in the vicinity of the Waianae sewage ocean outfall, O‘ahu, Hawai‘i—summer 1975. Tech. Rep. 104, Water Resources Research Center, University of Hawaii at Manoa, Honolulu. 36 pp.

Russo, A.R. 1992. A survey of selected coral and fish assemblages near the Waianae Ocean Outfall, 1992. Spec. Rep. 10.19:92, Water Resources Research Center, University of Hawaii, Manoa, Honolulu. 8 pp.

Russo, A.R. 1993. A survey of selected coral and fish assemblages near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 1993. Proj. Rep. PR-94-10, Water Resources Research Center, University of Hawai‘i, Mo(¯,a)noa, Honolulu. 14 pp.

Russo, A.R. 1994. A survey of selected coral and fish assemblages near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 1994. Proj. Rep. PR-95-04, Water Resources Research Center, University of Hawai‘i, Mo(¯,a)noa, Honolulu. 23 pp.

Russo, A.R. 1995. A survey of selected coral and fish assemblages near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 1995. Proj. Rep. PR-96-01, Water Resources Research Center, University of Hawai‘i, Mo(¯,a)noa, Honolulu. 25 pp.

Russo, A.R. 1996. A survey of selected coral and fish assemblages near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 1996. Proj. Rep. PR-97-03, Water Resources Research Center, University of Hawai‘i, Mo(¯,a)noa, Honolulu. 26 pp.

Russo, A.R. 1997. A survey of selected coral and fish assemblages near the Waianae Ocean Outfall, Oahu, Hawaii, 1997. Proj. Rep. PR-98-03, Water Resources Research Center, University of Hawai‘i at Mo(¯,a)noa, Honolulu. 26 pp.

Russo, A., and L.S. Lau. 1986. Benthic and fish survey in the vicinity of the Waianae sewer outfall. Unpubl. rep. to City and County of Honolulu. Water Resources Research Center, University of Hawaii at Manoa, Honolulu.

Sokal, R.R., and F.J. Rohlf. 1995. *Biometry: The principles and practice of statistics in biological research.* 3d edition. San Francisco: W.H. Freeman & Co. 887 pp.

Tabata, R. 1981. Ta‘ape: What needs to be done? Workshop Proc. Paper 46, University of Hawaii Sea Grant College Program, Honolulu. 31 pp.

TABLE 1. Fish Abundance (no./transect) at Station W-2, Waianae Ocean Outfall, O‘ahu, Hawai‘i, for 1991 Through 1998

Taxon	1991	1992	1993	1994	1995	1996	1997	1998
FAMILY CHAETODONTIDAE								
Chaetodon miliaris	18	13	20	20	11	10	25	20
Chaetodon multicinctus	0	1	2	1	3	5	6	6
Chaetodon kleinii	2	2	2	9	7	12	8	12
Chaetodon ornatissimus	0	3	0	0	0	0	1	1
Chaetodon lunula	0	0	1	0	0	0	0	0
Forcipiger flavissimus	1	0	1	1	4	6	4	5
Chaetodon quadrimaculatus	0	0	0	0	0	0	2	4
FAMILY POMACANTHIDAE								
Holacanthus arcuatus	0	0	1	0	0	1	0	0
Centropyge potteri	0	0	2	0	1	2	1	1
FAMILY ACANTHURIDAE								
Acanthurus olivaceus	0	2	11	7	2	2	3	2
Naso lituratus	1	0	1	0	4	3	2	6
Naso hexacanthus	2	1	3	12	0	7	11	17
Zanclus cornutus	0	1	1	1	2	5	3	4
Ctenochaetus strigosus	4	6	3	8	9	6	8	10
Zebrasoma flavescens	0	1	12	4	6	11	4	12
Acanthurus thompsoni	0	1	0	0	0	0	0	0
Acanthurus nigroris	3	4	4	5	4	0	3	9
Acanthurus sp.	0	0	0	25	5	3	12	2
Acanthurus nigrofuscus	0	0	0	3	0	1	0	0
Naso unicornis	0	0	0	0	0	0	0	17
FAMILY POMACENTRIDAE								
Dascyllus albisella	25	21	13	11	40	17	16	19
Chromis agilis	0	0	1	4	4	1	0	0
Chromis hanui	0	1	6	8	8	14	8	7
Stegastes fasciolatus	0	0	0	0	0	0	0	4
Abudefduf sordidus	0	0	0	0	0	0	0	5
FAMILY LABRIDAE								
Thalassoma duperrey	6	12	4	5	11	4	8	7
Labroides phthirophagus	1	1	0	0	1	2	2	2
Thalassoma ballieui	0	0	1	0	1	0	0	1
Gomphosus varius	0	0	0	0	2	2	0	0
FAMILY BALISTIDAE								
Sufflamen bursa	1	2	3	4	4	3	2	7
Rhinecanthus rectangulus	1	0	1	0	1	2	1	0
Melichthys vidua	0	2	2	1	1	5	5	3
Melichthys sp.	0	0	1	0	1	1	2	1
FAMILY MULLIDAE								
Mulloidichthys flavolineatus	0	0	11	0	0	12	7	2
Parupeneus multifasciatus	2	2	1	2	1	2	7	3
Parupeneus porphyreus	1	3	8	1	0	0	0	0
FAMILY LUTJANIDAE								

Lutjanus kasmira	50	33	18	60	32	33	30	28

TABLE 1—*Continued*

Taxon	1991	1992	1993	1994	1995	1996	1997	1998
FAMILY MONACANTHIDAE								
Pervagor spilosoma	1	4	0	0	0	0	0	0
FAMILY DIODONTIDAE								
Diodon hystrix	0	0	0	1	1	1	2	5
FAMILY TETRAODONTIDAE								
Canthigaster jactator	0	1	0	0	2	1	0	1
Arothron hispidus	1	0	1	1	1	0	2	6
FAMILY SCARIDAE								
Scarus dubius	0	1	0	0	0	3	0	1
FAMILY CIRRHITIDAE								
Paracirrhites forsteri	0	2	1	1	1	0	0	1
FAMILY LETHRINIDAE								
Monotaxis grandoculis	0	0	2	0	0	0	0	5
FAMILY AULOSTOMIDAE								
Aulostomus chinensis	0	0	0	1	0	0	0	2
FAMILY MURAENIDAE								
Gymnothorax meleagris	1	0	0	0	1	1	0	0
Total No. of Individuals	121	120	138	196	171	178	185	238
Total No. of Species	18	24	30	25	30	31	28	36

TABLE 2. Total Coral Cover for Selected Quadrats at Station W-2, Waianae Ocean Outfall, O‘ahu, Hawai‘i, for 1991 Through 1998

Quadrat	Coral Cover (%)							
	1991	1992	1993	1994	1995	1996	1997	1998
AAA1	17.2	19.6	19.8	26.0	25.0	29.6	27.8	29.4
AAA3	39.8	38.4	46.6	46.7	48.8	44.9	42.9	43.1
AAB1	30.5	41.2	34.5	28.0	32.9	35.6	40.1	33.0
AAB2	29.8	34.0	28.0	13.2	18.4	20.1	21.5	21.3
AAB3	33.4	30.8	33.0	39.5	36.6	38.5	38.9	23.5
AAB4	63.6	53.2	59.3	57.7	55.1	52.6	53.8	62.1
AAC1	40.8	51.9	51.2	35.5	49.4	47.9	47.9	46.6
AAC2	29.4	28.4	29.5	49.8	42.7	38.7	37.4	40.8
AAC3	49.5	48.4	48.7	62.2	57.8	55.1	54.2	53.5
AAC4	36.4	42.7	42.8	54.9	55.3	59.7	58.8	60.6
Mean	37.0	38.9	39.3	41.4	42.2	42.3	42.3	41.4

TABLE 3. Fish Abundance (no./transect) at Station W-3, Waianae Ocean Outfall, O'ahu, Hawai'i, for 1992 Through 1998

Taxon	1992	1993	1994	1995	1996	1997	1998
FAMILY ACANTHURIDAE							
Acanthurus nigrofuscus	10	2	0	2	1	0	0
Acanthurus sp.	5	2	1	1	0	0	0
Acanthurus olivaceus	4	5	7	9	3	5	37
Acanthurus nigroris	0	0	5	0	0	12	5
Ctenochaetus strigosus	0	0	0	0	0	0	4
Naso lituratus	0	0	0	4	1	1	3
Naso hexacanthus	0	0	0	0	0	0	5
Zanclus cornutus	0	0	0	2	0	2	2
Zebrasoma flavescens	0	0	0	0	0	0	9
FAMILY BALISTIDAE							
Sufflamen bursa	3	4	2	3	3	2	3
Rhinecanthus rectangulus	1	1	0	0	0	0	0
Melichthys vidua	0	8	2	1	2	2	4
Melichthys niger	0	2	1	0	0	0	2
FAMILY CHAETODONTIDAE							
Heniochus diphreutes	0	2	0	4	3	4	3
Forcipiger flavissimus	0	1	1	0	0	0	0
Chaetodon miliaris	0	0	7	0	15	5	2
Chaetodon kleinii	0	0	3	10	6	35	43
Chaetodon multicinctus	0	0	0	3	0	2	0
Chaetodon lunula	0	0	0	1	0	0	0
Chaetodon auriga	0	0	0	0	0	0	1
FAMILY MULLIDAE							
Parupeneus multifasciatus	2	5	14	2	2	5	6
FAMILY MONACANTHIDAE							
Pervagor spilosoma	3	0	0	0	0	0	0
FAMILY LABRIDAE							
Bodianus bilunulatus	0	2	2	0	0	1	4
Coris gaimard	0	0	1	1	1	1	1
Thalassoma duperrey	0	0	2	2	1	21	17
FAMILY POMACENTRIDAE							
Chromis hanui	0	0	5	6	1	2	5
Chromis vanderbilti	0	0	0	1	0	0	0
FAMILY TETRAODONTIDAE							
Arothron hispidus	0	0	0	0	0	0	1
Total No. of Individuals	28	34	53	52	39	100	157
Total No. of Species	7	11	14	16	12	15	20

TABLE 4. Fish Abundance (no./transect) at Station WW, Waianae Ocean Outfall, O‘ahu, Hawai‘i, for 1994 Through 1998

Taxon	1994 Transect Alpha	1994 Transect Beta	1995 Transect Alpha	1995 Transect Beta	1996 Transect Alpha	1996 Transect Beta	1997 Transect Alpha	1997 Transect Beta	1998 Transect Alpha	1998 Transect Beta
FAMILY ACANTHURIDAE										
Acanthurus olivaceus	3	16	0	8	1	13	0	5	0	5
Acanthurus blochii	0	121	0	3	0	0	0	0	0	0
Acanthurus nigroris	0	10	0	3	0	5	0	1	0	0
Acanthurus triostegus	0	0	0	3	0	1	0	0	0	3
Ctenochaetus strigosus	0	33	0	35	0	18	0	13	0	16
Zanclus cornutus	0	0	0	3	0	2	0	1	1	0
Zebrasoma flavescens	0	0	0	5	0	1	0	2	0	12
FAMILY BALISTIDAE										
Sufflamen bursa	5	0	5	0	1	2	4	2	4	0
Melichthys vidua	2	0	0	0	0	0	0	4	0	1
Rhinecanthus rectangulus	1	0	0	1	0	0	2	0	0	0
FAMILY CHAETODONTIDAE										
Chaetodon miliaris	0	5	0	8	0	30	0	18	0	6
Chaetodon multicinctus	0	0	0	6	0	1	0	4	0	6
Chaetodon fremblii	0	0	0	2	0	1	0	2	0	1
Forcipiger longirostris	0	2	0	2	0	1	0	0	0	0
FAMILY CIRRHITIDAE										
Paracirrhites forsteri	0	2	0	1	0	0	0	0	1	0
FAMILY LABRIDAE										
Thalassoma duperrey	3	35	6	8	1	5	5	3	5	5
Bodianus bilunulatus	2	1	0	2	0	0	0	0	0	1
Coris gaimard	0	0	0	1	0	0	0	0	0	0
Anampses chrysocephalus	0	0	0	2	0	0	0	2	0	2
FAMILY LETHRINIDAE										
Monotaxis grandoculis	0	2	0	0	0	0	0	0	0	0
FAMILY LUTJANIDAE										
Lutjanus kasmira	0	200	0	60	0	15	0	12	0	25
FAMILY MONACANTHIDAE										
Pervagor spilosoma	0	0	1	0	0	0	0	0	0	0
FAMILY MULLIDAE										
Parupeneus multifasciatus	2	6	10	6	0	3	0	2	0	0
Parupeneus porphyreus	0	2	0	8	0	10	0	3	2	6
Mulloidichthys flavolineatus	0	5	0	1	0	50	0	31	0	30
Mulloidichthys vanicolensis	0	0	0	6	0	5	0	12	0	8
FAMILY HOLOCENTRIDAE										
Myripristis berndti	0	12	0	9	0	20	0	12	0	30
Sargocentron sp.	0	0	0	12	0	4	0	2	0	1

TABLE 4—*Continued*

Taxon	1994		1995		1996		1997		1998	
	Transect		Transect		Transect		Transect		Transect	
	Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta
FAMILY POMACENTRIDAE										
Dascyllus albisella	0	45	5	19	0	46	0	10	0	18
Chromis agilis	0	10	2	2	0	0	0	1	3	11
Chromis hanui	0	12	0	6	0	3	0	2	0	8
Chromis verator	0	2	0	2	0	6	0	3	0	4
Chromis vanderbilti	0	0	0	5	0	11	0	0	0	0
Abudefduf sordidus	0	2	0	1	0	5	0	3	0	2
Abudefduf abdominalis	0	0	0	65	0	45	0	28	0	37
FAMILY TETRAODONTIDAE										
Arothron hispidus	2	0	1	0	1	0	1	1	0	1
FAMILY SERRANIDAE										
Epinephelus quernus	0	0	0	1	0	0	0	0	0	0
FAMILY FISTULARIIDAE										
Fistularia commersonii	0	0	0	1	0	0	0	1	0	1
Total No. of Individuals	20	523	30	297	4	303	12	180	16	240
Total No. of Species	8	20	7	33	4	25	4	27	6	25