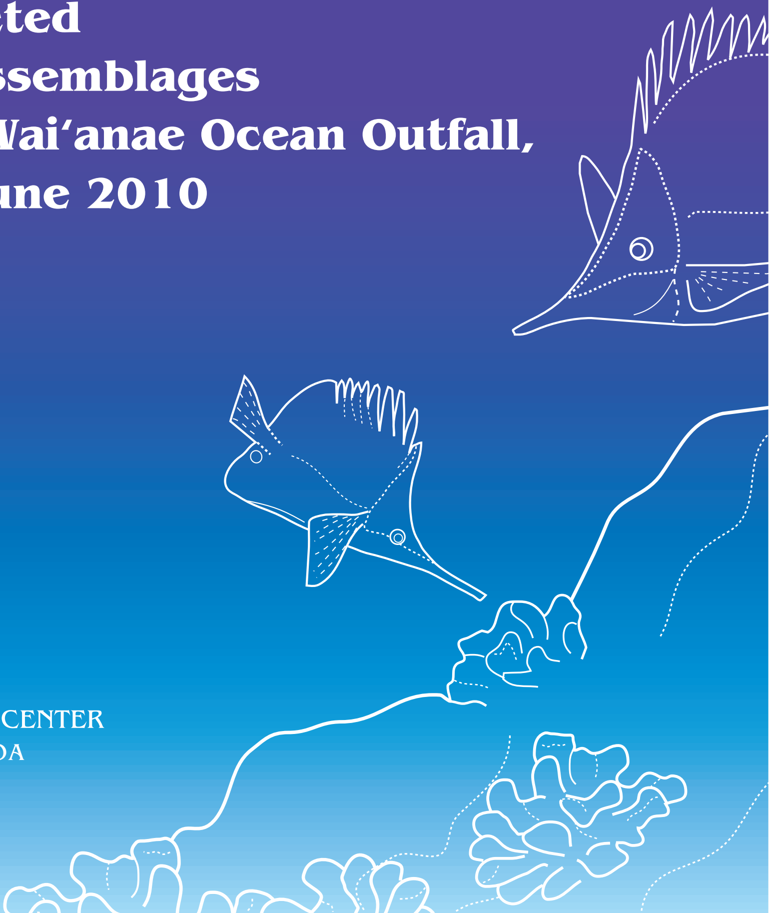
PROJECT REPORT PR-2011-05

A Survey of Selected Coral and Fish Assemblages Adjacent to the Wai‘anae Ocean Outfall, O‘ahu, Hawai‘i, June 2010



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November 2010

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12 ABSTRACT (PURPOSE, METHOD, RESULTS, CONCLUSIONS)

In 2010 coral growth and fish abundance were monitored at stations located at and adjacent to the Waianae ocean outfall diffuser, Oahu, Hawaii. Fish abundance at diffuser station W-3 was 338 individuals representing 18 species and 7 families. Total fish biomass was 89.8 kg. Station W-2, which was a control station in the past, was replaced by station Z in 2003. Station W-2 was replaced because of the dangerous deterioration of the sunken ship *Mahi* on which this station was located. Station Z, located inside the area of fish-haven habitat (artificial reef) controlled by the Hawaii Department of Land and Natural Resources, is approximately 1.0 km southeast of the diffuser at a depth of 16 m. A total of 623 fish individuals were seen at station Z, along both transects combined, representing 40 species of 14 families contributing a total of 45.6 kg of fish biomass. Total abundance was up from 2009 values. At station WW, an inshore station located 0.8 km from shore, fish abundance was high with a total of 927 individuals representing 51 species on two transects combined. This represents a decrease in abundance from total 2009 counts but an increase in the total number of species. The abundance and diversity of fishes at this station remains high. Fifteen families of fish were recorded at this station (both transects combined) contributing a total of 93.2 kg of biomass. Fish populations normally fluctuate from year to year in response to physical and biological factors. On the outfall covering of armor rock at station WW (transect Beta) fish aggregated in large numbers, probably due to the artificial topographical relief provided by the armor rock. Total fish biomass (>86 kg) on the armor rock on the 25 m Beta transect alone was almost twice that recorded at station Z for both transects combined. Large numbers of the acanthurids *Acanthurus nigrofuscus* and *Acanthurus olivaceus* were counted. The mullet *Mulloidichthys vanicolensis* was abundant, as were the pomacentrids *Chromis ovalis*, *Dascyllus albisella*, and *Abudefduf abdominalis*. The snapper *Lutjanus kasmira,* which accounted for 73.7% of the total abundance of fish seen at this transect in 2009, was conspicuously absent in 2010. This species was abundant in the years 2004 through 2009. The fish species seen inshore at station WW are comparable to those seen in similar natural (large rock) biotopes around Hawaii (Hobson 1984). Permanent coral quadrats previously set up at station Z were photographed for coral cover. Coral cover at five selected quadrats ranged from approximately 13.1% to 60.2%. At the outfall diffuser corals were seen growing on the diffuser and on the riser discharge ports. In 1986, when the outfall diffuser began operation with a discharge rate of 0.07 m^3/s (1.5 million gallons per day), no corals were seen at the outfall diffuser. In 2010 at inshore station WW corals not actually attached to the ocean outfall were sparsely distributed but those on the armor rock covering the outfall were numerous and thriving. Before 2004 the alga *Dictyopteris plagiogramma* was seen at this station. From 2004 through 2010 no algal cover was reported. Large aggregations of invertebrates were seen at all stations. On both transects combined at the inshore station WW, of the 334 invertebrates recorded most were sea urchins of the genera *Echinometra, Echinothrix,* or *Tripneustes.* At the outfall diffuser (station W-3) approximately 47 invertebrates, mostly sea urchins, were recorded. At station Z, a total of 267 invertebrates, mostly sea urchins, were recorded (both transects combined). Sea urchins were dominant at all stations. The water was clear at all stations surveyed (11–14 m horizontal visibility) and the surrounding sediments were clean and white. The high abundance and diversity of fishes indicate that no serious effects on the biological community at the stations surveyed are caused by the outfall diffuser and the discharge of treated effluent. There continues to be no evidence that the Waianae outfall diffuser is adversely affecting the abundance or diversity of corals and fishes at the selected survey stations adjacent to the outfall diffuser.

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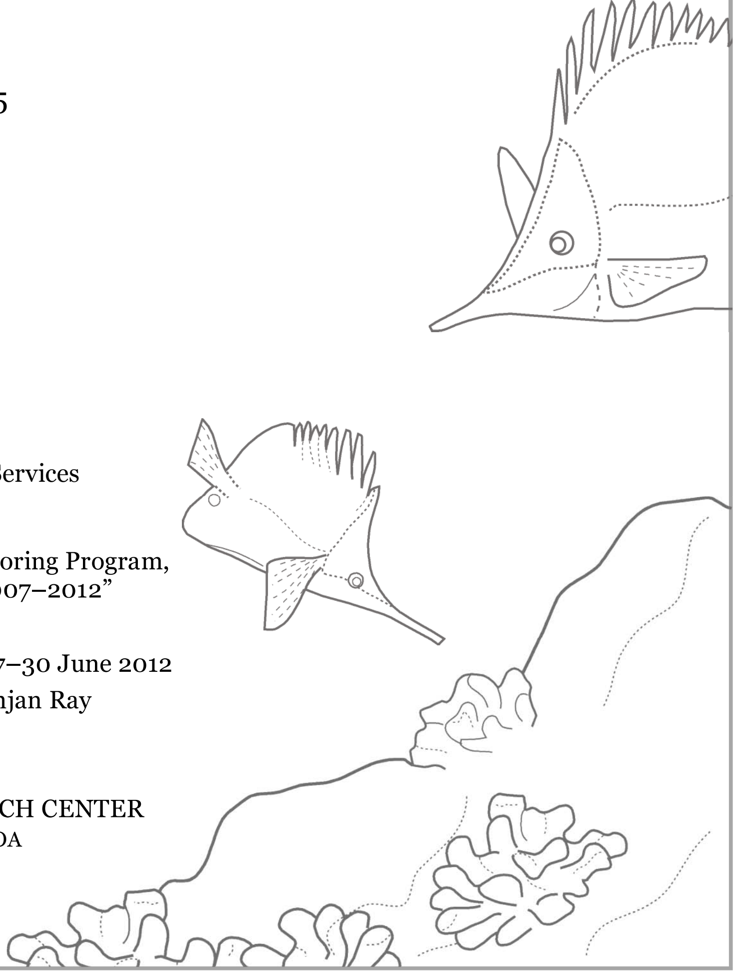

Abstract

In 2010 coral growth and fish abundance were monitored at stations located at and adjacent to the Waiʻanae ocean outfall diffuser, Oʻahu, Hawaiʻi.

Fish abundance at diffuser station W-3 was 338 individuals representing 18 species and 7 families. Total fish biomass was 89.8 kg.

Station W-2, which was a control station in the past, was replaced by station Z in 2003. Station W-2 was replaced because of the dangerous deterioration of the sunken ship *Mahi* on which this station was located.

Station Z, located inside the area of fish-haven habitat (artificial reef) controlled by the Hawaiʻi Department of Land and Natural Resources, is approximately 1.0 km southeast of the diffuser at a depth of 16 m. A total of 623 fish individuals were seen at station Z, along both transects combined, representing 40 species of 14 families contributing a total of 45.6 kg of fish biomass. Total abundance was up from 2009 values.

At station WW, an inshore station located 0.8 km from shore, fish abundance was high with a total of 927 individuals representing 51 species on two transects combined. This represents a decrease in abundance from total 2009 counts but an increase in the total number of species. The abundance and diversity of fishes at this station remains high. Fifteen families of fish were recorded at this station (both transects combined) contributing a total of 93.2 kg of biomass.

Fish populations normally fluctuate from year to year in response to physical and biological factors. On the outfall covering of armor rock at station WW (transect Beta) fish aggregated in large numbers, probably due to the artificial topographical relief provided by the armor rock. Total fish biomass (>86 kg) on the armor rock on the 25 m Beta transect alone was almost twice that recorded at station Z for both transects combined. Large numbers of the acanthurids *Acanthurus nigrofuscus* and *Acanthurus olivaceus* were counted. The mullet *Mulloidichthys vanicolensis* was abundant, as were the pomacentrids *Chromis ovalis*, *Dascyllus albisella*, and *Abudefduf abdominalis*. The snapper *Lutjanus kasmira*, which accounted for 73.7% of the total abundance of fish seen at this transect in 2009, was conspicuously absent in 2010. This species was abundant in the years 2004 through 2009. The fish species seen inshore at station WW are comparable to those seen in similar natural (large rock) biotopes around Hawaiʻi (Hobson 1984).

Permanent coral quadrats previously set up at station Z were photographed for coral cover. Coral cover at five selected quadrats ranged from approximately 13.1% to 60.2%. At the outfall diffuser corals were seen growing on the diffuser and on the riser discharge ports.

In 1986, when the outfall diffuser began operation with a discharge rate of 0.07 m^3/s (1.5 million gallons per day), no corals were seen at the outfall diffuser. In 2010 at inshore station WW corals not actually attached to the ocean outfall were sparsely distributed but those on the armor rock covering the outfall were numerous and thriving.

Before 2004 the alga *Dictyopteris plagiogramma* was seen at this station. From 2004 through 2010 no algal cover was reported.

Large aggregations of invertebrates were seen at all stations. On both transects

combined at the inshore station WW, of the 334 invertebrates recorded most were sea urchins of the genera *Echinometra*, *Echinothrix*, or *Tripneustes.* At the outfall diffuser (station W-3) approximately 47 invertebrates, mostly sea urchins, were recorded. At station Z, a total of 267 invertebrates, mostly sea urchins, were recorded (both transects combined). Sea urchins were dominant at all stations.

The water was clear at all stations surveyed (11–14 m horizontal visibility) and the surrounding sediments were clean and white.

The high abundance and diversity of fishes indicate that no serious effects on the biological community at the stations surveyed are caused by the outfall diffuser and the discharge of treated effluent. There continues to be no evidence that the Waiʻanae outfall diffuser is adversely affecting the abundance or diversity of corals and fishes at the selected survey stations adjacent to the outfall diffuser.

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Executive Summary

The ocean waters adjacent to the Wai‘anae outfall diffuser are used for diving, fishing, and other recreational activities. Over the years, beginning prior to 1990, University of Hawai‘i researchers and City and County of Honolulu oceanographers have monitored the status of corals, fish, and large invertebrate populations at and adjacent to the Wai‘anae outfall diffuser to determine if there has been any impact from treated effluent on these organisms.

At the Wai‘anae outfall diffuser treated effluent is discharged at the rate of 0.14 m^3/s (3.24 million gallons per day [mgd]) at a depth of 33.5 m (110 ft). The treated effluent passes through the ocean outfall running 1.8 km (6,000 ft, a little over a mile) from shore to the outfall diffuser. Treated effluent is discharged from the outfall diffuser through vertical risers (elbow ports) 0.5 m (1.5 ft) off the bottom.

In June 2010 observations were made by a University of Hawai‘i researcher and the City and County of Honolulu Department of Environmental Services Oceanographic Team at three permanent stations.

One station is inshore in shallow (8 m; 26.2 ft) water approximately 1 km (0.62 mi) from the outfall diffuser. A second station is located at the outfall diffuser. The third station is in a fish-haven habitat (an artificial reef made of concrete slabs) at a depth of 16 m (52.5 ft) approximately 1 km (0.62 mi) from the outfall diffuser.

At each station the number of fish individuals and species found along permanently laid lines (25 m transects) was recorded. A video CD of the activity along the outfall diffuser was also made. The Oceanographic Team photographed permanently placed squares (meter-square quadrats) for coral-cover percentages. The number of other organisms (e.g., large shells, sea cucumbers, sea urchins, etc.) found along each line was also recorded.

Results over the years of study have shown that large numbers of fish individuals and large numbers of fish species reside at these stations. At those areas where armor rock covers the outfall diffuser, very high fish abundances and species numbers were reported by divers and recorded on photographs and the video CD. At the outfall diffuser, where the treated effluent is discharged, large numbers of fish were recorded along with corals and other organisms growing on the vertical risers and on adjacent rocks. The video CD of the outfall diffuser environment, made this year by the Oceanographic Team, also shows all diffuser ports working properly.

Fish population abundance has varied slightly from year to year as would be expected because of natural fluctuations. However the fish community composition (kinds of fish and numbers of species) seen has remained fairly constant from year to year. Coral-cover percentage has not significantly differed among the years of the studies and reflects normal growth. Large numbers of sea urchins and other invertebrates were counted along the transect lines.

The added bottom relief generated by the ocean outfall and diffuser and covering armor rock attracts many fishes and provides a hard bottom on which organisms such as corals can attach. Fishes make use the of the armor rock for aggregation, breeding, and protection from predators.

Since 1986, when these studies commenced, no adverse affects from the treated effluent have been seen on coral and fish populations. The treated effluent discharged by the Wai‘anae outfall diffuser does not appear to adversely affect these organisms while the ocean outfall structure actually seems to attract marine life.

Introduction

The City and County of Honolulu’s (CCH’s) conservation-district use permit for the installation of an ocean outfall diffuser at Wai‘anae, O‘ahu, Hawai‘i, was approved subject to several conditions (Board of Land and Natural Resources letter to the City and County of Honolulu, 15 November 1983; ref. no. CPO-844, file no. OA-4/11/83-1541). Among the conditions was the requirement that, adjacent to the outfall diffuser, fishery stocks be assessed and benthic organisms be photographically monitored, both annually, after the first year of discharge of treated effluent.

It is worth noting that fishery pressures, both recreational and commercial, may well be affecting the fishery stocks adjacent to the outfall diffuser. However any such possible affects lie outside the scope of this study and are impossible to quantify by the study methods used here.

The Wai‘anae Wastewater Treatment Plant (WWTP) is a secondary-treatment system that, as of June 2010, discharged approximately 0.14 m^3/s (3.24 mgd) of secondary-treated effluent from wastewater of primarily domestic origin through an ocean outfall 1.8 km (6,000 ft) offshore with the outfall diffuser at a depth of approximately 33.5 m (110 ft). The outfall diffuser is 161.8 m (531 ft) long and discharges treated effluent through vertical risers approximately 0.5 m (1.5 ft) above the seafloor.

In the summer of 2010 a research diver from the University of Hawai‘i and oceanographic personnel from the CCH Department of Environmental Services collaborated on a scuba-diving survey of the marine community near the Wai‘anae outfall diffuser. This report summarizes the results of that survey and comparatively analyzes the 2010 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 is given below.

Station Z is located in the fish-haven habitat established by the Hawai‘i State Department of Land and Natural Resources (DLNR) 1.0 km southeast of the outfall diffuser at a depth of approximately 16 m. The substratum is flat limestone and rubble with coral growth. Two transect lines (each 25 m long) are spaced 27 m apart and positioned perpendicular to shore. These were permanently placed near artificial reefs, which make up part of the fish-haven habitat, and near a ledge that drops off to 23 m depth (Figure 2).

This station was set up in 2003 roughly 300 m east of the old station W-2, which was on the sunken ship *Mahi*. Because of dangerous shifting and corrosion of the ship it was deemed unsafe to continue diving on the wreck for future coral transect and fish counts. Hawai‘i State DLNR gave the CCH permission to set up station Z to replace station W-2.

Station W-3 is located at the middle of the outfall diffuser at a depth of approximately 30 m. The 1.07 m (42 in) diameter outfall diffuser is buried in the sediment and covered with trémie concrete. Discharge is through risers projecting vertically from the outfall diffuser. Surrounding sediments consist of coarse carbonate sands. A corals-and-fish transect was set up on the diffuser (Figure 3). Flow activity of the diffuser, along with fish aggregations and coral growth along the diffuser, were recorded by a video camera.

Station WW is located 1 km offshore on the ocean outfall at a depth of approximately 8 m. Two transects—one approximately 20 m north of the ocean outfall (transect Alpha) and the other on the ocean outfall (transect Beta)—were set up at this station (Figure 4). The ocean outfall in this area is covered with trémie concrete and surrounded by large armor rock.

Transect Alpha lies on a flat limestone substratum and transect Beta is on the armor rock covering the ocean outfall. Both transects are approximately 25 m long and run perpendicular to shore. With authorization from DLNR, station WW became a permanent station in 1994; it was established to monitor, temporally, the effects of any inshore movement of treated effluent discharged through the outfall diffuser. Transect Alpha was monitored in 1990 and 1991 although its monitoring was not then required by DLNR. It was not monitored in 1992 or 1993 because it was destroyed by Hurricane Iniki in September 1992. A new transect Alpha was established in 1994.

In late April 1995 the CCH Department of Environmental Services Oceanographic Team found the 5.08 cm (2 in) diameter transect wire at transect Alpha to be damaged, with large sections moved or altogether removed from the area. It is not clear whether this was due to natural causes (e.g., storms and/or wave action) or other causes (e.g., theft, vandalism, and/or anchor dragging). The transect wire was replaced 8–9 May 1995 by the CCH Department of Environmental Services Oceanographic Team.

There are no spatial/distance control stations in this study—instead the stations for this study are located at different depths with differing bottom types and differing topographical relief. Topographical relief is provided by artificial structures (e.g., the outfall diffuser, armor rock, and artificial reefs). Given the uniqueness of each station, valid comparisons cannot be made among stations spatially for coral and fish abundance and species richness. Only year-to-year comparisons of survey data obtained from the same stations may be validly made.

Artificial reefs in the vicinity of station Z attract fishes and provide substrata for coral growth. Artificial structures (armor rock and diffuser ports) at stations WW and W-3 provide habitats for fish as well as surfaces and relief for coral settlement, colonization, and growth. At station WW (8 m depth), armor rock covering the ocean outfall provides relief in areas where the substratum is normally flat limestone with 1% to 2% coral cover.

At all stations fish counts were made along the permanent 25 m transects (Figures 2, 3, and 4) by divers equipped with scuba (Brock 1982). Fishes were counted along the transect as the diver first swam up the line looking 3 m to the right and then swam down the line looking 3 m to the right.

Year-to-year comparisons of fish abundance, diversity, and species composition are made for each station using similarity indices (Cochran's [1950] Q-test). As discrepancies will occur because of differences in technique and capability among observers, beginning in 2004 the same diver/observer (R. Brock) has performed the fish counts annually.

Estimates of coral cover on selected permanent quadrats at station Z were made using bottom photography and subsequent projection of the photos on a grid. The percentage of coral cover was estimated by total area cover (estimated within a grid) of the indicated coral species relative to the total area of the quadrat. At station Z the percentage cover of selected quadrats containing coral was compared between years 2009 and 2010 using a paired t-test (Daniel 1987, Sokal and Rohlf 1995).

Besides counting the individuals of all fishes seen, the length of each fish is estimated for later use in the determination of the fish biomass using linear regression techniques (Ricker 1975). Species-specific regression coefficients have been developed over the last thirty years by the author (Brock) and others at the University of Hawaiʻi, the Naval Undersea Center (see Evans 1974), and the Hawaiʻi Division of Aquatic Resources from weight and body measurements of captured fishes; for many species the coefficients have been developed using sample sizes in excess of a hundred individuals.

The presence or absence of any macroinvertebrates was also recorded for all three stations.

Findings

The figures and tables in this report only present data from 2004 to present; however, for comparison in the discussion of results, some reference is made to pre-2004 data. Results of earlier studies for the years between 1986 and 2003 may be reviewed at City and County of Honolulu Department of Environmental Services and various Hawaiʻi state offices and libraries and may be readily accessed by anyone wishing to examine them (or purchased from the Water Resources Research Center, as noted on page ii of this report).

Station Z

At station Z total fish abundance (transects 1 and 2 combined) was 623 individuals representing 40 species (Table 1). *Naso hexacanthus* (*kala lōlō* or sleek unicornfish) was relatively abundant as was the mullet *Parupeneus multifasciatus* (*moāno* or manybar goatfish). Total fish abundance, species richness, and biomass increased over 2009 values. Fish biomass in 2009 was approximately 12.9 kg; in 2010 it was 45.6 kg.

The area is generally flat but there is some topographical relief to attract large numbers of fishes. This area may still be in the process of reaching fish-community equilibrium. Coral cover at selected quadrats ranged from 13.1% to 60.2% (Table 2; Figures 5 and 6). A large number (267) of invertebrates, especially sea urchins (genus: *Echinometra* or *Echinothrix*) and annelids (genus: *Spirobranchus*), were seen on both transects combined.

Station W-3

On the outfall diffuser transect at station W-3 a total of 599 fishes representing 23 species were counted in 2009. In 2010 these values decreased to 338 individuals representing 18 species (Table 3). There were relatively large numbers of *Chaetodon kleinii* (*kīkākapu* or butterflyfish) and the tang *Acanthurus olivaceus* (*naʻenaʻe* or orangeband surgeonfish). The species *Parupeneus multifasciatus* was abundant

(49 individuals) in 2010. Total fish biomass was 89.8 kg this year. This represented a significant increase from the 2009 outfall diffuser biomass of 39.8 kg.

In 1986, 24 fishes representing 6 species were seen at station W-3 (Russo and Lau 1986). In 1987 and 1989 this station was not monitored. In 1988 and 1991 no fishes were seen along the transect although they were seen swimming in the area. After 1989 fish began aggregating near the ocean outfall. Fish abundance and species richness for 2004 through 2010 are shown in Figures 7 and 8.

As in earlier years, in 2010 corals of the genus *Pocillopora* were seen growing on the concrete cover of the outfall diffuser (corals 10–17 cm in diameter) and on the riser ports (corals 5–14 cm in diameter; Figures 9 and 10). In the last few years the number of coral heads (mostly *Pocillopora meandrina* [cauliflower coral]) in the outfall diffuser vicinity increased from each previous year and coral heads grew larger (>19 cm in diameter). The dominant species of corals seen at this station include *Montipora verrucosa*, *Pocillopora meandrina*, and *Porites lobata* (lobe coral).

In 1986, the year the ocean outfall was completed and in service below (at 0.07 m^3/s [1.5 mgd]) full-discharge capacity, no corals were seen growing on the outfall diffuser or in its vicinity. Only after 1991 were corals seen colonizing the outfall diffuser substratum. In 1991 the treated effluent discharge rate was approximately 0.09 m^3/s (2 mgd); it increased to 0.13 m^3/s (2.9 mgd) in 1994 and to approximately 0.16 m^3/s (3.5 mgd) in 2010.

The 47 macroinvertebrates recorded in 2010 at station W-3 were mostly sea urchins (*Echinothrix diadema* [long-spined black sea urchin]). The annelid *Spirobranchus giganteus corniculatus*, a Christmas tree worm, was also abundant.

Station WW

The location of transect Alpha is the same as that of a transect set up in 1990 to monitor inshore movement of treated effluent. 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. The hurricane changed the substratum characteristics and destroyed the earlier transects emplaced in 1990. New transects were set up at station WW in 1994.

At station WW total fish abundance (transects Alpha and Beta combined) was 927 individuals representing 51 species. On transect Beta, on the armor rock covering the ocean outfall, 878 individuals representing 42 species were seen. On transect Alpha 49 individuals representing 15 species were recorded (Table 4). Abundant species consistently seen on transect Beta were the damselfishes *Chromis ovalis* (oval chromis—216 individuals), fishes of the genus *Abudefduf* (82 individuals), and *Dascyllus albisella* (*‘alo‘ilo‘i* or Hawaiian Dascyllus—65 individuals). *Lutjanus kasmira* (*ta‘ape* or bluestriped snapper), a species that normally congregates in large schools, which was relatively abundant (226) last year was absent this year. The species *Acanthurus olivaceus* (*na‘ena‘e* or orangeband surgeonfish) was represented by 81 individuals; up from last year’s count of 68.

In 1999 there were large numbers of the species *Mulloidichthys vanicolensis* (*weke ‘ula* or yellowfin goatfish) but they dwindled to low numbers after a few years and were replaced by other species. This species reappeared in 2009 and was relatively abundant in 2010 (130 individuals) as was *Myripristis amaena* (*menpachi* or brick soldierfish; 56 individuals). Generally large shifts in abundance of fish populations occur naturally, in most marine environments, in response to biological and physical factors, many of which remain unclear. There is probably intensive interspecific competition for new niche space and food causing fish-species composition to fluctuate slightly as community equilibrium is approached. Rare species are usually not being counted as often, relative to the three or four dominants that increased dramatically over the last few years. These dominants shift in importance. In recent years (2004–2010) the damselfishes of the genera *Abudefduf* and *Chromis* have remained dominant.

Many more fish individuals and species were recorded at transect Beta (on the ocean outfall) than at transect Alpha (on flat bottom). Fishes appear to aggregate over the artificial substrata that provides ample hard structure for the colonization of corals. Fish biomass reached 87.3 kg for both transects combined. This was a slight decrease from the 2009 biomass of approximately 88 kg.

In 1998 the bottom at transect Alpha was covered (30%) with the alga *Dictyopteris plagiogramma* (*limu līpoa*) and there was very little relief. In 1999 this alga disappeared. In 2000 and 2001 it reappeared with approximately 30% to 45% bottom cover. In 2002 the algal cover was approximately 10%. This was followed by an increase to about 20% in 2003. This alga has not been reported since 2004.

Corals were seen colonizing on the armor rock and on a 5.08 cm (2 in) diameter cable that was discarded or moved close to transect Alpha during Hurricane Iniki in 1992. More coral heads (mostly *Pocillopora meandrina*) were seen in this area in 2009 and 2010 than in 2004. Still the coral bottom cover was below 2.5%. At both transect Alpha and transect Beta large numbers of sea urchins were counted.

There were no significant differences (all P>0.05) in fish-species composition compared among all stations between 2009 and 2010. Species composition between years at each station had a high degree of fidelity.

Additional Observations

Fish biomasses in 2010 for stations Z, W-3, and WW, respectively, are shown in Figure 11. Of the 87.3 kg of biomass at station WW, more than 86.5 kg were recorded on the armor rock at transect Beta. This station has substantially more relief than the outfall diffuser station since the outfall diffuser is covered with trémie concrete flush with the bottom and not held in place by armor rock as at other Hawai‘i outfalls. This fact again points out the attractiveness of bottom relief for fish aggregation. The armor rock represents a spatial reference point for aggregation of fishes as well as substratum for the attachment of invertebrate larva. Fish biomass data at the outfall diffuser for years 2007 through 2010 are shown in Figure 12.

Fish biomass has been used extensively around the world as an aid to fisheries-resource management and to estimate the health and age distributions of fish populations. Some studies include lakes in Finland (Rask and Arvola 1985), coastal temperate regions (Polunin 1996), and tropical reef environments (Sherman 1994).

Discussion

Coral cover is normally low (1% to 2% of bottom area) off the Wai‘anae coast and is dominated by two coral species, *Pocillopora meandrina* and *Porites lobata* (Reed et al. 1977). This dominance existed long before the old ocean outfall, 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. The modified Wai‘anae ocean outfall began discharging treated effluent in January 1986.

At station Z, in the artificial reef zone, large numbers of fish individuals and species were counted. Unlike the old station W-2, at station Z there is little topographical relief on the bottom; therefore not as many fishes are attracted to this site as they were to the sunken ship *Mahi.* Station Z is monitored closely and comparisons are made from year to year for fidelity of species composition, abundance of fishes, and coral cover.

At station W-3 in 2010 fishes were fairly abundant as they have been over the past few years of sampling. Fish diversity and abundance were both high relative to areas near the ocean outfall. Plankton-feeding fishes may be attracted to the outfall diffuser. Russo (1982) observed planktivorous fishes feeding on particulate matter from the outfall diffuser at Barbers Point. Effluent particulate matter may be an alternate source of food for many fishes, especially those dominants seen this station.

Corals were seen colonizing the areas near the outfall diffuser and on the outfall diffuser riser ports themselves. In 1986 through 1988 corals were not seen at this station. After 1993 coral heads (approximately 10–25 cm in diameter) of *Pocillopora meandrina* and *Porites lobata* became established (Russo 1994, 2001, 2002, 2003a, 2003b; Russo and Brock 2005, 2008, 2009). The surrounding sediments, which are made mostly of coral sands, were clean and white and there seemed to be no buildup of particulates in the sediments.

At station W-3 fish abundance decreased dramatically from 2007 to 2008, increased in 2009, and decreased in 2010. Fish species richness also decreased from 2007 to 2008, increased in 2009, then dropped in 2010. The large decrease in abundance from 2007 to 2008 is due to the disappearance of genus *Decapterus,* which was seen in very large numbers (500 individuals) in 2007. This species was not seen at this station in 2008, 2009, or 2010.

Variations in fish abundance and diversity may be affected by food resources, especially by particulates in the water column. If effluent loads are not excessive, some particulate matter may be utilized by water-column-planktivorous-feeding fishes (Hobson 1984, Pastorak and Bilyard 1985). Pomacentrids (damselfishes), which are planktivorous, were the most dominant group of fishes in terms of relative abundance seen in this area.

At station WW many fishes were counted over the ocean outfall and armor rock (transect Beta) whereas fewer were seen over the flat, algal-dominated, limestone bottom (transect Alpha).

Over the survey years from 2004 to 2010 fish abundance and species richness fluctuated at transect Beta. In 2004, 2007, and 2009 abundance was relatively high (1,209, 1,128, and 1,221 individuals, respectively). In 2006 abundance was a low of 704. In 2007 species richness was up to a high of 44, an increase from 2006. In 2010 abundance dropped to 878 from a 2009 total of 1,221 and species richness increased from 34 in 2009 to 42 in 2010. This transect, over armor rock, still remains quite rich and diverse in fish fauna.

Large numbers of the species *Mulloidichthys vanicolensis*, *Dascyllus albisella*, and other common fish species were seen swimming over the rocks at transect Beta. Two damselfish species, *Abudefduf abdominalis* (*mamo* or sergeant major) and *Chromis ovalis*, were very abundant at transect Beta in 2004 through 2010. *Lutjanus kasmira* was abundant in 2004 and 2005, but was low in numbers in 2006 through 2008, was abundant again in 2009. None were counted in 2010.

Since being introduced to Hawai‘i in 1958 (Randall 1987), *Lutjanus kasmira* has been a topic of concern among researchers and fishermen because of its potential for rapid population growth. This species has become integrated into the fish community and seems to be of less concern presently than in past years (Tabata 1981). A study of the ecology and biology of *Lutjanus kasmira* was done in earlier years (Oda and Parrish 1982) but, since then, there seems to be no definitive evidence of habitat disruption because of its introduction. Populations of *Lutjanus kasmira* seem to have reached equilibrium in Hawai‘i biotopes.

The ecological niche of *Lutjanus kasmira* is still not completely understood and more information is needed to conclusively determine its niche in the Hawaiian fish community. The decline in some locally important fish species believed due to competition, a belief which was earlier supported by large *Lutjanus kasmira* aggregations, may in fact have been generated by over-fishing (Grigg 1994) rather than by intense competition from *Lutjanus kasmira*.

Summary and Conclusions

Fish populations on and adjacent to the Wai‘anae outfall diffuser were species rich and abundant. High biomasses of fish were seen on the armor rock covering especially at the inshore station. The armor rock surrounding the ocean outfall 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 fish 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, before construction of the outfall diffuser, total fish abundance at a transect located approximately 1 km offshore from the Wai‘anae WWTP near the ocean outfall was 18 individuals representing 6 species (number adjusted to a 30 × 6 m transect area; Reed et al. 1977). At station WW, which is close (less than 50 m) to the above-mentioned transect, 927 individual fishes representing over 50 species were recorded in 2010 on both transects combined.

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 1999 through 2010 surveys. For example, Hobson’s (1984) record of aggregations over “boulder” regions includes schools of damselfishes including *Chromis* sp. and *Dascyllus albisella*, the surgeonfish *Acanthurus olivaceus*, the surgeonfish *Ctenochaetus strigosus* (*kole* or goldring surgeonfish), the soldierfish *Myripristis amaena*, and the labrid *Thalassoma duperrey* (*hinālea lau-wili* or saddle wrasse). These same taxa, and many others identified with the boulder biotope, were seen over the armor rock at station WW in 2010.

In 2010 there was no observable indication that the treated effluent was adversely affecting the coral, fish, or macroinvertebrates at sampling stations adjacent to the Wai‘anae outfall diffuser.

Since studies before 1986 were not conducted at the same deeper stations but in a shallower (8 m depth) area closer to shore, a before-and-after discharge comparison of the studied stations cannot be made. Generally, however, the dominant fishes and coral species seen from 1986 through 2010 were essentially the same as those seen in earlier years and before the ocean outfall was modified (Reed et al. 1977).

Sediments at all stations were clean and horizontal visibility in the water was good. At station W-3 corals were growing on the outfall diffuser ports and seemed to be thriving where none were seen prior to 1991. Fishes were abundant and species rich.

Fishes associated with corals became more abundant after 1991. At the inshore station WW fish populations were abundant and diverse as well as representative of similar biotopes (Hobson 1984) found in Hawai‘i.

Coral coverage was generally low on natural substrata—a condition typical of shallow, flat, low-relief bottoms in this area (Reed et al. 1977). Corals were, however, thriving on the armor rock at the inshore ocean outfall, probably because of the artificial topographical relief. Invertebrates, mostly echinoids, were abundant at all stations.

Fishes are frequently used as bio-indicators since they are relatively easy to identify and are of particular interest to local agencies because of recreational and commercial fishing. Monitoring fish populations is recommended over the long term and, if it is determined that biological impacts are occurring, there may be a strong argument for adaptive management strategies where particular factors such as effluent treatment, flow rate, and periodicity of discharge can be changed or monitored to improve environmental health (Smith et al. 1999).

This continuing study has shown that, since the beginning of biomonitoring in 1986, no significant deleterious effects have occurred to the coral and fish communities at the stations surveyed.

References

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

Cochran, W.G. 1950. The comparison of percentages in matched samples. *Biometrika* 3:22–38.

Daniel, W.W. 1987. *Biostatistics: A Foundation for Analysis in the Health Sciences*. New York: Wiley and Sons.

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

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 *Proceedings of the Second Symposium on Resource Investigations in the Northwestern Hawaiian Islands*, ed. R.W. Grigg and K. Tanoue, 101–122, MR-84-01. Honolulu: University of Hawaii Sea Grant College Program.

Oda, D.K., and J.D. Parrish. 1982. Ecology of commercial snappers and groupers introduced to Hawaiian reefs. In *Proceedings of the 4th International Coral Reef Sympsoium*, Vol. 1, ed. E.D. Gomez, C.E. Birkeland, R.W. Buddemeier, R.E. Johannes, J.A. Marsh Jr., and R.T. Tsuda, 59–67. Manila: University of the Phillippines Marine Sciences Center.

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

Polunin, N.V.C. 1996. Trophodynamics and productivity of reef fisheries. In *Reef Fisheries*, ed. N.V.C. Polunin and C.M. Roberts, 86–112. London: Chapman & Hall.

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

Rask, M., and L. Arvola. 1985. The biomass and production of pike, perch, and whitefish in two small lakes in Finland. *Ann. Zool. Fennici* 22:129–136.

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*. Technical Report No. 104. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *B. Fish. Res. Board Can.* Vol. 191.

Russo, A.R. 1982. Temporal changes in fish community structure near a marine sewer outfall, Mokapu, Oahu, Hawaii. *Mar. Environ. Res.* 6:83–98.

Russo, A.R. 1994. *A Survey of Selected Coral and Fish Assemblages Near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 1994*. PR-95-04. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Russo, A.R. 2001. *A Survey of Selected Coral and Fish Assemblages Near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 2000*. PR-2001-06. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Russo, A.R. 2002. *A Survey of Selected Coral and Fish Assemblages Near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 2001*. PR-2002-08. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Russo, A.R. 2003a. *A Survey of Selected Coral and Fish Assemblages Near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 2002*. PR-2003-06. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Russo, A.R. 2003b. *A Survey of Selected Coral and Fish Assemblages Near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 2003*. PR-2004-05. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Russo, A.R., and R.E. Brock. 2005. *A Survey of Selected Coral and Fish Assemblages Near the Waianae Ocean Outfall, O‘ahu, Hawai‘i, 2004*. PR-2005-05. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Russo, A.R., and R.E. Brock. 2008. *A Survey of Selected Coral and Fish Assemblages Near the Wai‘anae Ocean Outfall, O‘ahu, Hawai‘i, June, 2008*. PR-2009-04. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Russo, A.R., and R.E. Brock. 2009. *A Survey of Selected Coral and Fish Assemblages Adjacent to the Wai‘anae Ocean Outfall, O‘ahu, Hawai‘i, June, 2009*. PR-2010-06. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

Russo, A., and L.S. Lau. 1986. Benthic and fish survey in the vicinity of the Waianae sewer outfall. Unpublished report to City and County of Honolulu. Honolulu: University of Hawai‘i at Mānoa Water Resources Research Center.

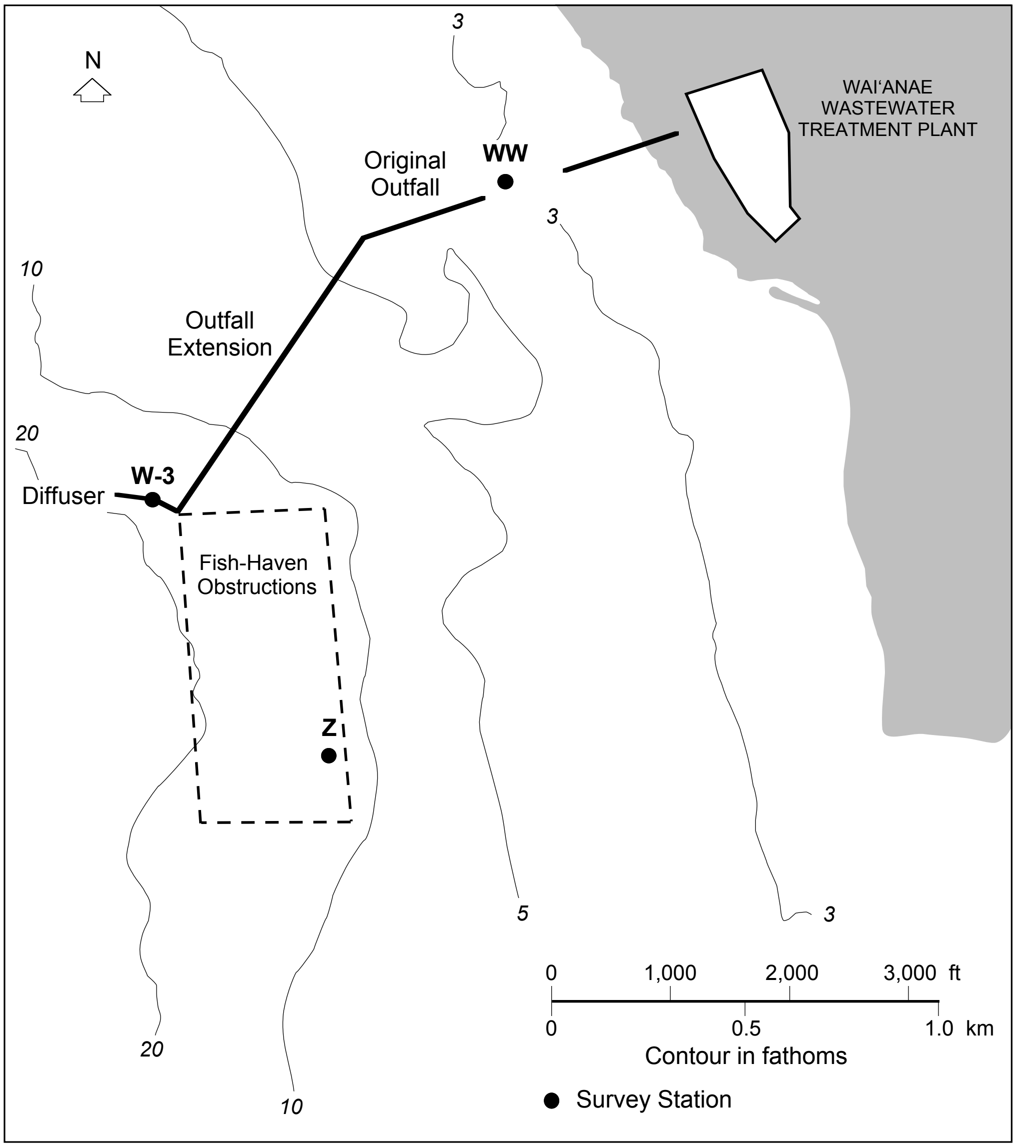
Sherman, K. 1994. Sustainability, biomass yields, and health of coastal ecosystems: An ecological perspective. *Mar. Ecol. Prog. Ser.* 112:277–301.

Smith, A.K., P.A. Ajani, and D.E. Roberts. 1999. Spatial and temporal variation in fish assemblages exposed to sewage and implications for management. *Mar. Environ. Res.* 47:241–260.

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.

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

Figures



Adapted from Russo and Lau (1986)

Figure 1. Biological survey stations in the vicinity of the improved Waiʻanae ocean outfall sampling stations, Oʻahu, Hawaiʻi

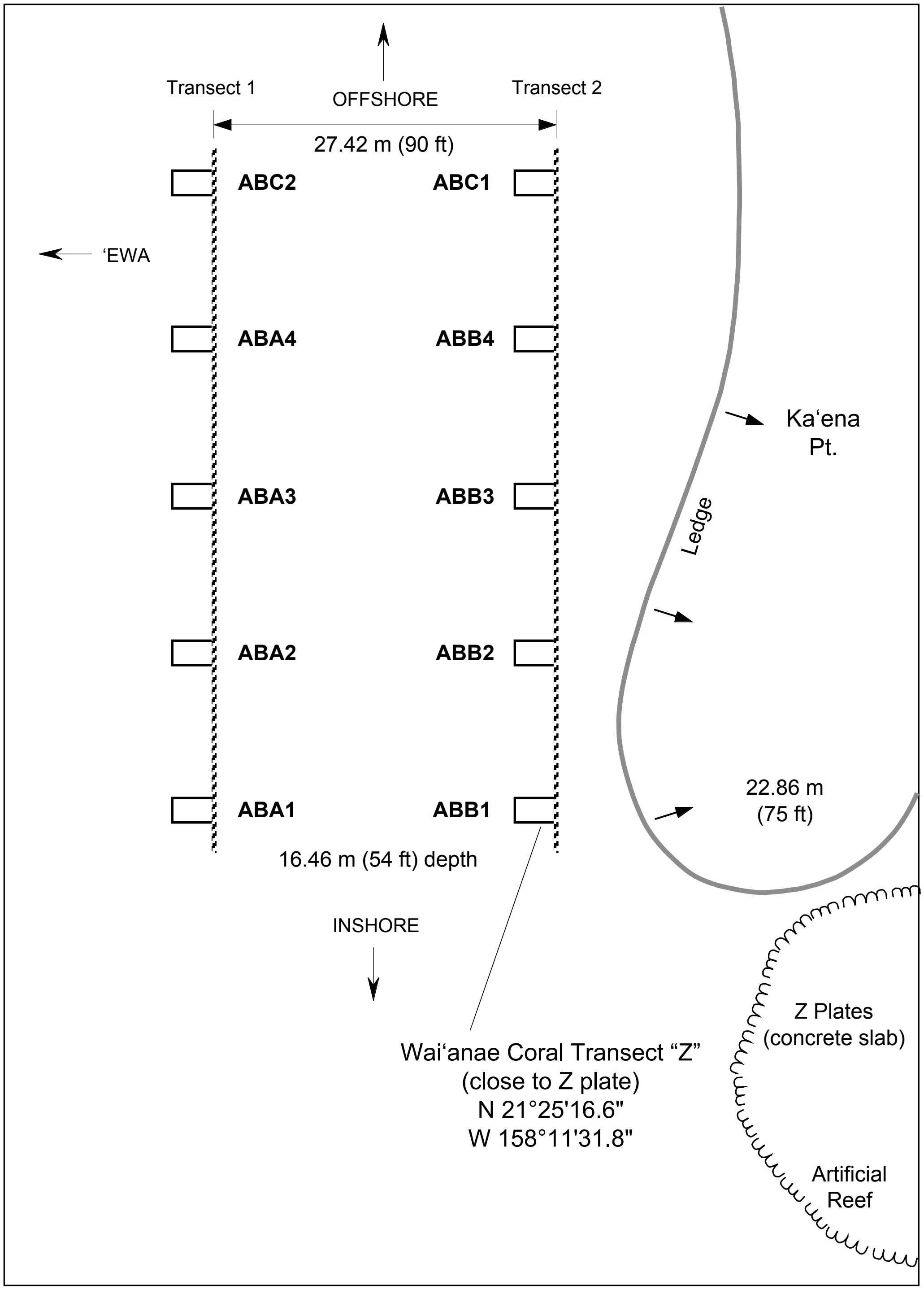


Figure 2. Transects at station Z, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i

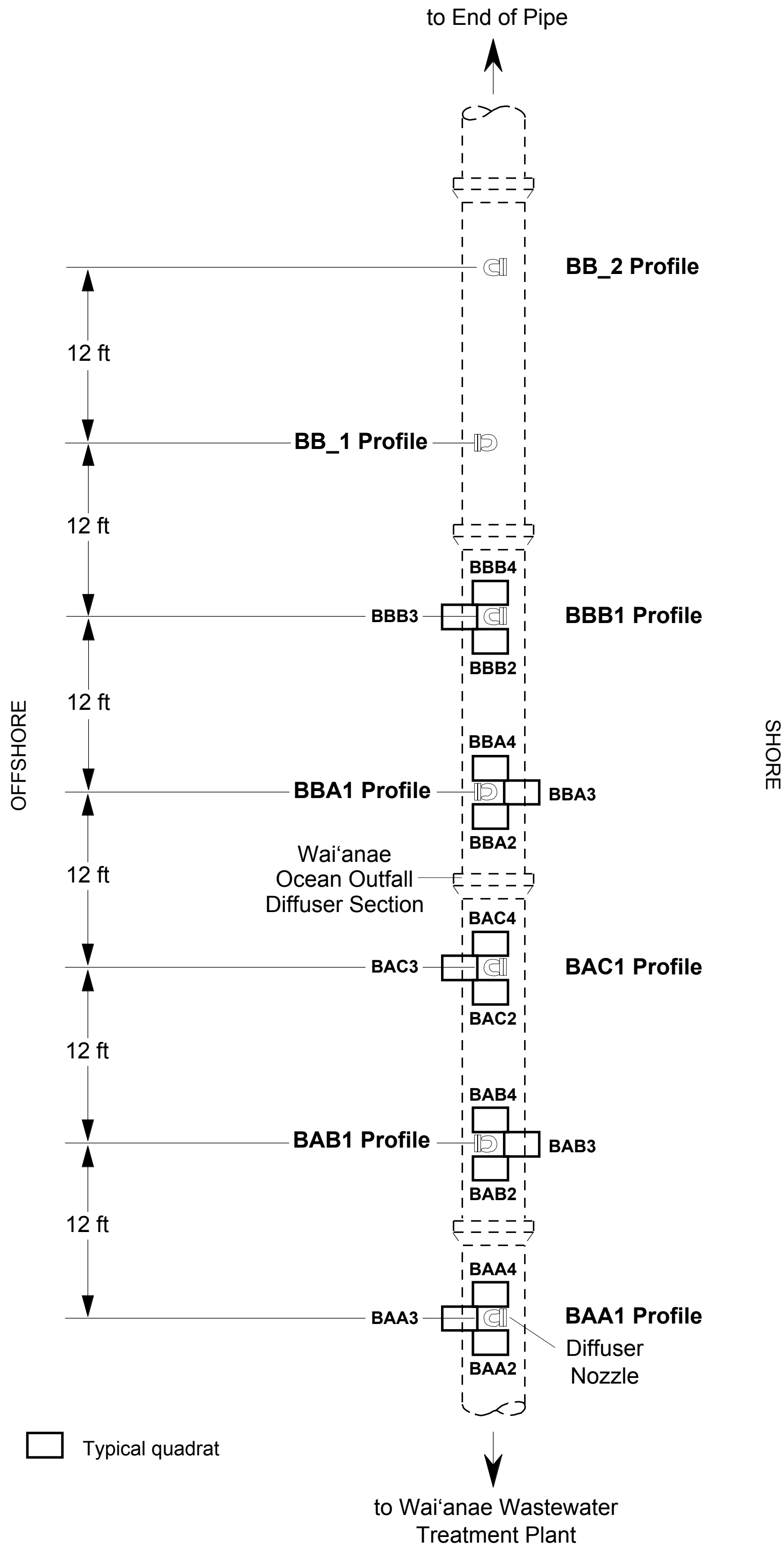


Figure 3. Transect at station W-3, on the diffuser, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i

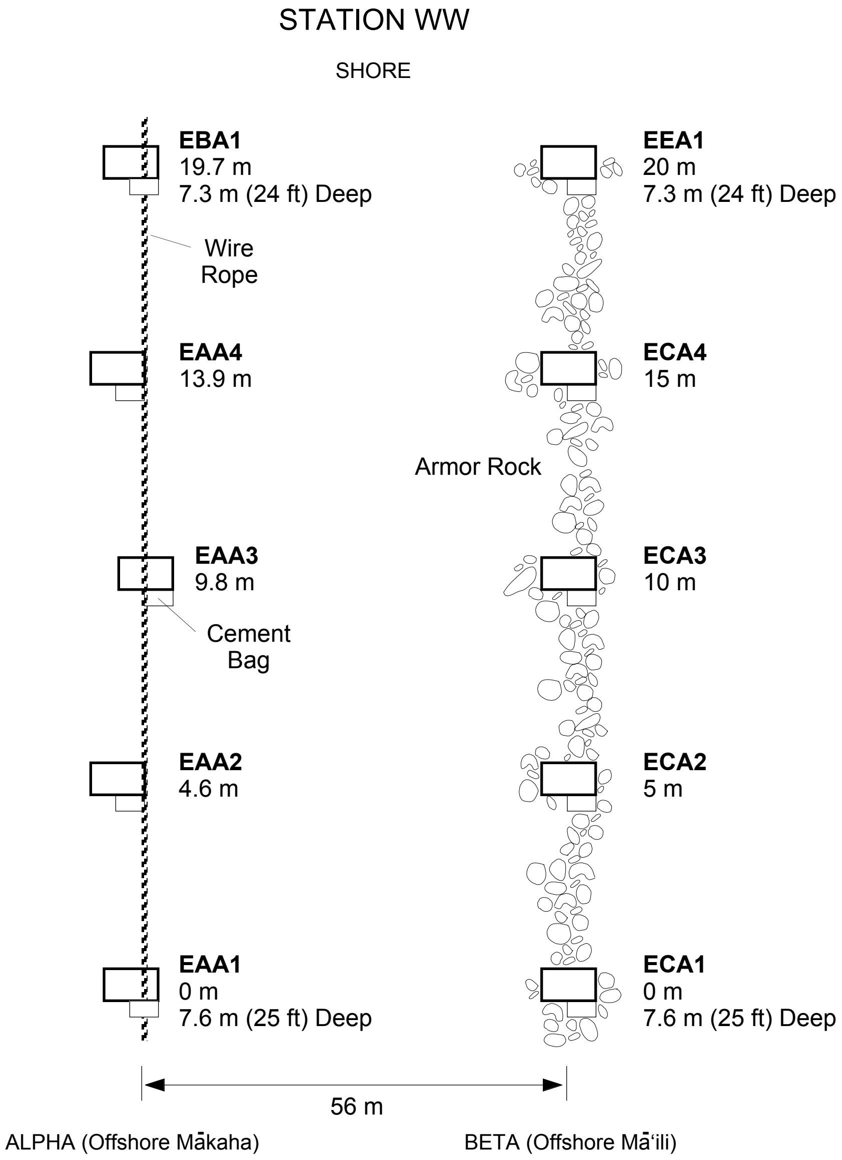


Figure 4. Transects at station WW, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i

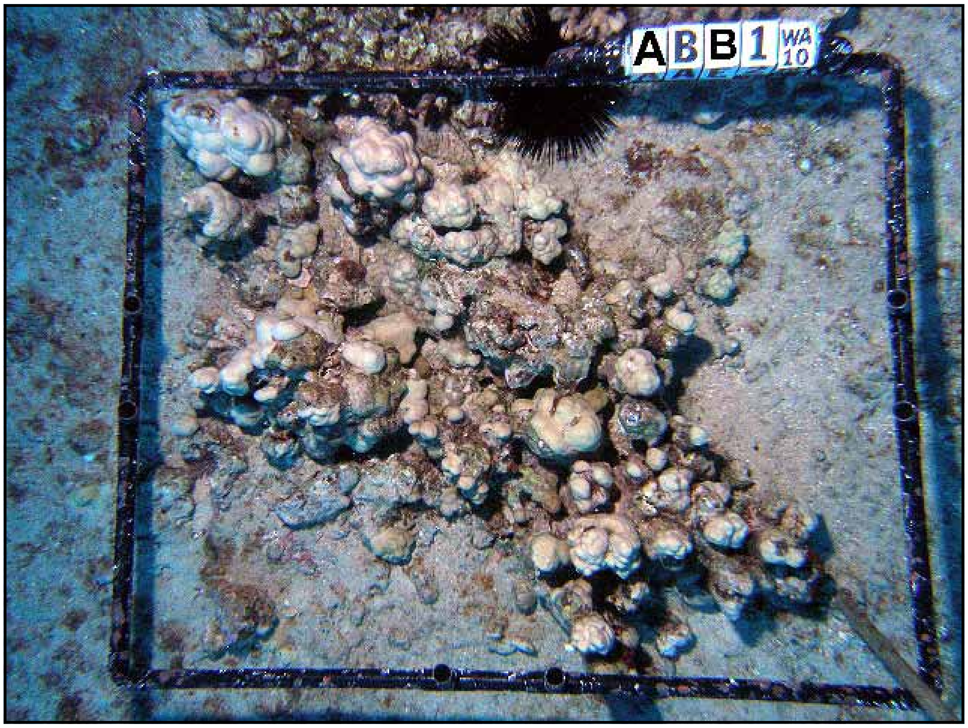


Figure 5. Coral growth in quadrat ABB1 at station Z, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i, 2010

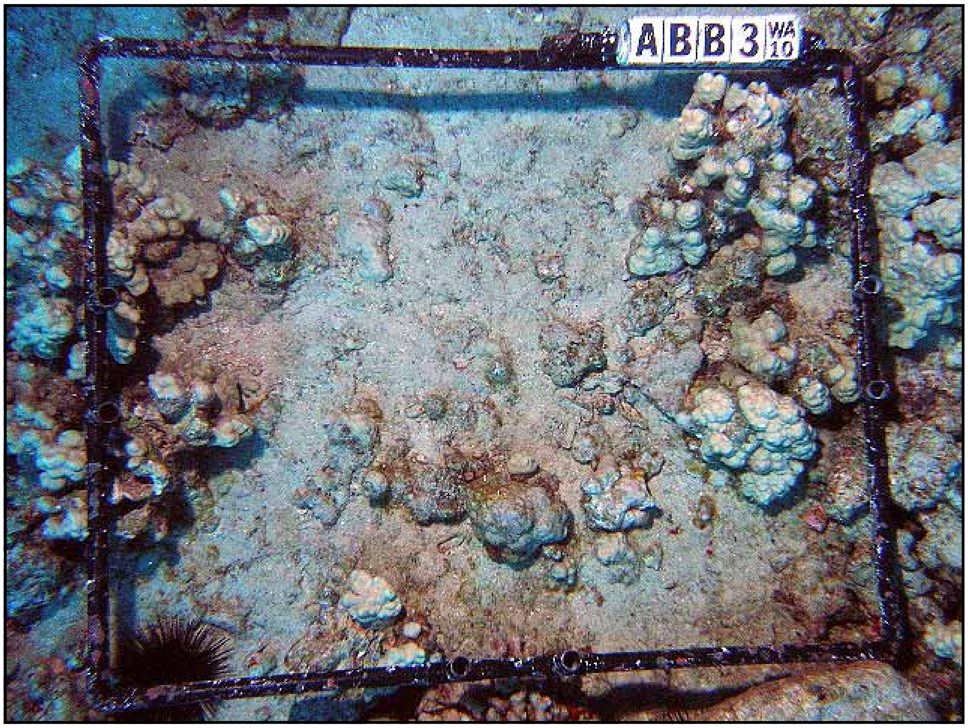


Figure 6. Coral growth in quadrat ABB3 at station Z, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i, 2010

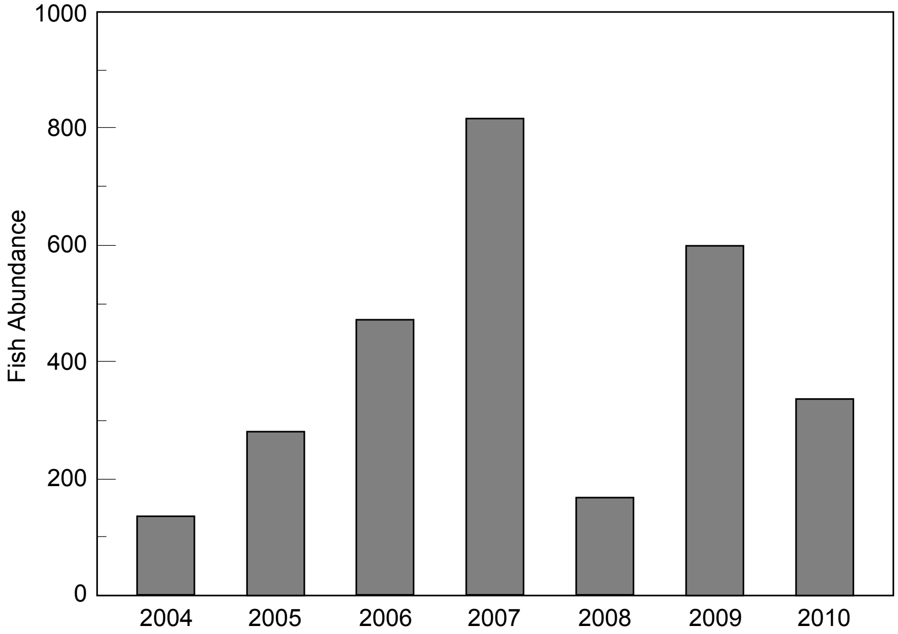


Figure 7. Fish abundance at station W-3 for 2004 through 2010, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i

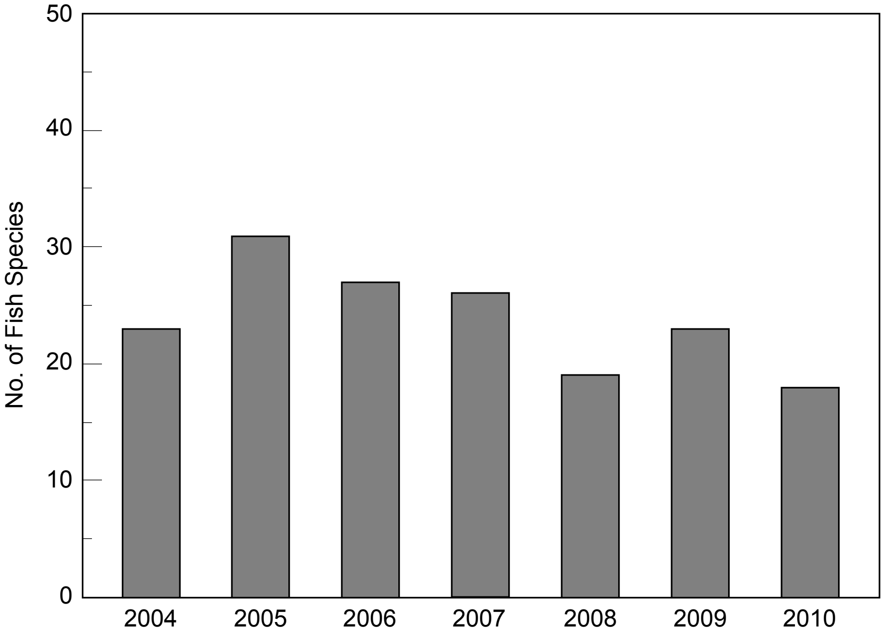


Figure 8. Fish species richness at station W-3 for 2004 through 2010, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i

Figure 9. Coral, red sponge, and coralline algal growth on diffuser port BB_1 at station W-3, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i, 2010

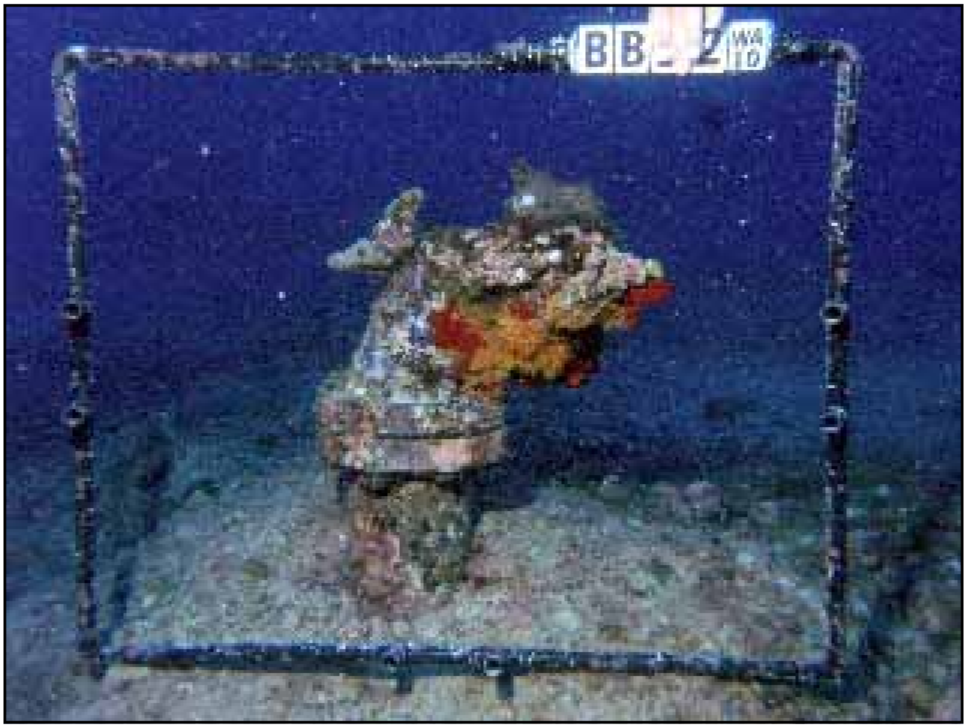


Figure 10. Coral, sponge, bryzoa, and coralline algal growth on diffuser port BB_2 at station W-3, Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i, 2010

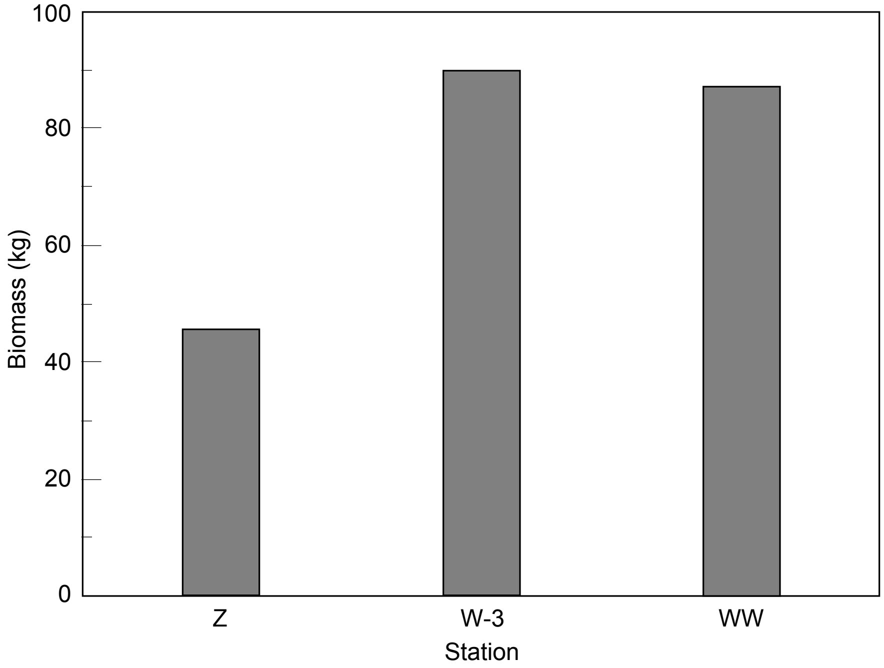


Figure 11. Total fish biomass compared among sampling stations at Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i, June 2010

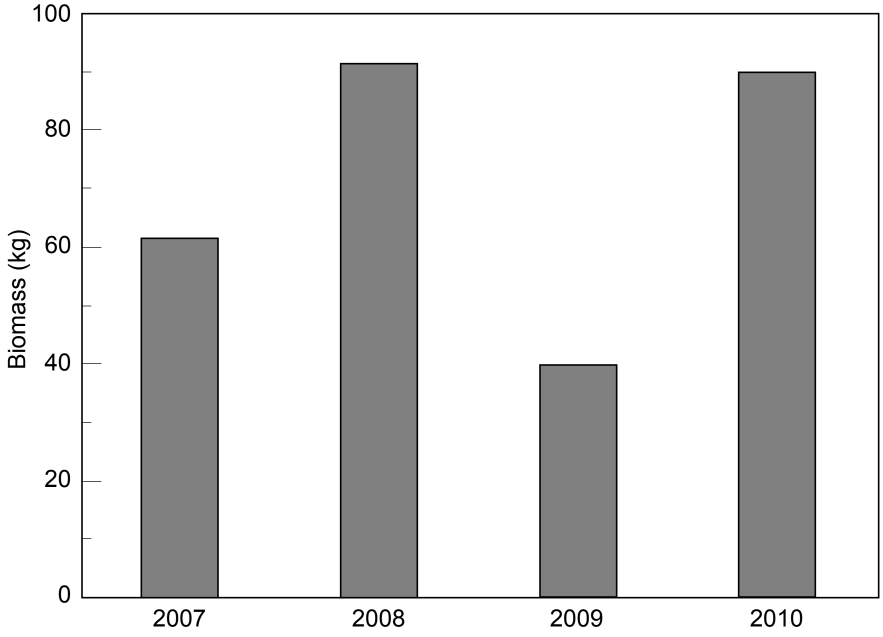


Figure 12. Fish biomass at station W-3 for 2007 through 2010 at Wai‘anae ocean outfall sampling stations, O‘ahu, Hawai‘i

Tables

Table 1. Fish abundance (no./transect) at station Z (W-2, A, and B), Waiʻanae ocean outfall, Oʻahu, Hawaiʻi, for the years 2004 through 2010.

Taxon	No. of Individuals													
	Transect 1							Transect 2						
	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
ACANTHURIDAE														
Acanthurus achilles	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Acanthurus blochii	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Acanthurus nigroris	3	4	4	0	5	0	0	0	0	0	0	0	0	0
Acanthurus nigrofuscus	49	19	9	15	14	23	17	4	17	3	19	7	2	12
Acanthurus olivaceus	0	1	8	1	6	20	29	0	0	5	7	4	0	0
Ctenochaetus strigosus	0	0	7	0	0	0	0	0	0	0	0	0	0	0
Naso brevirostris	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Naso hexacanthus	0	0	1	17	0	70	45	27	0	0	0	0	41	55
Naso lituratus	1	0	7	2	0	4	4	1	1	1	0	1	1	4
Zanclus cornutus	0	0	0	1	0	0	2	2	2	2	0	0	0	0
Zebrasoma flavescens	1	4	3	0	0	0	3	0	0	0	0	1	0	0
ANTENNARIIDAE														
Antennarius sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0
APOGONIDAE														
Pristiapogon kallopterus	0	0	0	2	0	0	0	0	0	0	0	0	0	0
AULOSTOMIDAE														
Aulostomus chinensis	0	0	0	0	0	0	0	0	0	0	0	0	0	1
BALISTIDAE														
Melichthys vidua	1	2	1	2	1	2	0	1	0	1	0	1	1	1
Sufflamen bursa	4	3	3	3	5	4	3	1	4	2	2	1	2	3
Sufflamen fraenatum	0	0	0	3	0	1	0	1	0	0	0	0	0	0
Xanthichthys mento	0	1	1	0	3	0	5	15	3	2	8	2	2	0
BLENNIDAE														
Plagiotremus ewaensis	0	0	0	0	0	1	0	0	0	0	0	0	0	0
CARANGIDAE														
Caranx melampygus	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Decapterus macarellus	0	0	0	0	0	0	0	0	0	0	0	0	0	65
Scombroides laysan	0	0	0	0	0	0	7	0	0	0	0	0	0	9
CHAETODONTIDAE														
Chaetodon fremblii	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Chaetodon kleinii	14	19	8	23	0	22	26	32	23	2	4	8	21	11
Chaetodon miliaris	1	3	0	1	0	5	21	0	0	0	0	0	0	0
Chaetodon multicinctus	2	4	8	17	0	4	2	2	4	4	20	2	0	0
Chaetodon ornatissimus	0	2	0	0	0	0	0	0	0	1	0	0	0	0
Chaetodon quadrimaculatus	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetodon unimaculatus	0	0	0	0	0	0	0	0	2	0	0	1	0	0
Forcipiger flavissimus	3	1	1	0	0	2	2	0	2	0	0	0	0	0
CIRRHITIDAE														
Cirrhitops fasciatus	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Paracirrhites arcatus	1	14	8	10	4	5	18	2	11	2	9	3	4	3
Paracirrhites forsteri	0	1	1	0	0	0	0	0	0	0	0	1	0	0
FISTULARIDAE														
Fistularia commersonii	0	0	0	0	1	1	0	0	0	0	0	0	0	0
LABRIDAE														
Anampses chrysocephalus	0	0	9	2	0	0	0	0	0	0	0	0	0	0
Coris gaimard	0	0	0	0	0	0	1	0	1	2	1	0	1	0
Coris venusta	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Gomphosus varius	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Halichoeres ornatissimus	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Labroides phthirophagus	0	0	0	0	2	2	0	0	0	0	0	0	0	0
Macropharyngodon geoffroy	3	0	0	9	5	0	0	0	0	0	1	0	0	0

Table 1—*Continued.*

Taxon	No. of Individuals													
	Transect 1							Transect 2						
	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
Oxycheilinus bimaculatus	0	0	0	1	7	0	0	2	2	4	1	8	3	3
Pseudocheilinus octotaenia	1	1	1	5	1	0	1	0	2	0	0	0	0	1
Pseudocheilinus tetrataenia	2	0	0	2	3	0	0	0	0	0	0	0	0	0
Pseudojuloides cerasinus	0	4	4	7	29	12	5	0	4	4	3	8	2	4
Stethojulis balteata	0	2	0	1	3	1	3	0	0	0	1	2	0	0
Thalassoma duperrey	3	24	14	27	17	14	22	3	19	3	3	4	1	7
LUTJANIDAE														
Aphareus furca	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MALACANTHIDAE														
Malacanthus brevirostris	0	0	0	0	0	0	0	0	1	1	1	0	0	0
MONACANTHIDAE														
Cantherhines dumerilii	0	1	0	1	0	0	1	1	1	2	0	1	0	0
Pervagor aspricaudus	0	0	0	0	0	2	0	0	0	0	0	0	0	0
MULLIDAE														
Aprion virescens	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Parupeneus multifasciatus	14	16	29	10	0	27	56	0	13	21	24	25	2	10
Parupeneus pleurostigma	0	1	2	0	0	0	0	0	4	17	0	0	0	0
MURAENIDAE														
Gymnothorax sp.	1	0	0	0	0	1	1	0	0	0	0	0	0	0
POMACANTHIDAE														
Centropyge fisheri	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Centropyge potteri	0	0	4	4	0	2	0	0	0	0	0	0	0	0
Holacanthus arcuatus	0	0	0	0	0	0	0	1	0	0	0	0	0	0
POMACENTRIDAE														
Chromis agilis	0	0	8	70	21	16	16	0	0	0	0	3	0	7
Chromis hanui	0	7	14	57	6	27	24	0	0	0	0	7	3	6
Chromis vanderbilti	59	47	19	93	40	26	21	0	0	0	12	0	0	0
Chromis verator	0	0	0	0	0	0	42	0	0	0	0	0	0	0
Dascyllus albisella	19	6	15	0	0	0	0	16	19	0	17	4	0	24
Plectroglyphidodon johnstonianus	3	8	1	4	0	2	0	1	3	2	1	2	1	0
Stegastes fasciolatus	0	0	0	0	0	1	2	0	0	0	0	0	0	0
SCARIDAE														
Calotomus carolinus	0	0	0	1	0	0	1	0	0	0	1	0	1	0
Scarus psittacus	4	0	4	0	0	0	4	0	0	0	0	0	0	0
Scarus sordidus	0	0	0	0	0	0	5	0	0	0	0	0	0	0
SCORPAENIDAE														
Taenianotus tricanthus	0	0	0	0	0	0	1	0	0	0	0	0	0	0
TETRAODONTIDAE														
Arothron hispidus	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Canthigaster coronata	2	1	0	1	0	1	0	0	3	1	1	2	7	2
Canthigaster jactator	2	3	3	1	4	3	1	0	3	1	3	1	2	2
Total No. of Individuals	195	202	198	395	181	302	392	112	145	83	141	99	97	231
Total No. of Species	24	30	30	33	23	30	33	17	24	22	23	24	18	21

Table 2. Coral-cover percentage within five selected quadrats at station Z (W-2, A, and B), Wai‘anae ocean outfall, O‘ahu, Hawai‘i, for the years 2003 through 2010.

Quadrat	Coral Cover (%)							
	2003	2004	2005	2006	2007	2008	2009	2010
ABB1	60.8	57.6	59.8	61.2	60.4	63.8	64.4	60.2
ABA1	24.0	25.2	24.7	25.7	26.0	22.3	20.1	22.1
ABA3	25.4	26.0	24.6	22.8	20.0	20.9	22.8	20.8
ABB3	48.1	49.5	50.1	48.8	47.6	45.9	43.7	45.9
ABC2	8.2	7.8	7.4	8.7	9.1	10.1	11.5	13.1

Table 3. Fish abundance (no./transect) at diffuser station W-3, Waiʻanae ocean outfall, Oʻahu, Hawaiʻi, for the years 2004 through 2010.

Taxon	No. of Individuals						
	2004	2005	2006	2007	2008	2009	2010
ACANTHURIDAE							
Acanthurus dussumieri	2	0	0	0	0	0	0
Acanthurus nigrofuscus	0	2	19	6	3	15	33
Acanthurus nigroris	2	2	12	0	3	0	0
Acanthurus olivaceus	43	14	32	32	7	34	104
Acanthurus thompsoni	0	0	0	0	0	34	0
Acanthurus triostegus	0	1	0	0	0	0	0
Ctenochaetus strigosus	3	6	0	7	0	0	8
Naso annulatus	0	0	0	5	0	0	0
Naso brevirostris	4	26	47	2	76	75	27
Naso hexacanthus	3	31	97	111	9	164	14
Naso lituratus	2	2	0	1	0	3	9
Naso unicornis	0	0	0	0	0	19	5
Zanclus cornutus	0	0	0	1	0	0	0
Zebrasoma flavescens	0	1	0	0	0	0	0
APOGONIDAE							
Pristiapogon kallopterus	0	32	19	11	6	0	0
AULOSTOMIDAE							
Aulostomus chinensis	1	0	0	1	0	0	0
BALISTIDAE							
Labroides phthirophagus	0	0	0	0	0	0	1
Melichthys vidua	0	4	4	3	0	4	2
Sufflamen bursa	1	2	5	2	9	5	4
Xanthichthys mento	6	0	2	1	0	9	0
CARANGIDAE							
Decapterus macarellus	0	0	0	500	0	0	0
Seriola dumerili	0	0	0	0	1	0	0
CHAETODONTIDAE							
Chaetodon kleinii	23	55	51	25	8	57	42
Chaetodon lunula	0	0	0	0	0	2	4
Chaetodon miliaris	4	3	67	4	4	0	6
Chaetodon multicinctus	0	2	2	0	0	0	0
Chaetodon ornatissimus	0	2	0	0	0	0	0
Forcipiger flavissimus	3	0	0	0	0	0	0
Heniochus diphreutes	0	0	1	0	0	0	0
CIRRHITIDAE							
Paracirrhites arcatus	3	3	2	4	4	0	0
FISTULARIDAE							
Fistularia commersonii	0	0	1	0	0	0	0
HOLOCENTRIDAE							
Myripristis amaena	0	0	0	0	4	0	0
Neoniphon sammara	0	1	0	0	0	0	0
Sargocentron xantherythrum	0	0	0	0	9	0	0
LABRIDAE							
Bodianus albotaeniatus	0	0	2	0	0	0	0
Halichoeres ornatissimus	0	0	0	1	0	0	0
Pseudocheilinus octotaenia	1	2	5	1	1	4	0

Table 3—*Continued.*

Taxon	No. of Individuals						
	2004	2005	2006	2007	2008	2009	2010
Pseudojuloides cerasinus	2	1	9	5	9	24	0
Stethojulis balteata	2	2	9	0	0	0	0
Thalassoma duperrey	4	13	17	3	7	59	4
LUTJANIDAE							
Lutjanus kasmira	0	3	0	0	0	0	0
MONACANTHIDAE							
Cantherhines dumerilii	1	0	0	0	0	0	0
MULLIDAE							
Parupeneus multifasciatus	3	16	19	5	0	28	49
Parupeneus pleurostigma	0	6	14	0	1	4	0
POMACANTHIDAE							
Centropyge potteri	0	2	1	0	0	0	0
POMACENTRIDAE							
Chromis agilis	6	7	23	61	0	14	16
Chromis hanui	0	30	9	23	0	12	9
Chromis ovalis	0	0	0	0	0	25	0
Chromis vanderbilti	12	0	0	0	0	0	0
Plectroglyphidodon johnstonianus	0	0	0	0	0	4	0
SCARIDAE							
Scarus rubroviolaceus	0	0	0	0	4	0	0
SERRANIDAE							
Cephalopholis argus	0	3	0	0	0	0	1
TETRAODONTIDAE							
Canthigaster coronata	0	3	1	1	0	1	0
Canthigaster jactator	4	4	2	2	1	3	0
Total No. of Individuals	135	281	472	818	166	599	338
Total No. of Species	23	31	27	26	19	23	18

Table 4. Fish abundance (no./transect) at station WW, Wai‘anae Ocean Outfall, O‘ahu, Hawai‘i, for the years 2004 through 2010.

Taxon	No. of Individuals													
	Transect Alpha							Transect Beta						
	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
ACANTHURIDAE														
Acanthurus dussumieri	0	0	1	0	0	0	2	0	0	0	0	0	0	0
Acanthurus leucopareius	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Acanthurus nigrofuscus	0	0	0	0	0	0	0	18	20	0	15	23	12	36
Acanthurus olivaceus	0	0	0	0	0	1	1	11	29	16	4	2	68	81
Acanthurus triostegus	0	0	0	0	0	0	0	0	0	0	2	1	0	21
Ctenochaetus strigosus	0	0	0	0	1	0	0	29	1	29	83	48	23	4
Naso brevirostris	0	0	0	0	0	4	0	0	0	0	0	1	0	9
Naso hexacanthus	0	0	0	0	0	0	0	0	0	0	10	0	0	25
Naso lituratus	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Naso unicornis	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Zanclus cornutus	0	0	0	0	0	0	0	2	0	0	3	0	2	0
Zebrasoma flavescens	0	0	0	0	0	0	0	4	0	6	4	0	0	0
APOGONIDAE														
Pristiapogon kallopterus	0	0	0	0	0	0	0	0	0	0	0	9	0	0
AULOSTOMIDAE														
Aulostomus chinensis	0	0	0	0	0	0	0	4	3	2	6	2	2	2
BALISTIDAE														
Cantherhines dumerili	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Melichthys niger	0	0	0	0	0	0	0	0	5	2	0	16	0	0
Melichthys vidua	0	0	0	0	0	0	0	2	3	0	2	2	2	2
Rhinecanthus rectangulus	2	0	2	3	0	2	1	0	0	0	0	0	0	0
Sufflamen bursa	1	0	0	0	0	1	1	1	4	4	4	4	3	3
Sufflamen fraenatum	0	0	0	0	0	0	0	0	0	0	0	0	1	2
BLENNIIDAE														
Exallias brevis	0	0	0	0	1	0	0	0	0	0	1	0	0	0
Plagiotremus ewaensis	0	1	1	0	1	0	0	0	0	0	0	0	0	0
CHAETODONTIDAE														
Chaetodon auriga	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Chaetodon fremblii	0	0	0	0	0	0	0	0	1	1	2	5	3	1
Chaetodon miliaris	0	0	0	0	0	0	0	3	2	36	17	24	19	12
Chaetodon multicinctus	0	0	0	0	0	0	0	0	2	2	2	1	0	2
Chaetodon ornatissimus	0	0	0	0	0	0	0	0	0	0	2	5	0	2
Chaetodon quadrimaculatus	0	0	0	0	0	0	0	0	0	0	3	0	2	0
Forcipiger flavissimus	0	0	0	0	0	0	0	0	1	4	0	10	4	0
CIRRHITIDAE														
Cirrhitops fasciatus	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Cirrhitus pinnulatus	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Paracirrhites arcatus	0	0	0	0	1	0	2	0	9	0	0	1	0	2
Paracirrhites forsteri	0	0	0	1	0	0	0	1	3	1	1	1	0	2
FISTULARIIDAE														
Fistularia commersonii	0	0	0	0	0	0	0	0	0	0	1	0	0	0
GOBIIDAE														
Bathygobius cocosensis	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Gnatholopsis anjerensis	0	0	0	0	0	0	1	0	0	0	0	0	0	0
HOLOCENTRIDAE														
Myripristis amaena	0	0	0	0	0	0	0	100	114	30	132	65	21	56
Neoniphon sammara	0	0	0	0	0	0	0	1	0	0	1	0	3	0
Sargocentron diadema	0	0	0	0	0	0	0	9	0	17	0	0	0	0
Sargocentron tiere	0	0	0	0	0	0	0	0	0	0	3	1	0	10
Sargocentron xantherythrum	0	0	0	0	0	0	0	0	0	0	0	0	9	0

Table 4—*Continued.*

Taxon	No. of Individuals													
	Transect Alpha							Transect Beta						
	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
LABRIDAE														
Anampses chrysocephalus	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Bodianus albotaeniatus	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Cheilio inermis	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Coris gaimard	0	0	0	0	0	0	0	0	1	0	0	1	1	1
Coris venusta	0	2	7	0	3	2	2	0	0	0	0	0	0	0
Gomphosus varius	0	0	0	0	0	0	0	0	0	0	2	1	1	1
Halichoeres ornatissimus	0	0	0	0	0	0	0	1	3	2	1	1	7	2
Labroides phthirophagus	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Oxycheilinus bimaculatus	1	14	9	7	1	0	7	0	0	0	0	0	0	0
Pseudocheilinus octotaenia	0	0	0	0	1	0	0	0	1	0	0	0	0	1
Pseudojuloides cerasinus	0	0	0	0	0	5	1	0	0	0	0	0	0	0
Stethojulis balteata	0	4	9	1	4	0	8	0	0	0	3	3	0	0
Thalassoma ballieui	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Thalassoma duperrey	4	26	10	13	14	2	10	8	34	13	13	30	54	29
LETHRINIDAE														
Monotaxis grandoculis	0	0	0	0	0	0	0	24	1	1	8	0	5	11
LUTJANIDAE														
Aphareus furca	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Lutjanus fulvus	0	0	0	0	0	0	0	0	4	1	0	0	0	1
Lutjanus kasmira	0	0	0	0	0	0	0	200	125	1	48	3	226	0
MONACANTHIDAE														
Aluterus scriptus	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Cantherhines dumerilii	2	0	0	0	1	0	0	2	0	1	1	0	0	0
MULLIDAE														
Mulloidichthys vanicolensis	0	0	0	0	0	0	0	109	46	0	26	0	40	130
Parupeneus bifasciatus	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Parupeneus cyclostomus	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Parupeneus insularis	0	0	7	0	0	0	0	5	0	0	3	0	0	0
Parupeneus multifasciatus	0	0	1	0	0	0	0	0	0	0	1	2	0	15
Parupeneus pleurostigma	0	0	0	0	0	0	0	9	0	5	0	0	0	0
Parupeneus porphyreus	0	0	0	0	1	0	0	0	0	0	1	0	1	1
MURAENIDAE														
Gymnothorax sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0
POMACANTHIDAE														
Centropyge loriculus	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Centropyge potteri	0	0	0	0	0	0	0	2	1	2	2	26	0	2
POMACENTRIDAE														
Abudefduf abdominalis	0	0	0	0	0	0	0	124	202	217	239	210	265	27
Abudefduf vaigiensis	0	0	0	0	0	0	0	0	0	0	0	0	12	55
Chromis hanui	0	0	0	0	0	0	0	9	30	0	0	4	0	6
Chromis ovalis	0	0	0	0	4	0	0	447	135	182	350	143	284	216
Chromis vanderbilti	6	19	28	21	9	6	0	0	0	0	0	0	0	0
Chromis verator	0	0	0	0	0	0	0	23	12	17	12	0	0	21
Dascyllus albisella	0	1	1	0	0	1	1	37	66	105	87	87	125	65
Plectroglyphidodon imparipennis	0	5	3	1	2	0	1	0	0	0	0	0	0	0
Plectroglyphidodon johnstonianus	0	0	1	0	0	0	0	0	0	3	0	0	0	0
Stegastes marginatus	0	0	0	0	0	0	0	14	14	2	24	22	10	11
SCARIDAE														
Scarus sp.	4	0	0	0	0	0	0	1	0	0	2	0	9	0
SERRANIDAE														
Cephalopholis argus	0	0	0	0	0	0	0	3	0	0	0	1	0	0

Table 4—*Continued.*

Taxon	No. of Individuals													
	Transect Alpha							Transect Beta						
	2004	2005	2006	2007	2008	2009	2010	2004	2005	2006	2007	2008	2009	2010
TETRAODONTIDAE														
Canthigaster coronata	1	2	0	2	0	1	0	0	0	0	0	1	0	0
Canthigaster jactator	1	0	0	1	2	3	7	0	0	0	3	6	0	0
Total No. of Individuals	22	74	80	50	47	28	49	1,209	872	704	1,128	764	1,221	878
Total No. of Species	9	9	13	9	16	11	15	33	29	29	44	37	34	42