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HONOLULU GENERATING STATION MARINE BOTTOM BIOLOGICAL COMMUNITIES MONITORING (BBCM) PROJECT

2019

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EXECUTIVE SUMMARY

The National Pollutant Discharge Elimination System (NPDES) permit require the Hawaiian Electric Company, Inc. (HECO) to determine the status of the sessile marine invertebrates, algae and fishes as bioindicators of pollutants in the vicinity of the Honolulu Generating Station (HGS) (Environmental Consultants, Inc. 1976, HECO 1976). The HGS used seawater for cooling purposes and discharged the thermally elevated effluent back into the harbor via two outfalls. This continued from 1920 until 2014 when HECO deactivated the generating units and all cooling water, metal cleaning waste (MCW), and low volume waste (LVW) discharges ceased. Surveys were conducted annually from 1990 through 1995 and biennially thereafter based on the lack of adverse effects from the HGS discharge. Thus far, eighteen surveys, to assess impact to the biota within the designated zone of mixing (ZOM), have been conducted over the 28-year project period. This eighteenth report covers the continued monitoring of the six previously established stations within Honolulu Harbor. Methodological consistency follows the prior surveyor, Brock, (1995-2017) to maintain consistency and comparability across sampling years.

Bottom biological community monitoring (BBCM) surveys began in 1990 when the monitoring design was developed to include two disparate habitats or biotopes within the ZOM. Hard bottom substrate communities include corals, fishes, and particulate feeders (i.e., tunicates, polychaetes, bryozoans) and are predominately found on early limestone reefs, concrete walls, and pier pilings. Corals can act as a bioindicator of pollution or other impacts because they are a long-lived organism that provide an integrated signal of environmental conditions. These primary habitat forming organisms are continually exposed to impacts, have narrow environmental tolerances, and respond predictably to a variety of anthropogenic stressors. Fluctuations in coral cover can be related to bleaching events. Reef corals have a symbiotic relationship with tiny algae, zooxanthellae. The algae supply their coral hosts with the food they need to survive. In return, the algae receive a place to live and nutrients from waste products from the coral. However, this delicate association functions only within a very narrow range of environmental conditions. Under severe stressful, environmental conditions (increases in: sedimentation, nutrients, light, salinity, or temperature) most algae will be expelled, resulting in a bleached colony that can be fatal if this relationship is not rapidly restored. The statewide bleaching event in 2014/15 resulted in a 17.4% decline in coral cover at the Honolulu Harbor hardbottom stations and a statewide average of 36% (Bahr et al. 2017, Kramer et al. 2016, Nielsen 2014). Recovery in Honolulu Harbor was reported in 2017 with a 9.2% increase since 2015. Another less severe statewide bleaching event occurred in late 2019 and may account for some of the loss recorded in the present survey. Fish and benthic community factor values were also lower than the previous year both inside and outside the ZOM. Coral cover and diversity were found to differ significantly between stations located inside and outside the ZOM with higher coral inside the ZOM. Coral and fish assemblages are highly correlated with high fish abundance associated with complex reef systems. Loss of coral cover leads to loss of fish food and shelter.

The dominant habitat within the ZOM is softbottom mud and sand that is mainly comprised of deposit feeders. Species richness and diversity is very low in this habitat and prone to high disturbance from ship traffic. The low spatial relief excludes most species of fishes that prefer higher rugosity provided by corals and other sessile benthic organisms that offer dietary and protective resources. The two softbottom habitats within the ZOM and one softbottom habitat located outside of the ZOM show significant differences in 2019 in the benthic habitat for number of invertebrate species present, number of coral species present, and overall coral cover. In addition to differences in benthic composition, significantly higher abundance and diversity of fishes were recorded at stations within the ZOM as compared to outside the ZOM.

The change in the surveyor, a shift in transect location, and / or coral bleaching with associated fish loss may have contributed to the recorded declines. This survey can serve as a baseline for successive surveys to separate extraneous factors that may lead to decline.

INTRODUCTION

Purpose

A requirement of the National Pollutant Discharge Elimination System (NPDES) to allow the Hawaiian Electric Company, Inc. (HECO) to operate the Honolulu Generating Station (HGS) is to conduct biennial surveys of extant marine benthic communities. Permit conditions were based on concerns of impact to the fish and benthic communities from the elevated temperature discharge and any cleaning agents utilized by the plant. Bottom Biological Communities Monitoring (BBCM) surveys commenced in 1990 and continued annually until 1995. Thereafter, lack of adverse effects from the HGS discharge prompted regulatory agencies to reduce the survey intervals to a biennial schedule. From 1997 through 2019 the Honolulu Generating Station Marine BBCM Project has been conducted and reported every other year.

The deactivation of the HGS and the termination of discharge water occurred in February of 2014. Although discharge operations have ceased, as a requirement of the current National Pollutant Discharge Elimination System (NPDES) permit, biennial surveys of the biological marine communities continue in the receiving waters fronting the HGS and at a similar nearby control area used for comparison. A quantitative environmental assessment of the biological communities and analyses of any spatial or temporal changes was conducted biennially by Richard Brock from 1995 through 2017. Five years have passed since there has been a discharge from the HGS.

The purpose of this study is to 1) define biological parameters to be assessed; 2) carry out quantitative studies of extant communities in the receiving waters (the ZOM) for the HGS to determine if changes are occurring in these communities and 3) report on the findings of the fieldwork (from Brock 2017). Eighteen surveys have been conducted since 1990. This report describes the results of the latest survey conducted on 11 December 2019.

Background

The Honolulu Generating Station (HGS) located at 170 Ala Moana Boulevard, Honolulu, Hawai'i, 96813 began operations in 1920, discharging thermally elevated cooling water through two outfalls into Honolulu Harbor. The HGS intake and discharge basins are separated by Pier 7 that extends 130 m seaward of Aloha Tower Drive. The 60 x 130 m basins are located in the southeast corners of harbor. An ancient reef platform that has been dredged to a depth of 10 m is adjacent to the concrete walls and structures that comprise Pier 7 on the north, south and east sides of the basins. The HGS plant is comprised of two electrical generating units. The station is capable of producing 113-megawatts of electrical energy however, as renewable energy generation became available in the years preceding the deactivation, the facility generally operated well under this capacity.

Sampling Strategy

The sampling strategy for the HGS BBCM was originally designed to address impacts from the discharge of the HGS (Brock 2017). Honolulu Harbor has and continues to be impacted by numerous anthropogenic influences. Thus, the sampling strategy was designed to separate the effects of the HGS from other extraneous anthropogenic impacts as well as natural variability. Stations follow a gradient from the HGS discharge to determine impacts, with distance, from the point-source. Two habitats were selected to encompass the disparate biota in the hard and soft substrate. To separate possible influential impacts from the potential impact of the HGS discharge, a control station at the mouth of the harbor, adjacent to Sand Island, was selected to compare areas of similar habitat within and outside the ZOM.

Geographic Location and Setting

Honolulu Harbor's perimeter and basin is primarily man-made. In the late 1700's, a natural channel carved through the fringing reef, originating at the mouth of Nu'uanu Stream, was extended to mark the first of a series of dredgings that would continue to present times. Successive dredging would increase the area and depth of the harbor and join Kapālama Basin to the main harbor. Kapālama Basin, like Nu'uanu Stream, was originally a natural channel separated from Nu'uanu Stream by an expansive fringing reef that was dredged to between 9 and 12 meters (m) (30 to 39 feet [ft]). To accommodate large ships, a series of bulkheads and piers were constructed. Decreasing depth from sediment deposition from streams and drainage systems requires removal of over 200,000 cubic yards (cu. yds) of mud every 5 years to maintain original depths of 9 to 12 m (30 to 39 ft) within the harbor and 15 m (49 ft) at the east end. The Kalihi Channel to the west was closed when the Sand Island development began. Until its reopening in the 1950s, the eastern Honolulu or Fort Armstrong Channel was the only entrance and exit out of the harbor (U.S. ACOE 1958,1976,1977,1981).

Physiography

Sand Island (Anuenue) was built in several stages to provide protection to Honolulu Harbor from open ocean swells. This low islet was constructed on the south and west sides of the harbor. A shallow reef flat served as the base for dredged spoils deposited during the construction of Honolulu Harbor. Subsequent dredging added material to enlarge the islet on several occasions. Sand Island was joined to Oʻahu by filling the area west of the Kapālama Basin. With the reopening of the Kalihi Ship Channel in Keʻehi Lagoon, Sand Island was again separated from the Oʻahu shoreline (Watson 1933). Construction was completed in the 1940s with the addition of a bridge on the western end of the islet. Sand Island is presently 208 hectares (ha) (514 acres) (Sea Engineering Services 1975).

Reef Structure/Habitat Classification

The outer part of the Honolulu channel along the western margin consists of limestone boulders and rubble to a depth of 6 m (20 ft). The sides of the channel entrance consist of sand and rubble with limestone reef rock outcrops. The bottom of Honolulu Harbor is predominately fine silt and clay. Sediment deposition continues with the input from Kapālama and Nuʻuanu Streams and several drainage ditches.

The biota in Honolulu Harbor is limited. Fouling species are abundant and include: barnacles, bryozoans, hydroids, sponges and worms. On hard substratum and along the Sand Island side of the channel entrance, corals can be found. Many soft bottom invertebrate species inhabit the benthos in the harbor. These include crabs, shrimp, tubeworms and small infaunal organisms. Over 50 species of fishes have been recorded from the harbor. Honolulu Harbor serves as a nursery ground for hammerhead sharks, jacks, mullet, barracuda and goatfish (AECOS 1990).

Oceanographic Conditions

The Honolulu area is sheltered from large North Pacific winter swells and the typical north-east trade wind generated waves. South swells during summer months can produce moderately large swells. Atypical Kona or south storms can also impact the south shore of all islands. Much of the shallow fringing reefs, that once naturally provided protection to the coastline, have been dredged and filled. Protective structures were constructed to stabilize the shoreline. Winds and tides drive the weak nearshore currents. Honolulu Harbor is also typically protected from major storms. Water circulation greatly improved with the reopening of the western Kalihi Channel in the 1950s. Stagnant waters now flush through both the Honolulu or Fort Armstrong Channel and the Kalihi channel. Harbor flushing time or water residency is estimated at approximately 6 hours.

Harbor Use

Honolulu Harbor is the main commercial port for the entire state of Hawaiʻi. It handles over 11 million tons of cargo every year and serves as the primary distribution center for the state. Over 80% of all resources consumed in the state are imported. Of these, 98% are shipped in from locations throughout the world. This deep-draft harbor is lined with commercial piers, light industry, commercial businesses, and the Hawaiʻi Pacific University at Aloha Tower. Recreational cruise ships depart from the harbor. Aloha Tower completed in 1926 has become a

salient landmark in Honolulu. Sand Island is home to a U.S. Coast Guard base, the Anuenue Fisheries Research Center, the Sand Island Wastewater Treatment Plant, Sand Island State Park, the University of Hawai'i's Snug Harbor and several industrial facilities. Recreational pole and line fishing activity occurs throughout the harbor. Fishing efforts are concentrated at the entrance channels, piers, and Sand Island State Park. Crabbing and pole-fishing are common on piers and docks throughout the area (Jokiel et al. 2004).

Water Quality

Water clarity in the harbor is generally poor, ranging from less than a half meter when vessel traffic is heavy to about 10 m (33 ft). The water quality in Honolulu Harbor does not meet national water quality standards. The State of Hawai'i's Department of Health included Honolulu Harbor on the list of impaired waters under section 303 (d) of the Clean Water Act. Elevated levels of pollutants, nutrients, pathogens, heavy metals, sediment, enterococci, and chlorophyll-*a* have been reported. One of the most severe of the three fish kills documented, occurred in 2013 when 1,400 tons of molasses spilled into Honolulu Harbor suffocating thousands of fishes and killing benthic marine organisms. The State's Dept. of Health (DOH) and the Environmental Protection Agency (EPA) have combined efforts for cleanup assessment and implementation. Pollutants have been recorded within the harbor as early as 1920. The main source of these pollutants is in sediments from maintenance dredging, waterfront construction and ship traffic. Benthic sediments contain high concentrations of heavy metals. Stream and point source discharges originate from streams, drainage ditches and storm drains. Agricultural, residential, industrial and urban runoff all contribute to these sources (ie. sewage, nutrients). Process water and wash water with its associated pollutants from upstream, discharge into the harbor. Current regulations prohibit release of petroleum products into the harbor and the streams that feed into it. However, pipeline and storage tank leaks along with oil from drains and sewers are still contributing to the pollution problems in Honolulu Harbor. These sub-surface oil plumes are influenced by tides, storms, groundwater fluctuations and physical barriers (Jokiel et al. 2004).

Salinity at depth is comparable to seawater (23-34 ppt), while freshwater input from streams, storm drains, and rainfall can lower surface salinities by one-third. Nu'uanu Stream alone flushes 5 million gallons a day into the harbor (Jokiel et al. 2004).

Invasive Species

Numerous foreign and domestic deep draft ships enter Honolulu Harbor. Ballast water from ships can be host to alien species that can spread rapidly and compete with native species for resources. Discharged ballast water can introduce algae, invertebrates and other organisms along with viruses and bacteria that can become established and seriously affect native species. Hulls of ships can also carry marine aliens to distant ports and fishing vessels can carry live marine species not native to the state. In response to these concerns, the National Invasive Species Act of 1996 was enacted in attempt to control and regulate the spread of nuisance species. The

Hawaiʻi Alien Aquatic Taskforce was subsequently founded in 1997 to identify the potential threats to coastal waters from introduced species. A deep-water ballast exchange program has reduced the spread of these nuisance species. Currently, 287 non-native marine invertebrate species have been identified statewide. This is equivalent to 7% of the known species of invertebrates (4099 documented). Most invertebrate introductions are a result of hull fouling and / or solid ballast or ballast water dumpings. Most of these introductions have become well established (87%, 248 sp.) The overwhelming majority of these alien species arrive from the Indo Pacific/Philippines and the tropical western Atlantic/Caribbean regions (Coles and Eldridge 2002, Godwin et al. 2006).

Historical/Cultural Importance

Honolulu Harbor has been responsible for much of the economic growth in the State. As the port of entry for nearly all imported goods it has historically served as the major harbor since the late 1700's. The Hawaiian name for Honolulu Harbor is "Ke Awa O Kou," the harbor of Kou. The first western use of the harbor was documented in 1794. At this time, the harbor was 200 ft wide, ¾ mile long, and 30 ft deep. Fur traders took on supplies and wintered their ships here. Beginning in 1819, whaling vessels repaired, refitted and supplied ships. At this time the population in the surrounding area was between 3,000 and 4,000. Whaling activity ceased after about 40 years of intense activity due to the discovery of petroleum. Shortly thereafter in 1850, King Kamehameha III established Honolulu as the capital city of Hawaiʻi. The activity at Honolulu Harbor was responsible for the development and expansion of the surrounding area. Commerce and tourism were severely disrupted when steamer service was re-routed to the Atlantic Coast during World War II. With the end of the war came a resurgence of economic activity and Kewalo Basin (55 acres) was created in 1920 to alleviate some of the congestion in Honolulu Harbor (Watson 1933).

METHODOLOGY

Survey Stations

The sampling design was developed in 1990 to encompass the major communities within the study area. This was determined through short reconnaissance dives to assure continuity within the biotopes. Exact locations were selected as representative of the larger area and to include a gradient from the discharge (Brock 2017). Station selection criteria was primarily based on coverage of the two major biotopes, the habitats associated with different ecological communities. For this eighteenth survey, the six previously established stations continue to be monitored. The habitat containing corals and filter feeders includes walls, piers, pilings, and other hard substrate (Stations 1, 3 and 5). The dominant soft bottom habitat located on the harbor floor is comprised mainly of deposit feeders (Stations 2, 4 and 6). To determine any impacts from the discharge, both biotopes were included in the surveys (Brock 1991-2017). Stations 1-4 are within the ZOM. A brief description of each of the six stations are presented below; locations are shown on Figure 1:

Station 1 is adjacent to the Aloha Tower wall between Piers 6 & 7 where the previously operating discharge from the HGS is located at a depth of 1.2 - 3 m. The intake structure is located between piers 7 & 8 just in front of the current berth of the sailing ship, Falls of Clyde.
Station 2 is established 25 m seaward of the discharge, parallel to Station 1 at 8 m depth.
Station 3 is located at the end of Pier 7 approximately 155 m seaward of Station 1 at 2.5 - 4 m depth.
Station 4 is located approximately 175 m seaward of the HGS and parallel to Station 3 at a depth of 4.7 – 7.5 m. Stations 5 and 6 are the control stations and located outside the ZOM near Honolulu Harbor’s Channel Marker No. 7 on the west side of the entrance to the harbor adjacent to Sand Island Beach Park.
Station 5 is located 760 m seaward of the HGS discharge in 1.4 - 3 m of water. Station 5 serves as the control site for Stations 1 and 3 located within the ZOM and selected for the similar coral and particulate feeder habitat.
Station 6 is located at 8.5 m depth, parallel to Station 5. Station 6 was selected as the control site for Stations 2 and 4 within the ZOM and chosen for soft bottom habitat similarity.

Control sites are selected to represent an area outside the zone of impact that is not affected by activity or discharge. These control sites ideally are highly similar in all aspects of the environment with the exception of the disturbance of interest. Control sites are typically used for compliance and regulation assessments. However, the selection of a control site is subjective. No two areas are identical since numerous factors are involved. There can be high heterogeneity and spatial and temporal variability that prevent fine scale discrimination. Nevertheless, a control site can be an accurate reference of change when monitored over a long period of time as in this case. The statistical power to detect differences increases over time due to an increase in the sample size. As you increase power, you increase the chances that you will detect an effect if it exists. More samples (more years) allow for both large and small effect sizes, regardless of the variability in the data, due to an increase in information.

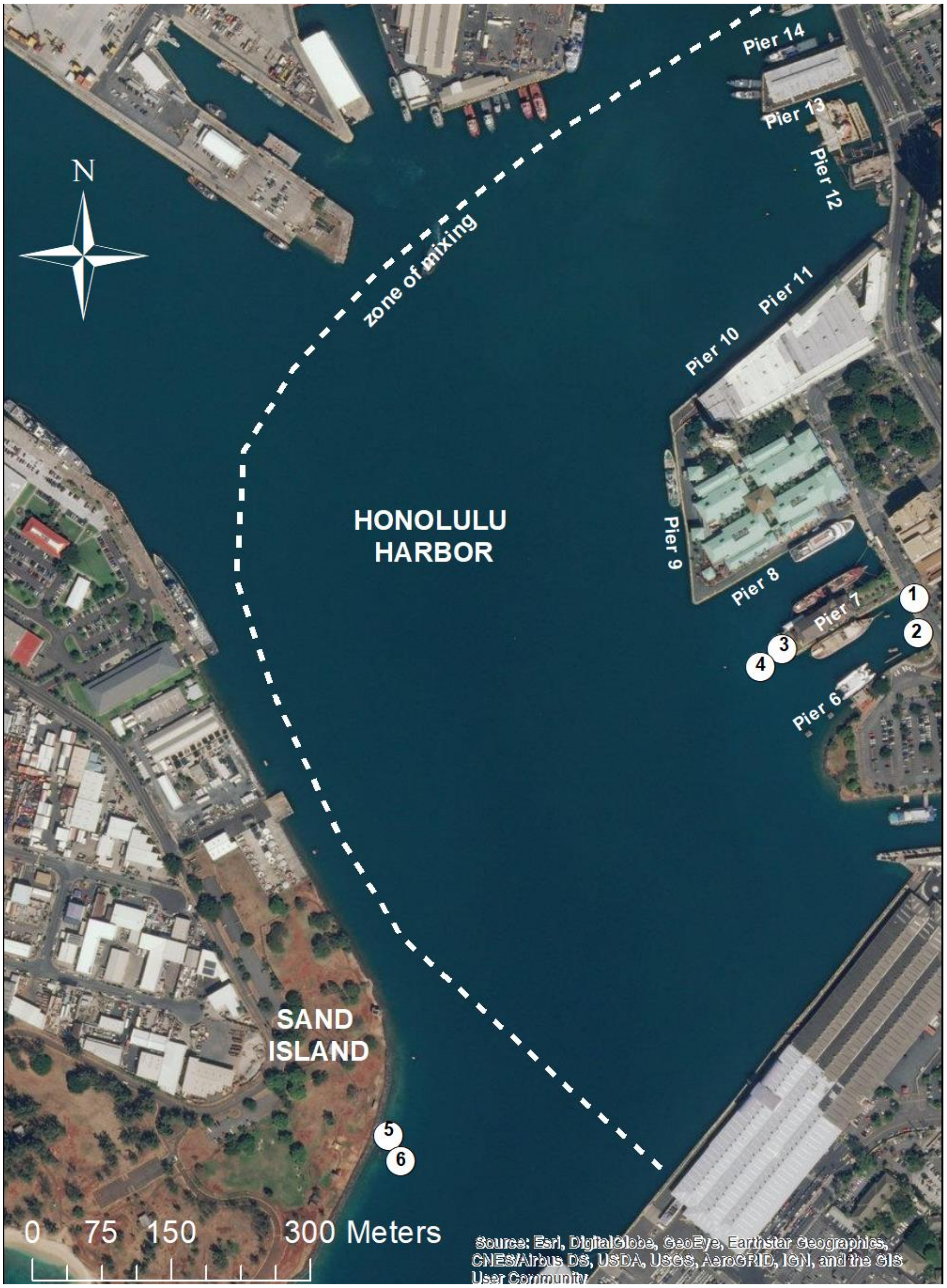

Figure 1. Map of Honolulu Harbor located on O'ahu, Hawai'i depicting the zone of mixing, locations of monitoring stations, and the Sand Island control site stations.

Survey Methodology

This report includes the results of the December 11, 2019 surveys with comparisons to the previous 17 surveys. A change in the surveyor occurred in 2019; however, the experience level of the past and present surveyor is comparable, and all methodology remains consistent throughout the fish and benthic surveys detailed below. Digital images and/or collections are taken of unidentifiable species for later identification.

1) *Fish Surveys*

The four transect stations located within the ZOM in Honolulu Harbor and two control stations located outside the ZOM are surveyed biennially for fish species, biomass, and abundance (Fig. 1). The station locations are determined through salient markers to within several meters. The exact start location has been permanently marked with either a cinder block, a prominent geologic feature, and/or surface landmarks. The bearing direction of the transect was initially predetermined and continued throughout the project. At each station, fish surveys are conducted to quantify any spatial or temporal changes in the fish communities within and between stations.

A modified visual transect (line/belt/strip) (Brock 1954) (species abundance methodology) is deployed to quantify fish communities. The fish surveyor spools out the 25 m transect line while recording, species, size [total length (TL) in centimeter(cm)] and the number of individual fishes to 2 m on each side of the transect line (4 m width). The three commonly used measures of fishes are standard length (excludes the caudal fin), total length (from tip of snout to tail tip), and fork length (from tip of snout to deepest notch of the tailfin). Spooling the line as you survey eliminates changes in fish behavior and allows fishes to equilibrate from previous activity. The surveyor records on a slate equipped with underwater writing paper with the use of self-contained underwater breathing apparatus (SCUBA). All fishes within the linear 100 m^2 transect from the benthos to the surface are recorded. A transect length of 25 m was selected to assure only a single habitat type was included (Brock 2017). Error can increase with surveyor inexperience, changes in visibility, or observations between surveyors. To reduce error, another highly experienced surveyor was selected to replace the previous surveyor and methodological consistency was maintained. Visibility is recorded at each station to statistically determine its effect on fish counts.

Biomass estimates are derived through total length, estimated to the nearest cm in the field and converted to biomass estimates (tons/hectare) using length-weight fitting parameters. In estimating fish biomass from underwater length observations, most fitting parameters are obtained from the Hawai'i Cooperative Fishery Research Unit (HCFRU), which is consistent with previous analyses. Additionally, locally unavailable fitting parameters are obtained from Fishbase (www.fishbase.org) whose length-weight relationship is derived from over 1,000 references. Congeners of similar shape within certain genera are used in those rare cases lacking information. Conversions between recorded total length (TL) and other length types (e.g. fork length FL) contained in databases involve the use of linear regressions and ratios from Fishbase, linking length types. A predictive linear regression of logM vs. logL is used in most cases to estimate the fitting parameters of the length-weight relationship. Visual length estimates are converted to weight using the formula M = a . Lb where M=mass in grams, L=standard length in millimeters (mm), and a and b are fitting parameters. Any anomalous values are detected by calculating a rough estimate for a given body type. The general trend for a 10 centimeter (cm) fish of the common fusiform shape should be approximately 10 grams (g). Any gross deviations are replaced with values from the alternate source.

2) *Benthic Surveys*
To assure a comprehensive assessment of the biological benthic communities, three methodologies are employed. This ensures representation of the diversity and richness of smaller organisms that may otherwise be overlooked.

a) Macro Invertebrate Survey: An assessment of all diurnal, exposed macroinvertebrates, with the exception of corals, is conducted along the same transect laid out for fishes. Invertebrates less than 2 cm are surveyed within the 100-square meters (m^2) footprint that fishes are censused. Invertebrates are identified to the lowest taxon possible. Enumerating only exposed organisms eliminates habitat disturbance that can greatly reduce visibility in soft bottom habitats.

b) *Corals, Sponges, and Macroalgal Survey*: A quantitative quadrat methodology is used to sample dominant corals, sponges, and macroalgae along the previously laid transect line. A stringed 1 m^2 quadrat with 10 by 10 square centimeter (cm^2) partitions to aid in percent cover determinations, is positioned at 0, 5, 10, 15, 20, and 25 m along the 25 m transect. Species and/or substrate type is recorded as percent cover. Small (less than 2 cm) or cryptic organisms and turf algae are not included in the survey to remain consistent with previous surveys.

c) *Point-Intercept Method*: Benthic organisms and substrate are recorded to the lowest taxonomic level possible, every half meter along the 25 m transect line previously deployed for fishes. The number of points for each organism or substratum is then divided by the total number of points and multiplied by 100 to obtain a percent. Percent cover is the estimate of the area a species or substrate covers in an area. For example, if a coral species is present on 10 of the 50 points surveyed, the percent cover is 20% (10 coral points ÷ 50 total points = 0.2 x 100 = 20%).

Statistical Methods
Non-parametric independent-samples Kruskal-Wallis Tests were utilized to determine if control stations were significantly different from their paired stations located within the ZOM. Pairwise comparisons were used to further explore the differences within each biotope. A number of parameters were examined for differences throughout the years: fish biomass, number of coral species, number of fish individuals, number of fish species, number of invertebrate species, and

percent coral cover. All statistical explorations and tests were completed using IBM SPSS 64-bit version software.

RESULTS AND DISCUSSION

The Biotope of Corals and Particulate Feeders (Stations 1, 3, 5)

Three stations were surveyed within the biotope of corals and particulate feeders. Station 1 and Station 3 are located within the ZOM, while Station 5 is located outside of the ZOM. These three stations were originally (established in 1990) restricted to areas of hard substratum, comprised of natural limestone substratum or man-made pier pilings and vertical concrete walls. Man-made substratum is the dominant hard surface at Stations 1 and 3 within the ZOM. However, a layer of mud and sand covers much of hard substrate at Stations 1 and 5.

Station 1

Three sponge and one coral species were documented in quadrat surveys at Station 1 (Table 1). Coverage of sponges increased from 0.6% in 2017, to a mean coverage of 3.5% in 2019. Sponge species observed within quadrats in 2019 were *Liosina paradoxa* (1.7%), *Plakortis simplex* (1.5%), and *Lotochota protea* (0.3%), all of which differed from sponge species observed in 2017 (*Mycale armata*, *Halichondria dura*, *Suberites zeteki*). Since the 2017 survey with an estimated overall coral coverage of 48.5%, the mean coral coverage has decreased to 1.3%, a 97.3% decline. Coral species diversity has also decreased from seven species present in 2017 to one species, *Montipora capitata*, present in 2019. Mud and sand covering the hard substratum comprised the majority of benthic coverage at this site (93.5%) with little visible coverage of hard substratum (1.7%).

Solitary macroinvertebrates encountered in the 4 x 25 m census area include the soldier cone (*Conus miles*), banded coral shrimp (*Stenopus hispidus*) and six species of urchins (slate pencil urchin (*Heterocentrotus mammilatus*), long-spined urchin (*Diadema paucispinum*), pale rock-boring urchin (*Echinometra mathaei*), blue-black urchin (*Echinothrix diadema*), banded urchin (*Echinothrix calamaris*), and collector urchin (*Tripneustes gratilla*). The collector (100 individuals) and blue-black urchin (90 individuals) dominate the invertebrate population at Station 1. Ten species of fishes (37 individuals) were noted in the 100 m^2 survey area (Appendix A). The standing crop of fishes at Station 1 was estimated to be 18 grams per square meter (g/m^2) compared to 29 g/m^2 in 2017. Species contributing heavily to the biomass include the Hawaiian dascyllus (*'alo'ilo'i*) (*Dascyllus albisella*) (23%), yellow tang (*lau'īpala*) (*Zebrasoma flavenscens*) (21.7%), and moorish idol (*kihikihi*) (*Zanclus cornutus*) (15.5%).

Station 3

Benthic surveys conducted at Station 3 noted three coral species (*M. capitata* (0.7%), *Pocillopora meandrina* (0.3%), and *Porites lobata* (0.16%) (Table 2). Total coral cover is quantified at 1.2%. Coral coverage at this site has decreased 7.4% from the last survey with two fewer coral species reported (not present *Pocillopora damicornis* and *Montipora patula*) This equates to an 83.8% decline in coral cover. No algae or sponge species were observed during the 2019 surveys. Rubble comprised the majority (42.8%) of substrate cover at this site, followed by mud and sand (30.5%) and hard substratum (25.5%)

Invertebrates encountered include one species of oyster, the Hawaiian pearl oyster (*Pinctada galtoffi* formally *P. margaritifera*), and three species of urchins, the pale rock-boring urchin (*E. mathaei*), the banded urchin (*E. calamaris*) and the collector urchin (*T. gratilla*) (Table 3). The collector urchin dominateds the invertebrate census with 68 individuals while the banded urchin had 6 individuals and the pale rock-boring urchin had 3 individuals. A single Hawaiian pearl oyster was present. In the previous census, two species of oysters, two species of polychaetes and six species of urchin were present. Thirteen species of fishes (45 individuals) were noted in the 100 m^2 survey area (Appendix A). The most common fish in the 2017 census was identical to 2019, the Hawaiian dascyllus (*'alo'ilo'i*) (*D. albisella*) comprising 39% of the standing crop. The yellow tang (*lau'īpala*) (*Z. flavescens*) also greatly contributes to biomass with 20% of the standing crop. The estimated total biomass in the 2019 survey for Station 3 was 27 g/m^2 (151 g/m^2 less than estimated biomass in the 2017 survey). The main difference between years are large schools of over 200 *Abudefduf adominalus*, the Hawaiian Sargent (*mamo*) and nearly 50 *Acanthurus nigrofuscus*, the brown surgeonfish (*ma'i'i'i*) not occurring in 2019.

Station 5 (control)

Quadrat surveys at Station 5 located outside of the zone of mixing noted one sponge species (*Microciona maunaloa* (0.16%)) and two coral species (*Porites compressa* (0.16%) and *M. capitata* (0.16%)) (Table 3). Mean coral cover is estimated at 0.33% (a 78% decrease from the 2017 survey). Benthic coverage of sponges also decreased from the 2017 surveys from 1.5% to 0.16% in 2019. Substratum was dominated by mud and sand (71.7%) with some hard substratum (21%) and rubble (6.8%).

The invertebrate census for Station 5 noted three species of sea cucumbers (paradoxical sea cucumber (*Bohadschia paradoxa*), brown sea cucumber (*Bohadschia vitiensis*) and the black sea cucumber (*Holothuria atra*)) and three species of urchins (pale rock-boring urchin (*E. mathaei*), the banded urchin (*E. calamaris*) and the collector urchin (*T. gratilla*)) (Table 3). The collector urchin is the dominant invertebrate with 25 individuals, followed by the pale rock-boring urchin with 10 individuals. The same invertebrate species were dominant in the 2017 survey, but they occurred in greater abundance and there was higher diversity of invertebrates present at Station 5 in 2017 (one polychaete, one shrimp, one crab, two sea cucumber species and seven species of urchins). In 2019, three species of fishes (5 individuals) were documented: the Moorish idol (*kihikihi*) (*Zanclus cornutus*), the slender lizardfish (*Saurida gracillis*) and the saddle wrasse (*hinalea lauwili*) (*Thalassoma duperrey*) (Appendix A). The Moorish idol (*kihikihi*) made up 91% of the standing crop with the saddle wrasse comprising 8%, followed by the lizardfish (1%). The estimated biomass for Station 5 is 1.9 g/m^2. In the 2017 census, twelve species (143 individuals) of fishes were present and the estimated biomass was 269 g/m^2. The most common fish in the

2017 census were the yellowstriped goatfish (*weke*) (*Mulloidichthys flavolineatus*), the yellowfin goatfish (*weke'ula*) (*Mulloidichthys vanicolensis*) and the brown surgeonfish (*ma'i'i'i*) (*Acanthurus nigrofuscus*), none of which were present in the 2019 fish transect at Station 5.

Summary of Biotope of Corals and Particulate Feeders

The number of invertebrate species, number of coral species, coral cover, number of fish species, number of fish individuals and fish biomass were compared between stations over the 18 survey dates. Fish abundance, fish biomass, fish species diversity, and number of invertebrates were not found to differ between stations within this biotope. Station 1 had significantly higher coral cover and diversity when compared to both Station 3 ($p<0.001$, $p = 0.002$) and Station 5 ($p<0.001$, $p<0.001$). Coral cover was also significantly greater at Station 3 when compared to Station 5 ($p = 0.024$). Station 5, the control for this biotope, did not have similar coral cover or number of coral species as Stations 1 and 3 within the ZOM.

The Biotope of Deposit Feeders (Stations 2, 4, 6)

This biotope is dominated by mud and sand substratum and due to the shifting nature of these soft particulates, very little hard substrate is encountered. Three stations were surveyed in the biotope of deposit feeders, two within the ZOM (Station 2 and Station 4) and one outside of the ZOM (Station 6). The substrate is dominated by urchins and sea cucumbers.

Station 2

Quadrat surveys found no invertebrate species present at Station 2. The substratum consists of 98% mud and sand with 2% hard substratum (Table 4). Benthic coverage is consistent to that observed in 2017 (100% sand/mud). Only the algae, *Halophila decipiens* was reported in 2017. Benthic surveys report four species of urchins found within the 100 m^2 transect area: the long-spined urchin (*Diadema paucispinum*), the blue-black urchin (*E. diadema*), the slate pencil urchin (*H. mamillatus*) and the collector urchin (*T. gratilla*). The collector urchin was the dominant invertebrate at Station 2 with 25 individuals, followed by the blue-black urchin with 8 individuals, the slate pencil urchin with 4 individuals and the long-spined urchin with 1 individual. In the 2017 survey, no urchins were present, but one species of polychaete and two species of crabs were noted. The fish census documented two species of fishes (3 individuals). The estimated biomass at this site was 6 g/m^2. The bandtail goatfish, (*weke pueo*) *Upeneus taeniopterus*, 1 individual, 73% standing crop) and the Hawaiian dascyllus (*'alo'ilo'i*) (*D. albisella*, 2 individuals, 27% standing crop) made up the biomass of fishes present along Station 2. In 2017, there was only one individual (*Upeneus taeniopterus*) present along the Station 2 transect (5 g/m^2).

Station 4

Benthic surveys conducted at Station 4 within the deposit feeders biotope noted one species of seagrass (*Halophila sp.* (1%)) and one species of sponge (*Liosina paradoxa* (0.17%)) (Table 5).

Similar to Station 2, Station 4 consists of 97.7% mud and sand substratum with some rubble (0.5%) and hard substratum (0.67%).

Invertebrate surveys note one olive-green cone snail (*Conus lividus*), four feather duster worms (*Sabellastarte spectabilis*) and 2000 snapping shrimp as estimated from holes (*Alpheus spp.*) (Table 5). In the previous survey, a polychaete and swimming crab were recorded, along with several (1/0.1 m^2) unidentified and unenumerated Goby-Shrimp holes (about ½ m^2). The fish census in 2017 only recorded one species of one individual fish, the Flowery Flounder (*Bothus mancus*) (*paki'i*). In the 2019 fish census, four species of fishes (33 individuals) were present which compose an estimated biomass of 47 g/m^2 as compared to 0.2 g/m^2 in 2017 (Brock 2017). Fish species in 2019 include the Hawaiian dascyllus (*'alo'ilo'i*) (*D. albisella*), the yellowstripe goatfish (*weke*) (*M. flavolineatus*), the saddle wrasse (*hinalea lauwili*) (*T. duperrey*) and the yellowfin surgeonfish (*pualu*) (*Acanthurus xanthopterus*). The yellowstripe goatfish, *weke*, made up 63% of the standing crop at Station 4, followed by the Hawaiian dascyllus, *'alo'ilo'i* (20%), the yellowfin surgeonfish, *pualu* (16%) and the saddle wrasse, *hinalea lauwili* (1%).

Station 6 (control)
Located outside of the ZOM, quadrat surveys at Station 6 found two species of sponges (*Microciona maunaloa* (0.17%) and *Chondrosia chucalla* (2%)) (Table 6). Benthic substratum at Station 6 differs from Stations 2 and 4, containing 18% rubble and 80% mud and sand (an increase in rubble of 17% from 2017).

Station 6 has low diversity with high abundance of a single invertebrate species and a single fish species (Table 6). Snapping shrimp (600 individuals), *Alpheus spp.*, are the dominant invertebrate within the 100 m^2 area. In the 2017 invertebrate survey, the report also noted tube worms, one crab species, and one sea cucumber. No fishes were present along Station 6 transect. In 2017, only two fishes were present along the transect with an estimated biomass of 1 g/m^2 from one individual Sharpback puffer (*Canthigaster jactator*) and one individual Lei triggerfish, *humuhumu lei* (*Sufflamen bursa*).

Summary of Biotope of Deposit Feeders
Number of invertebrates ($p = 0.037$), coral ($p = 0.044$) and fish species ($p = 0.014$), coral cover ($p = 0.044$), fish abundance ($p = 0.023$) and biomass were compared between Stations 2, 4, and 6 within the biotope of deposit feeders. All except for fish biomass were found to significantly differ between stations. Pairwise comparisons found Station 6, the control for this biotope, to have significantly less invertebrate species ($p = 0.035$), fish species ($p = 0.021$) and total number of fish present along the transect ($p = 0.035$) (Table 7).

SUMMARY
From the survey performed in 2017 to the present 2019 survey, the average number of invertebrate species across all transects has decreased (7, 4 respectively). Declines were also

found in the number of coral species (3,1), benthic coverage of coral (9.7%, 0.8%) and overall biomass of fishes (80 g/m^2, 19 g/m^2) (Table 8). This pattern is consistent between stations located within the ZOM and those located at control sites outside the ZOM. Coral cover and diversity at all three stations located in the biotope of corals and particulate feeders has decreased within the past two years (Table 8). All stations in both biotopes have decreased in the number of invertebrate species present within the 100 m^2 transect area. Fish biomass (g/m^2) and number of individuals appears to fluctuate greatly from year-to-year. Despite normal fluctuations, it is worth noting that decreases in biomass were seen in all stations across both biotopes, with the exception of Station 4 which was found to be significantly greater than the control Station 6 (fish number, $p = 0.035$). There is high temporal variability over the course of surveys. When examining mean values for each transect across all years both inside and outside the ZOM, all 2019 values are within the range of survey values with the exception of coral species which was lower inside the ZOM in 2019 (Table 9).

These shifts may be due to a number of factors or combination of variables including change in surveyor, a slight shift in the location of a transect, storms, coral bleaching, or water visibility as described below.

- Surveyor variation: A change in surveyors can result in error without careful calibration. However, a highly experienced surveyor familiar with species, sizes, and organismal ecology considerably reduces the error associated with a shift in surveyors. This is unlikely to be a major reason for differences seen between the 2017 and 2019 surveys because both surveyors have comparable knowledge and skill.

- Shift in transect location: In heterogenous habitats (transects 1, 3, 5) the error can be magnified if the transect location is not precise. In homogenous habitats such as sand or mud (transects 2, 4, 6) the margin of error is greatly reduced. This is apparent in previous surveys. The Biotope of Corals and Particulate Feeders on hard substrate with high diversity has greater variability between survey years than the Biotope of Deposit Feeders on soft substrate with few species. A shift in transect position can be remedied in future surveys with more prominent start and end markers.

- Storms/loss of habitat: The northwest storms that generated large storm surf early in 2019 has been documented to have resulted in habitat loss of corals. At Keʻei, on the Island of Hawaiʻi, the reef was reduced to rubble up to 40 feet in depth. The shallow eastern reef flat at Pilaʻa, Kauaʻi saw displacement and extensive breakage of large coral colonies. However, most of the coral species at the shallow Honolulu Harbor stations have strong skeletal strength that can better withstand the forces of wave energy thus having little impact on corals.

- Visibility: Water clarity was fairly good on the 2019 survey however; no mention of visibility is reported from the previous 2017 survey for comparison. Successive surveys will be able to compared fish counts with visibility.

- Coral loss from bleaching: Hawai'i's only bleaching events that resulted in coral mortality occurred in 2014/15 and this past summer (2019). In other bleaching events (1996, 2002), corals recovered quickly. Certain species of fishes are more likely to be missing when coral is not available. Spatial complexity is heavily influenced by coral cover and diversity, which are also found to be highly correlated with fish populations. It is evident that fish populations are highly associated with topographical relief for several reasons.
    - Increased substrate provides habitat for benthic invertebrates, which serve as the main diet of many species of fishes, which in turn are utilized at other trophic levels.
    - Increase in coral cover feed obligate (only eat coral) corallivores.
    - Spatial complexity from coral increases habitat heterogeneity, providing increased areas of refuge for fish populations from predation and competition.
    - Coral can expand the availability of resources and fish production rates.
    - Increased rugosity results in higher heterogeneity, creating habitat complexity that increases fish diversity.

Spatial complexity can be an indicator in determining the distribution of fish size. For optimum protection, fishes select shelter that complement their size, reducing the risk of predation. Size of voids in reef structure are positively correlated to fish numerical and biomass densities. The 2019 bleaching event affected mainly the genus' Pocillopora and Montipora. These are two of the major genera found at the HGS survey sites. Some of the differences found in coral cover and fish communities may be attributed to a loss of coral habitat. However, it is unlikely to completely explain the declines.

Declines in fish and coral community factors since 2017 is likely attributed to a combination of factors described in detail above. Quantifying surveyor differences, visibility, bleaching, delineating precise transect locations, and recording stochastic weather events that may impact the marine benthic environment in successive surveys will assist in defining their influences. Declines found at stations both inside and outside the ZOM rule out any deleterious impacts at any one station. With the cessation of effluent from the HGS in 2014 (facility deactivation), no point source release is currently being discharged. This provides a good opportunity to determine baseline conditions should any future changes occur.

TABLES

TABLE 1. Summary of the benthic survey conducted at Station 1 in the ZOM adjacent to the Hawaiian Electric discharge in Honolulu Harbor in the biotope of corals and particulate feeders on 11 December 2019. Results of the 6 m^2 quadrat sampling of the benthic community (expressed in percent cover) are given in Part A; a 50-point analysis is presented in Part B and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth 1.2 - 3 m; mean coral coverage is 1.3% (quadrat method).

STATION 1

A. Quadrat survey

Species	0m	5m	10m	15m	20m	25m
Sponges						
Plakortis simplex					9	
Iotochota protea						2
Liosina paradoxa			4			6
Corals						
Montipora capitata		2	2	2	2	
Mud/Sand	90	98	94	98	89	92
Hard Substratum	10					

B. 50-Point Analysis

Species	Percent of the Total
Mud/Sand	85
Rubble	2
Hard Substrate	13

C. Invertebrate Census (4 x 25m)

Species	Common Name	Number
Phylum Mollusca		
Conus miles	Soldier Cone Snail	1
Phylum Arthropoda		
Stenopus hispidus	Banded Coral Shrimp	2
Phylum Echinodermata		
Heterocentrotus mammilatus	Slate Pencil Urchin	5
Diadema paucispinum	Long-spinedUrchin	9
Echinometra mathaei	Pale Rock-boring Urchin	18
Echinothrix diadema	Blue-black Urchin	90
Echinothrix calamaris	Banded Urchin	12
Tripneustes gratilla	Collector Urchin	100

D. Fish Census (4 x 25m)

No. of Species	10
No. of Individuals	37

Estimated Biomass (g/m^2)	18

TABLE 2. Summary of the benthic survey conducted at Station 3 in the ZOM approximately 155 m from the Hawaiian Electric discharge in Honolulu Harbor in the biotope of corals and particulate feeders on 11 December 2019. Results of the 6 m^2 quadrat sampling of the benthic community (expressed in percent cover) are given in Part A; a 50-point analysis is presented in Part B and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth 2.5 - 4 m; mean coral coverage is 1.2% (quadrat method).

STATION 3

A. Quadrat survey

Species	0m	5m	10m	15m	20m	25m
Corals						
Montipora capitata		4				
Pocillopora meandrina			1			1
Porites lobata			1			
Mud/Sand	76	3	3	10	84	7
Rubble	2	11	89	86	11	58
Hard Substratum	22	82	6	4	5	34

B. 50-Point Analysis

Species	Percent of the Total
Mud/Sand	31
Rubble	40
Hard Substrate	21
Dead Coral	4
Pocillopora meandrina	2
Porites lobata	2

C. Invertebrate Census (4 x 25m)

Species	Common Name	Number
Phylum Mollusca		
Pinctada galtsoffi	Hawaiian Pearl Oyster	1
Phylum Echinodermata		
Echinometra mathaei	Pale Rock-boring Urchin	3
Echinothrix calamaris	Banded Urchin	6
Tripneustes gratilla	Collector Urchin	68

D. Fish Census (4 x 25m)

No. of Species	13
No. of Individuals	45
Estimated Biomass (g/m^2)	27

TABLE 3. Summary of the benthic survey conducted at Station 5 (control station) approximately 760 m seaward the Hawaiian Electric discharge (outside of the ZOM) in Honolulu Harbor in the biotope of corals and particulate feeders on 11 December 2019. Results of the 6 m^2 quadrat sampling of the benthic community (expressed in percent cover) are given in Part A; a 50-point analysis is presented in Part B and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth 1.4 - 3 m; mean coral coverage is 0.33% (quadrat method).

STATION 5

A. Quadrat survey

Species	0m	5m	10m	15m	20m	25m
Sponges						
Microciona maunaloa					1	
Corals						
Porites compressa			1			
Montipora capitata				1		
Mud/Sand	79	85		87	93	86
Rubble		15	15		5	6
Hard Substratum	21		84	12	1	8

B. 50-Point Analysis

Species	Percent of the Total
Mud/Sand	38
Rubble	47
Hard Substrate	13
Pocillopora meandrina	2

C. Invertebrate Census (4 x 25m)

Species	Common Name	Number
Phylum Echinodermata		
Bohadschia paradoxa	Paradoxical Sea Cucumber	6
Bohadschia vitiensis	Brown Sea Cucumber	2
Holothuria atra	Black Sea Cucumber	1
Echinometra mathaei	Pale Rock-boring Urchin	10
Echinothrix calamaris	Banded Urchin	6
Tripneustes gratilla	Collector Urchin	25

D. Fish Census (4 x 25m)

No. of Species	3
No. of Individuals	5
Estimated Biomass (g/m^2)	2

Table 4. Summary of the benthic survey conducted at Station 2 approximately 25 m from the Hawaiian Electric discharge in the ZOM of Honolulu Harbor in the biotope of deposit feeders on 11 December 2019. Results of the 6 m^2 quadrat sampling of the benthic community (expressed in percent cover) are given in Part A; a 50-point analysis is presented in Part B and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth 8 m; mean coral coverage is zero (quadrat method).

STATION 2

A. Quadrat survey

Species	0m	5m	10m	15m	20m	25m
Mud/Sand	90	100	100	100	100	100
Hard Substratum	10					

B. 50-Point Analysis

Species	Percent of the Total
Mud/Sand	81
Rubble	19

C. Invertebrate Census (4 x 25m)

Species	Common Name	Number
Phylum Echinodermata		
Diadema paucispinum	Long-spined Urchin	1
Echinothrix diadema	Blue-black Urchin	8
Heterocentrotus mamillatus	Slate Pencil Urchin	4
Tripneustes gratilla	Collector Urchin	25

D. Fish Census (4 x 25m)

No. of Species	2
No. of Individuals	3
Estimated Biomass (g/m^2)	6

Table 5. Summary of the benthic survey conducted at Station 4 approximately 175 m from the Hawaiian Electric discharge in the ZOM of Honolulu Harbor in the biotope of deposit feeders on 11 December 2019. Results of the 6 m^2 quadrat sampling of the benthic community (expressed in percent cover) are given in Part A; a 50-point analysis is presented in Part B and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth 4.7 - 7.5 m; mean coral coverage is zero percent (quadrat method).

STATION 4

A. Quadrat survey

Species		0m	5m	10m	15m	20m	25m
Seagrass							
	Halophila sp.						6
Sponges							
	Liosina paradoxa						1
Mud/Sand		99	100	97	100	97	93
Rubble						3	
Hard Substratum		1		3			

B. 50-Point Analysis

Species	Percent of the Total
Mud/Sand	80
Rubble	2
Hard Substrate	10
Halophila sp.	8

C. Invertebrate Census (4 x 25m)

Species		Common Name	Number
Phylum Mollusca			
	Conus lividus	Olive-Green Cone Snail	1
Phylum Annelida			
	Sabellastarte spectabilis	Feather Duster Worm	4
Phylum Arthropoda			
	Alpheus spp.	Snapping Shrimp	2000

D. Fish Census (4 x 25m)

No. of Species	4
No. of Individuals	33
Estimated Biomass (g/m^2)	47

Table 6. Summary of the benthic survey conducted at Station 6 (control station) approximately 760 m seaward of the Hawaiian Electric discharge (outside of the ZOM) in Honolulu Harbor in the biotope of deposit feeders on 11 December 2019. Results of the 6 m^2 quadrat sampling of the benthic community (expressed in percent cover) are given in Part A; a 50-point analysis is presented in Part B and counts of invertebrates in Part C. A short summary of the fish census is given in Part D. Water depth 8-9 m; mean coral coverage is zero (quadrat method).

STATION 6

A. Quadrat survey

Species	0m	5m	10m	15m	20m	25m
Sponges						
Microciona maunaloa		1				
Chondrosia chucalla		11	1			
Mud/Sand	70	15	93	100	100	100
Rubble	30	73	6			

B. 50-Point Analysis

Species	Percent of the Total
Mud/Sand	75
Rubble	25

C. Invertebrate Census (4 x 25m)

Species	Common Name	Number
Phylum Arthropoda		
Alpheus spp.	Snapping Shrimp	600

D. Fish Census (4 x 25m)

No. of Species	0
No. of Individuals	0
Estimated Biomass (g/m^2)	0

TABLE 7. Summary of observations made at the 6 stations sampled in this study at Honolulu Harbor on 11 December 2019. Stations 1, 3 and 5 are in the biotope of corals and particulate feeders and Stations 2, 4 and 6 are in the biotope of deposit feeders. Stations 5 and 6 located outside of the zone of mixing serve as control sites. Number of invertebrate species was documented using two methods, quadrat surveys and point-intercept surveys, as seen in the table below. Presence/absence of invertebrates is listed in Tables 2-7.

<u>1. Biotope of Corals and Particulate Feeders (4 x 25 m)</u>

	Quadrat Survey			Point Intercept			
Station	No. Invert. Species	No. Coral Species	% Coral Cover	No. Invert Species	No. Fish Species	No. Fish Individuals	Fish Biomass (g/m^2)
1	3	1	1.3	8	10	37	18
3	0	3	1.2	4	13	45	27
5 (outside ZOM)	1	2	0.33	6	3	5	2
Within ZOM Means	1.5	2.0	1.3	6.0	11.5	41.0	22.5

<u>2. Biotope of Deposit Feeders (4 x 25 m)</u>

	Quadrat Survey			Point Intercept			
Station	No. Invert. Species	No. Coral Species	% Coral Cover	No. Invert Species	No. Fish Species	No. Fish Individuals	Fish Biomass (g/m^2)
2	0	0	0	4	2	3	6
4	1	0	0	3	4	33	47
6 (outside ZOM)	2	0	0	1	0	0	0
Within ZOM Means	0.5	0.0	0.0	3.5	3.0	18.0	26.5

TABLE 8. Summary of the biological observations for eighteen surveys at six stations located in Honolulu Harbor, O'ahu. At the foot of the table are grand means within the zone of mixing (ZOM) and outside the ZOM for each parameter and year.

No. Invert. Species in 4 x 25 m Area (Years)

Station	90	91	92	93	94	95	97	99	01	03	05	07	09	11	13	15	17	19
1	3	5	5	6	6	10	7	9	11	9	13	12	8	9	9	10	10	8
2	3	1	1	1	0	2	1	0	2	0	0	2	1	2	4	4	3	4
3	4	4	4	7	5	5	7	9	10	8	8	11	6	9	10	10	10	4
4	6	4	3	2	2	2	2	3	2	0	0	4	2	2	5	2	2	3
5	4	4	4	6	5	7	10	8	6	5	8	11	6	8	8	7	12	6
6	2	1	0	0	0	1	1	1	1	0	0	3	1	2	3	4	3	1
Means (in ZOM)	4	3.5	3.25	4	3.25	4.75	4.25	5.25	6.25	4.25	5.25	7.25	4.25	5.5	7	6.5	6.25	4.75
Means (out ZOM)	3	2.5	2	3	2.5	4	5.5	4.5	3.5	2.5	4	7	3.5	5	5.5	5.5	7.5	3.5

No. Coral Species (Years)

Station	90	91	92	93	94	95	97	99	01	03	05	07	09	11	13	15	17	19
1	4	7	7	8	8	9	10	9	8	6	9	6	6	6	7	7	7	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2	2	2	2	2	2	4	4	4	4	4	5	4	4	5	4	5	3
4	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2	2	3	3	3	3	3	3	3	2	4	4	2	3	5	5	3	2
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means (in ZOM)	1.5	2.25	2.75	3	3	2.75	3.5	3.25	3	2.5	3.25	2.75	2.5	2.5	3	2.75	3	1
Means (out ZOM)	1	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	2	2	1	1.5	2.5	2.5	1.5	1

Table 8 cont. (2/3)

Percent Coral Cover (Years)

Station	90	91	92	93	94	95	97	99	01	03	05	07	09	11	13	15	17	19
1	6.8	9.7	18.6	21.5	27.3	22.8	20.3	19.7	20.3	28.2	27.6	25.7	28.1	41.5	56.7	39.3	48.5	1.3
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4.2	3.4	3	3.4	2.9	3.8	2.9	3.2	5.6	1.1	1.1	1.4	3.6	5.7	10.7	6.9	8.6	1.2
4	0	0.6	0.5	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2.6	2.1	2.5	1.4	0.6	0.3	0.7	0.7	0.7	0.3	1.9	1.1	1.1	1	2.9	5	1.3	0.33
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Means (in ZOM)	2.8	3.4	5.5	6.3	7.6	6.7	5.8	5.7	6.5	7.3	7.2	6.8	7.9	11.8	16.9	11.6	14.3	0.6
Means (out ZOM)	1.3	1.1	1.3	0.7	0.3	0.2	0.4	0.4	0.4	0.2	1.0	0.6	0.6	0.5	1.5	2.5	0.7	0.2

Number of Fish Species (Years)

Station	90	91	92	93	94	95	97	99	01	03	05	07	09	11	13	15	17	19
1	10	9	14	19	15	22	26	12	12	22	15	21	19	24	25	17	13	10
2	2	1	2	2	1	1	1	1	1	3	0	2	1	2	1	0	1	2
3	16	11	13	17	12	22	19	14	17	21	14	21	17	18	19	19	15	13
4	3	2	3	4	1	2	2	3	3	1	1	4	2	2	2	1	1	4
5	16	16	20	33	14	21	16	19	16	18	17	11	14	12	19	18	12	3
6	3	5	2	3	1	2	2	1	1	2	2	3	2	2	2	3	2	0
Means (in ZOM)	7.8	5.8	8.0	10.5	7.3	11.8	12.0	7.5	8.3	11.8	7.5	12.0	9.8	11.5	11.8	9.3	7.5	7.3
Means (out ZOM)	9.5	10.5	11.0	18.0	7.5	11.5	9.0	10.0	8.5	10.0	9.5	7.0	8.0	7.0	10.5	10.5	7.0	1.5

Table 8 cont. (3/3)

Number of Fish Individuals (Years)

Station	90	91	92	93	94	95	97	99	01	03	05	07	09	11	13	15	17	19
1	39	25	78	126	132	201	145	88	78	125	132	182	157	246	253	112	70	37
2	9	1	7	9	1	1	1	1	1	4	0	2	1	2	1	0	1	3
3	42	29	101	210	87	209	112	63	207	224	87	161	156	118	289	198	439	45
4	13	12	8	11	1	4	2	7	15	1	1	15	2	2	4	1	1	33
5	42	115	97	230	123	144	77	299	99	293	138	118	68	99	317	248	143	5
6	13	10	8	13	1	2	2	1	2	2	7	8	6	2	4	8	2	0
Means (in ZOM)	26	17	49	89	55	104	65	40	75	89	55	90	79	92	137	78	128	30
Means (out ZOM)	28	63	53	122	62	73	40	150	51	148	73	63	37	51	161	128	73	3

Biomass ($g/m^{2)}$ (Years)

Station	90	91	92	93	94	95	97	99	01	03	05	07	09	11	13	15	17	19
1	25	21	13	17	20	39	39	12	16	45	27	90	93	66	94	38	29	18
2	1	0.1	0.1	1	1	0.3	1	2	0.2	0.3	0	0.2	1	1	2	0	5	6
3	13	4	20	36	10	36	47	12	65	188	24	59	51	41	167	78	178	27
4	0.1	0.3	1	3	0.1	0.1	0.2	1	14	1	1	0.1	0	0.01	0.02	9	0.2	47
5	18	154	34	206	25	90	34	26	33	200	82	282	38	60	216	402	269	2
6	1	2	1	1	0.1	1	1	0.4	1	7	0.2	0.1	0.5	1	1	2	1	0
Means (in ZOM)	10	6	9	14	8	19	22	7	24	59	13	37	36	27	66	31	53	25
Means (out ZOM)	10	78	18	104	13	46	18	13	17	104	41	141	19	31	109	202	135	1

TABLE 9. 2017 vs. 2019 mean comparisons by transect. Large differences in bold. Range includes years from 1990 through 2017 (Brock 2017).

Station		# Inverts	Coral spp	% coral cover	# fish spp	# fish ind	fish biomass
		2017/2019	2017/2019	2017/2019	2017/2019	2017/2019	2017/2019
1		10/8	**7/1**	**48.5/1.3**	13/10	70/37	29/18
2		3/4	0/0	0/0	1/2	1/3	5/6
3		10/4	5/3	8.6/1.2	15/13	**439/45**	**178/27**
4		2/3	0/0	0/0	1/4	1/33	0.2/47
5		12/6	3/2	1.3/0.33	**12/3**	**143/5**	**269/2**
6		3/1	0/0	0.0	2/0	2/0	1/0
Range (min/max)	Inside ZOM	3.3/7.3	1.5/3.5	2.8/16.9	5.8/12.0	16.8/137	6.4/66
	Outside ZOM	2.0/7.5	1.0/2.5	0.2/2.5	7.0/18.0	27.5/161	9.5/202

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APPENDICES

Appendix A. Results of the quantitative visual censuses conducted at six locations in and outside of the zone of mixing for Honolulu Harbor on 11 December 2019. Each entry total is given at the foot of the table along with an estimate of the standing crop (m^2) of fishes present at each location**.**

Family and Species	Common Name	Hawaiian Name	1	2	3	4	5	6
Acanthuridae								
Acanthurus nigrofuscus	Brown Surgeonfish	*ma'i'i'i*	1		1			
Acanthurus nigroris	Bluelined Surgeonfish	*maiko*	1					
Acanthurus triostegus	Convict Tang	*manini*			4			
Acanthurus xanthopterus	Yellowfin Surgeonfish	*pualu*	4		1	9		
Ctenochaetus strigosus	Goldring Surgeonfish	*kole*			1			
Zebrasoma flavescens	Yellow Tang	*lau'īpala*	6		3			
Balistidae								
Rhinecanthus rectangulus	Reef Triggerfish	*humuhumunukunukuapua'a*			1			
Carcharhinidae								
Carcharhinus galapagensis	Galapagos Shark	*MANO*						
Chaetodontidae								
Chaetodon lunula	Racoon Butterflyfish	*kīkākapu*			1			
Chaetodon trifascialis	Chevron Butterflyfish		2					
Holocentridae								
Sargocentron ensiferum	Yellowstripe Squirrelfish							
Labridae								
Gomphosus varius	Bird Wrasse	*hīnālea 'i'iwi (M), hīnālea 'akilolo (F)*			1			
Pseudocheilinus evanidus	Disappearing Wrasse							
Thalassoma duperrey	Saddle Wrasse	*hīnālea lauwili*			5	2	1	

Appendix A cont. (2/2)

Family and Species	Common Name	Hawaiian Name	1	2	3	4	5	6
Mullidae								
Mulloidichthys flavolineatus	Yellowstripe Goatfish	*weke*				8		
Upeneus taeniopterus	Bandtail Goatfish	*weke pueo*		1				
Pomacentridae								
Abudefduf abdominalis	Sargent Major	*mamo*	2		1			
Chromis ovalis	Oval Butterflyfish							
Dascyllus albisella	Hawaiian Dascyllus	*alo'ilo'i*	7	2	24	14		
Synodontidae								
Saurida gracillis	Slender Lizardfish				1		1	
Scaridae								
Chlorurus spilurus	Bullethead Parrotfish	*uhu*	6					
Scarus psittacus	Palenose Parrotfish	*uhu*	1					
Tetraodontidae								
Canthigaster jactator	Hawaiian White Spotted Toby		3		1			
Zanclidae								
Zanclus cornutus	Moorish idol	*kihikihi*	4				3	
Number of Species			10	2	13	4	3	0
Number of Individuals			37	3	45	33	5	0
Biomass (g/m^2)			18	6	27	47	2	0