



NELHA BENTHIC AND BIOTA MONITORING PROGRAM



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Annual Survey Report – 2021

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ANNUAL SURVEY REPORT – 2021

PREPARED FOR:

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EXECUTIVE SUMMARY

The Natural Energy Laboratory of Hawaii Authority (NELHA) is a Hawaii state agency that operates an Ocean Science and Technology Park at Kailua-Kona on the West side of Hawaii Island. The purpose of the NELHA facility is to promote research, education, and commercial activities that focus on development of sustainable industries. The nearshore marine environment surrounding NELHA, known as Keahole Point, is known for supporting abundant and diverse benthic and fish communities. The development of NELHA included the installment of pipeline infrastructure on the reef in order to pump surface and deep seawater to the operational facilities. Since installing the underwater pipe components, a comprehensive monitoring program was developed to ensure the NELHA infrastructure and activities do not detrimentally affect the health and productivity of the nearby marine environments. This monitoring program performs annual characterizations of the anchialine habitats, benthic substrate, and nearshore fish assemblages.

Since the monitoring program began in 1989, more than 30 annual surveys of these environments have been conducted and extensive reports have been prepared. The results, findings, summaries, and references for these reports are both publicly available and discussed throughout this report, which presents the results of the 2021 surveys.

The anchialine pools in the vicinity of the NELHA facility are distributed into two main complexes, “Northern” and “Southern”, comprised of five pools in the Northern complex and ten in the Southern complex. The pools within both complexes are relatively clustered, apart from pool S-10, which is situated south of the main Southern complex. A faunal census of each pool was completed from March 16th to April 27th, 2021 during a high-tidal range (+0.96 to +2.21ft.). Temperature and salinity were documented, and photographs and visual observations were used to quantify all flora and fauna within and surrounding each pool.

The results of the 2021 survey were generally consistent with previous annual surveys, with observed variances described in the following report. The native red shrimp, ‘ōpae ‘ula (*Halocaridina rubra*), were found in all the pools. ‘Ōpae ‘ula was present in very low numbers in pool, S-1, which was the only pool that invasive fish were present this year. Overall species composition at each pool was similar to last year’s survey. Minimal turbidity was observed

across sites in 2021, including the pool with introduced fish present. Invasive algae were not observed in any pool. Observations at all pools suggest that the current water quality conditions can sustain a community of native species.

The results of this survey support the conclusion that the surveyed anchialine pools, adjacent to the NELHA facility, are not currently impacted by anthropogenic inputs from local facilities. Pool disturbance due to visitation and the presence of predatory invasive fish were noted as the key drivers of pool degradation. Three pools are already seeing a return to health based on the rapid increase in *H. rubra* population with the absence of fish within the past couple years.

The marine surveys are conducted at six stations along the coastline adjacent to the NELHA facilities. At each station, transects are conducted at three depth (fsw = feet salt water) gradients (~15-fsw, ~30-fsw, and ~50-fsw) for total of 18 transects. Benthic habitat is characterized by surveying all abiotic and biotic feature of the substrate along 50-m transects. The benthic surveys reported a gradual increase in coral cover for the first 20 years of the study (Ziemann 2010), and corals in the genus *Porites* have been the dominant species among all stations and depths. Data from the last ten years have found the coral cover to stabilize in the range of ~30.0 – 50.0%. The overall coral cover for 2021 was 39%, which is within this range and shows the benthic communities to have exhibited relatively consistent values of coral cover for the last ten years. Permanent pins were established in 2017, which improves the ability to temporally track shifts in benthic composition and structure over time. The data from 2021 were quite consistent to data collected from 2017 – 2020 which indicates the pins are assisting with temporal monitoring of the study sites.

The overall percent coral cover among the six stations was 39%, the most dominant corals were *Porites lobata* (29.5%), *Porites compressa* (17.3%), *Porites evermanni* (10.7%), *Montipora capitata* (5.8%), *Montipora patula* (5.1%), *Pocillopora meandrina* (4.2%), and *Pocillopora grandis* (3.5%). These coral species were present among all the stations. Other corals present were *Leptastrea purpurea*, *Leptastrea bewickensis*, *Montipora flabellata*, *Pavona varians*, *Porites brighami*, *Porites rus* and *Fungia scutaria*. These corals accounted for a small percentage of the overall relative benthic cover.

Monitoring of the nearshore fish assemblages was conducted at the same six stations and depths as the benthic community. Surveys were performed at the same spatial locations of the benthic surveys and used a 4 x 25-meter belt transect to record the abundance and size of all fish present in the survey area. Fish data exhibit inherent variability due to high mobility and spatial habitat ranges of the nearshore species. The results from this monitoring program have been variable throughout the ~30-year duration. The findings from 2021 show similar values of abundance, diversity, and biomass to 2020. Ultimately, data from the duration of the monitoring program shows the nearshore habitats surrounding NELHA support highly diverse and productive fish assemblages.

An intertidal survey was completed in 2020 to identify and enumerate all species residing within the intertidal habitat surrounding the NELHA facilities. This survey created a baseline characterization of organisms residing within the nearshore intertidal habitat. No survey was conducted in 2021 as there was no habitat disturbance or species observations that warranted another site characterization, thus there is no discussion of intertidal surveys in the 2021 report.

These results and findings from the surveys of the anchialine pools, nearshore benthic substrate, and nearshore fish assemblages indicate these environments are not exhibiting any signs of detrimental impacts associated with the NELHA facility.

Table of Contents

Annual Survey Report – 2021	1
Prepared for:.....	1
Prepared by:.....	1
EXECUTIVE SUMMARY	2
ANCHIALINE POOL SURVEY.....	6
INTRODUCTION	6
METHODS	9
RESULTS.....	11
DISCUSSION	14
FIGURES AND TABLES.....	18
MARINE BENTHIC BIOTA SURVEY	31
INTRODUCTION	31
RESULTS.....	36
COMPARATIVE ANALYSIS OF TEMPORAL TRENDS IN BENTHIC DATA.....	40
DISCUSSION	43
MARINE FISH BIOTA SURVEY	45
INTRODUCTION	45
METHODS	47
RESULTS.....	49
COMPARATIVE ANALYSIS OF TEMPORAL TRENDS IN FISH DATA.....	52
DISCUSSION	53
REFERENCES	55
APPENDICES	61
Appendix 1 – Pool Monitoring	61
Appendix 2 - Nearshore marine habitat characterization data.....	66
Appendix 3: Nearshore fish assemblage data.....	78
Appendix 4. Digital images of quadrats used for benthic habitat characterization	84

ANCHIALINE POOL SURVEY

INTRODUCTION

Anchialine pools are unique ecosystems characterized as nearshore, land-locked, brackish bodies of water, influenced by terrestrial groundwater inputs and marine tidal influx. These unique aquatic conditions host a similarly unique array of aquatic species. Hawai'i Island is known for its relatively high concentration of anchialine pools, with many examples at Keāhole Point where the NELHA facility is located. Interest in these ecosystems, previously described by numerous researchers, partially stemmed from the observations of abundant assemblages of tiny, red shrimp ('ōpae 'ula) that appeared to be restricted to this particular habitat (Holthuis 1973, Maciolek and Brock 1974). Anchialine systems occur globally and can be found on 30 tropical and subtropical islands within the Pacific Ocean, in nearshore areas of the Western Indian Ocean, on Ascension Island in the Atlantic Ocean, and at other inland sites in North America, Mesoamerica, and adjacent to the Red Sea (Chace and Manning 1972, Holthuis 1973, Maciolek 1983, Iliffe 1991, Hobbs 1994, Peck 1994). Anchialine pools are commonly found along the shoreline of West Hawai'i, and also occur on O'ahu, Maui, Moloka'i, and Kaho'olawe (Brock et al. 1987, Bailey-Brock and Brock 1993, Yamamoto et al. 2015).

The unusual environmental conditions that shape anchialine pool ecosystems have resulted in the presence of specialized native and endemic species (Bailey-Brock and Brock 1993, Yamamoto et al. 2015). As elsewhere, organisms found within the anchialine pools in Hawai'i are uniquely suited to the varying salinity conditions. Specialized species include crustaceans, mollusks, plants, and other taxa. Table 1 summarizes species previously reported from the pools located within and adjacent to the NELHA facility (Brock 2008, Ziemann and Conquest 2008).

Two specialized decapod shrimp species, endemic *Halocaridina rubra* ('ōpae 'ula) and indigenous *Metabetaeus lohena*, are common inhabitants in many of the anchialine pools at NELHA. *H. rubra* are omnivorous, and preferentially inhabit anchialine pools throughout the day to feed on microalgae, macroalgae, and detritus (Bailey-Brock and Brock 1993). Anchialine pools are typically connected to one another through lava tubes, rock fissures, and micro-cracks in the surrounding basalt substrate. Reproduction and larval dispersal of *H. rubra* generally occur within these subterranean (hypogean) sections of anchialine systems. *H. rubra*

have a relatively long lifespan of approximately 10 - 20 years, and are key grazers within anchialine pools, maintaining a controlled standing crop of plants, bacteria, diatoms, and protozoans in the pools through active grazing. This 'gardening' role contributes to the overall health of anchialine pool ecosystems, allowing other species to reside within the sunlit (epigeal) portion of the pools. Because of this critical ecosystem function, *H. rubra* are thought to be a keystone species within these systems (Bailey-Brock and Brock 1993). The relatively larger indigenous shrimp species, *M. lohena*, is omnivorous occasionally feeding on *H. rubra* (Yamamoto et al. 2015).

Introduced fish species (e.g. mosquitofish, guppies, tilapia) are a substantial threat to native species within anchialine pools in Hawai'i and can cause rapid and sharp declines in *H. rubra* abundance due to focused predation. The presence of invasive fish, which are active during the day, can also drive shifts in *H. rubra* foraging behavior by increasing nocturnal activities (Capps et al. 2009, Carey et al. 2011). Typically, anchialine pools with well-established populations of introduced fish are not able to support *H. rubra* and other native shrimp assemblages during the day in open, epigeal areas. However, the shrimp are able to take refuge within basalt fissures and cracks within the pool substrate, then emerge after dark to forage.

Several anthropogenic stressors can alter the health of anchialine pool ecosystems. Coastal development and other shoreline alterations can cause structural damage to the pools and/or disrupt surrounding groundwater influx and condition. Increased human presence adjacent to the pools can also lead to invasive species introductions and can alter to pool surroundings and substrate due to visitation and swimming. Additionally, recent sea-level rise forecast models suggest that anchialine pools on Hawai'i Island and throughout the state will eventually form larger pool complexes and have more frequent surface connections to the ocean in the coming decades (Marrack and O'Grady 2014). Concurrently, new anchialine pools may emerge further inshore, depending on elevation and groundwater connectivity. These anticipated changes associated with predicted sea-level rise could dramatically impact anchialine pool ecology. Fortunately, submarine connections between pools will likely allow *H. rubra* and other shrimp species to populate new higher elevation pools.

Recent investigations examining the DNA of *H. rubra* provided an improved understanding of population dynamics and contributed to more effective monitoring and management of anchialine pools in Hawai'i (Santos 2006). This study showed that two distinct lineages of *H. rubra* exist on the East and West coasts of the Hawai'i Island. Also, within small-scale geographic areas, populations were structured with low levels of gene flow, suggesting that local assemblages of *H. rubra* are genetically unique (Santos 2006). Therefore, local scale monitoring of anchialine pools in Hawai'i (e.g. at the level of pools and pool complexes) is appropriate for determining *H. rubra* population status and is utilized in this survey.

The two groups of pools adjacent to the NELHA facility have been surveyed for more than 30 years (Brock 1995, Brock 2008, Oceanic Institute 1997, Oceanic Institute 2007, Ziemann and Conquest 2008, Bybee et al. 2012, Bybee et al. 2013, Bybee et al. 2014, Whale Environmental Services 2015, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018, Burns and Annandale 2019, Burns et al. 2020). Through this continued annual monitoring program at the pools, changes in communities have been noted since 1989, with shrimp becoming absent in certain pools due to Poeciliid fish (mosquitofish and guppies) introductions (Brock 2008, Ziemann and Conquest 2008). More recently, signs of visitation and usage have been noted for certain easily accessible pools (Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018, Burns and Annandale 2019, Burns et al. 2020).

Results of the 2021 survey as part of NELHA's Comprehensive Environmental Monitoring Program (CEMP) are reported subsequently.

METHODS

Anchialine pools located within the NELHA facility form localized complexes, including five pools in the “Northern complex” and ten pools in the “Southern complex” (Figures 1 - 3). The Northern pool complex, including pools N-1 through N-5, is located approximately 100m inland of the cobble beach at Ho’ona Bay (Figure 2), and the Southern pool complex, including pools S-1 to S-10, is located approximately 200 m to 225 m from the shoreline at Wawaloli Beach Park, adjacent to Makako Bay Drive, with the exception of pool S-10, which is located approximately 500m south of the main pool complex (Figure 3).

Table 2 describes the location and size of each pool at the NELHA site. A Garmin 76Cx hand-held GPS unit was used to locate each pool during the 2020 survey based on previously recorded latitudes and longitudes. In 2017, site coordinates were updated to a five-decimal system for improved ease of pool relocation (Table 2). Upon arrival at each site, pool diameter was confirmed from measurements first reported by Brock 2008 (Table 2), except for pool S-10 which was first surveyed in 2015 (Whale Environmental Services 2015). Pool dimensions and basin characteristics for historically surveyed pools are included in Appendix 1.1 (Brock 2008).

Water level, water chemistry, and appearance of the anchialine pools vary with tidal level during the survey. The effect of tidal level is particularly apparent for the Northern pool complex, including pools N-2, N-3, N-4, and N-5. At low tide, these pools are separated by basalt substrate outcrops, however at high tide ($> +2.1\text{ft}$), these pools start to form a single body of water (Burns and Kramer 2018). This interconnectivity is particularly apparent during annual peak tides (also known as King’s tides) during which tidal levels exceed 2.4 ft. While the water level in the Southern group pools is also strongly tidally affected, pools were not observed to be interconnected during the 2021 survey.

Faunal surveys were conducted from March 16th to April 27th, 2021. Faunal observations for the 2021 survey were collected at tide levels just below the daily maximum to provide sufficient water for organismal observations. Sampling of the pools was conducted at tidal levels ranging from $+0.96$ to $+2.21\text{ft}$. Temperature and salinity measurements were collected concurrently

using a hand-held YSI Pro-Series Quatro water quality meter and data logger. Flora and fauna within and surrounding each pool was documented using visual observations and photographs taken with a FujiFilm FinePix XP130 digital waterproof camera. In-situ *H. rubra* counts were conducted by randomly placing ruler in the pool and counting a 10x10cm area to calculate density. The number of replicate counts depended on pool area and depth and ranged from 3 to 7 replicates. *H. rubra* density was determined for each quadrat, then averaged for each pool. *H. rubra* density was calculated for an area of 0.1 m² to allow for comparisons with previous survey results (Tables 3 and 4, Appendix 1.2).

RESULTS

Water quality measurements and faunal census results from the 2021 survey are summarized in Tables 3 and 4, and include temperature and salinity observations, *H. rubra* density, Poeciliid presence, *Ruppia maritima* presence, and other notes on pool status. Faunal presence at the pools during the 2021 survey was consistent with recent previous surveys (Burns et al. 2020). Pool characteristics were partially explained by location, with higher species diversity and higher density vegetation surrounding the Northern pools compared to the Southern pools (Figures 4 - 14). The Southern pools tended to be surrounded by non-vegetated or very sparsely vegetated basalt. Some Southern pools also had more signs of visitation, such as moved rocks, trash, and the presence of people.

Southern pools (with the exception of pool S-10) were less saline and slightly cooler compared to the Northern pools. For the Southern pools S-1 through S-9, temperature ranged from 21 to 22.3 °C and salinity ranged from 8.3 to 11.43 ppt. Slightly higher temperature and salinity readings were recorded for distal pool S-10 (24 °C, 11.98 ppt., respectively) (Table 4). For the Northern pools, temperature and salinity were relatively higher, ranging from 22.3 to 28.9 °C and from 12.7 to 15.5 ppt. (Table 3). This pattern observed for water quality characteristics corroborates previous surveys and reflects varying degrees of groundwater and marine influence within the pools (Bybee et al. 2014, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018, Burns and Annandale 2019, Burns et al. 2020; Appendix 1.1).

The majority of the Northern anchialine pools hosted higher densities of *H. rubra* compared to the Southern pools (Bybee et al. 2014, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Annandale 2019, Burns et al. 2020). During the 2021 survey, *H. rubra* were observed in high densities at all of the Northern Pools.

Within the Southern complex, two pools (S-10 and S-5) had very high densities of *H. rubra* (~200 individuals/ 0.1 m²), and four pools (S-3, S-4, S-7, and S-8) had high densities of *H. rubra* (~100 individuals/ 0.1 m²) (Table 4). *H. rubra* were present in high densities in S-7 and S-8 where *H. rubra* had been absent and invasive fish were observed in previous surveys (Burns

and Kramer 2017, Burns and Kramer 2018, Burns and Annandale 2019). *H. rubra* was also observed in very high densities in pools S-5 where they had not been observed in previous surveys (Burns and Kramer 2017, Burns and Kramer 2018) and were observed in very low densities in 2019 (Burns and Annandale 2019). *H. rubra* were present in very low densities (15 individuals/ 0.1 m²) in Pool S-1, where they had been absent in last year's survey and other previous surveys.

During the 2021 survey, *M. lohena* was observed within several Southern pools, including S-3, S-6, S-8, S-9, and S-10, and were noted to be particularly abundant at pool S-10 (Figure 14). *M. lohena* was also observed at three of the Northern pools (N-1, N-2, and N-5), compared to 2018 where *M. lohena* was absent from the Northern complex (Burns and Kramer 2018). *Macrobrachium grandimanus*, an uncommon indigenous species, was not observed at any of the pools during the 2021 surveys compared to previous years (Burns and Kramer 2018, Burns and Annandale 2019, Burns et al. 2020). Historically and in more recent surveys, *M. grandimanus* had been observed in pools S-1, S-5, S-7, S-8, and N-3 (Bybee et al. 2014, Burns and Kramer 2017, Burns and Annandale 2019, Burns et al. 2020) (Appendix 1.2).

Introduced Poeciliid fish, including *Gambusia affinis* and *Poecilia* spp., were observed at one of the southern area pools, S-1, in 2021 compared to 2019 where they were observed at four of the southern area pools (S-1, S-5, S-7, and S-8). In the 2021 survey, Poeciliid fish were absent from pools S-7, S-8, and S-5 in which they were very abundant in previous surveys and have been recorded since 2002, 2007, and 2008 respectively (Burns and Kramer 2018, Burns and Kramer 2018, Burns and Annandale 2019, Burns et al. 2020). In S-1, where introduced fish were present, shrimp populations, including *H. rubra* and *M. lohena*, were low or absent, respectively. As of the survey date in April 2021, introduced fish were not observed in any of the Northern pools (Table 3).

Tables 3 and 4 list additional species observed within and around each pool during in-situ visual observations. Generally, higher species diversity was observed for the Northern pools, which were typically surrounded by dense vegetation (Figures 4 - 7). Similar to previous surveys, Northern pools N-3, and N-5 hosted assemblages of the aquatic grass, *Ruppia maritima* (Figures 6 and 8). Thiarid snails (*Melanoides tuberculata* and *Terbia* grainers) were observed in three of the five Northern pools (N-2, N-4, and N-5). Similar to previous surveys,

very high densities of Thiariid snails were observed within the Northern pool N-4 (Table 3) (Bybee et al. 2014, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018, Burns and Annandale 2019, Burns et al. 2020).

Cultural archeological features were noted at several pools in both the Northern and Southern complexes, including pools N-1, N-5, S-5, S-7, S-8, and S-10. Features included water-worn basalt and/or coral stones within or surrounding the pools, walls or structures surrounding the pools, and water-worn stones embedded within trails leading to the pools.

DISCUSSION

The West Hawai'i coastline hosts more than 500 anchialine pools, which are unique, tidally influenced brackish ecosystems that host a specialized array of species (Yamamoto et al. 2015). Two complexes of pools adjacent to the NELHA facility have been monitored for multiple decades (Appendix 1.2), providing a foundation of data for evaluating status and change within these ecosystems. These datasets can help improve management of the pools locally and throughout Hawai'i Island by tracking ecosystem changes overtime and evaluating causative factors.

The anchialine pools at NELHA were resurveyed in March and April 2021, and compared to previous censuses, spanning back to May 1989. The census results from 2021 show the anchialine pool ecology has remained relatively stable in the last several years except for specific changes such as the recent absence of poeciliids and increased abundance of *H. rubra* in certain pools (Bybee et al. 2013, Bybee et al. 2014, Whale Environmental Services 2015, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018, Burns and Annandale 2019, Burns et al. 2020). The major drivers of pool ecology were: 1. pool location, either Northern or Southern areas, 2. groundwater influence reflected in temperature and salinity readings, 3. the presence or absence of introduced fish, and 4. the intensity of human visitor impacts to the pools (Tables 3 and 4).

Water quality is a key indicator in assessing anchialine pool ecosystem health and measurements collected in 2021 were consistent with surveys in previous years suggesting that groundwater influence within the pools has remained relatively consistent (Bybee et al. 2014, Whale Environmental Services 2015, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018, Burns and Annandale 2019, Burns et al. 2020; Appendix 1.1). Pool temperatures ranged from 21 to 28.9 °C and salinity ranged from 8.3 to 15.5 ppt. The Southern pools were cooler and less saline during the 2021 survey compared to the Northern pools. This suggests Southern pools have a relatively higher groundwater influence or the Northern pools have a greater ocean influence due to the pools' proximity to the shoreline. Pool S-10 also had higher water temperatures than previous years, potentially due to the removal of the Christmas berry (*Schinus terebinthifolia*) in January 2020 that used to shade the pool. The tree was removed to reduce the amount of introduced organic debris from the leaf litter accumulating in the pool. Less leaf litter was observed during the 2021 surveys than previous years.

All the Northern pools hosted *H. rubra* and four hosted *M. lohena*. *H. rubra* were now very abundant pool (368 individuals/m²) and *M. lohena* was present in pool N-3. Before the 2020 survey, shrimp were last observed in pool N-3 in the 2017 surveys. In 2018, an unusually dense and partially decaying assemblage of *R. maritima* was observed in pool N-3, which may have altered water quality (e.g. depleted oxygen levels) within the pool and deterred *H. rubra* (Approximately 5 gallons of decaying *R. maritima* material were removed from the pool following the survey). The presence of an aholehole (*Kuhlia sandvicensis*) swimming between pools N-3 and N-5 did not seem to affect the presence of *H. rubra*.

At high tides, pools N-2, N-3, N-4 and N-5 become interconnected (Figure 7), which provides a simple mechanism for organismal exchange following depletion events (in addition to submarine/ hypogeal pool connections). This interconnectivity suggests that *H. rubra* can easily move from pool to pool. This interconnectivity also likely promoted the rapid replenishment of *H. rubra* within pool N-5 and pool N-3. As documented in previous years, poeciliids were not observed in any Northern pools which allows for the continued diurnal presence of *H. rubra* (Bybee et al. 2014, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018).

The historical introduction of poeciliids within anchialine pools at NELHA has significantly affected pool ecology, but in the 2020 and 2021 surveys, these fish were only found in one Southern area pool, S-1 (Figure 9). Where introduced fish were present, shrimp populations, including *H. rubra* and *M. lohena*, were low or absent. *H. rubra* were observed in very low numbers in S-1 during the 2021 survey and just along the edge of the pool similar to the 2019 survey. *M. lohena* was not observed. Capps et al. (2009) and Carey et al. (2011) suggest that *H. rubra* within fish-invaded pools may alter their behavior by only residing within protected areas (inaccessible by fish) of the pool, or by only entering the epigeal regions of the pool at night to feed. During this survey, pools were surveyed during daylight hours and the nocturnal behavior of *H. rubra* was not assessed.

Poeciliids were not observed in pools S-5, S-7, and S-8 during the 2020 and 2021 survey, where they were abundant during the 2019 and other past surveys. With the absence of introduced poeciliid fish in pools S-5, S-7, and S-8, the *H. rubra* populations dramatically increased. These pools have the highest densities of the southern pools and are comparable to the northern pools in shrimp density. Starting in 2019 a concerted effort was made to remove the introduced poeciliids from four pools (S-1, S-5, S-7, and S-8) with support from the Hawaii Island Hui Loko and Hawaii State Parks. Eradication methods utilized carbon dioxide addition and baited fish traps. Carbon dioxide (CO₂) is an emerging alternative to traditional chemical control agents because it has been demonstrated to be toxic to fish but is also naturally occurring and readily neutralized. The absence of poeciliids and abundant presence of *H. rubra* in three of the pools during the 2020 and 2021 surveys show the success of the fish removal efforts.

The CO₂ treatment was not as successful in pool S-1, as poeciliids are still present and abundant. The cracks and crevices in this pool may be refuges for the fish during the treatment, however with such success in the other three pools, it is recommended to continue fish removal efforts in pool S-1.

Signs of visitor impacts were observed at several of the Southern pools in 2021. Affected pools were generally near access points, including Wawaloli Beach Park and Makako Bay Drive, and were also relatively visible due to minimal surrounding vegetation. Signs of recent visitor impacts were observed at four of the surveyed pools in the Southern complex (S-1, S-3, S-4, and S-5). Modifications in and around the pools included the addition of rocks to pool basins, litter, and the possible removal/addition of Poeciliid fish and *H. rubra* for fishing bait and other uses. Overall, visitation and disturbance can cause damaging physical changes to the pools. Local schools arrange field trips to the southern pools to raise awareness of these ecologically important habitats, however this may result in more visitation and disturbance to the sites. Substrate and surrounding rock movements can influence overall pool ecology, by altering light, water depth, turf algal growth, and food availability for *H. rubra* and other shrimp species. Trash and other refuse present may affect the water quality of the pools.

Predicted sea-level rise is a significant future threat to Hawaiian anchialine pool ecosystems will likely drive substantial changes to pool interconnectedness, depth, location, and water

chemistry (Marrack and O'Grady 2014). These physical changes will have a critical influence on faunal composition within the pools. The interconnectedness of pools with sea-level rise can allow poeciliids to invade nearby pools that currently do not have introduced fish. King Tides or seasonal high tides offer a preliminary view of potential anchialine pool ecosystem changes associated with rising sea-level. In the past few years these changes are becoming more apparent during the annual surveys. In the 2018 surveys, the northern pools were interconnected at tides $>+2.1$ ft. During the 2021 survey the northern pools were interconnected at a tide of $+1.7$ ft and a new pool to the south of N-2 was forming. In the southern pools, two new pools were also appearing to the south of N-3 and N-4 at a tide of $+2.2$ ft.

The results of the 2021 anchialine pool survey did not indicate that anthropogenic inputs from local aquaculture and other facilities at NELHA are degrading the pools. Pool disturbance due to visitation and the presence of predatory invasive fish were noted as the key drivers of pool degradation. The majority of the surveyed pools at NELHA had water quality and other ecosystem conditions supporting a healthy native shrimp population.

FIGURES AND TABLES



Figure 1. Overview of the study area, which includes Northern and Southern anchialine pool complexes in the vicinity of the NELHA facility. For this annual report, the pools were surveyed from March 16th through April 27st 2021. (Map generated using Google Earth Pro 7.3.3.7786).



Figure 2. Locations of the Northern complex of anchialine pools (N – 1 through N –5), located inland of the cobble beach at Ho'ona Bay. The Northern pools were surveyed on April 25th, 2021. (Map generated using Google Earth Pro 7.3.3.7786).



Figure 3. The Southern complex of anchialine pools (S-1 through S-10), located inshore and south of the Wawaloli Beach Park facility at NELHA. The Southern pools were surveyed from March 16th through April 27st 2021. (Map generated using Google Earth Pro 7.3.3.7786).



Figure 4. (left) Northern pool, N - 1 at a tide level of +1.61' with leaf litter floating on the surface of the pool and (right) (*Cyperus laevigatus*) growing in pool. Pools in the Northern group were typically characterized by relatively diverse faunal assemblages and dense surrounding vegetation. Surrounding vegetation has continued to encroach pool N – 1.

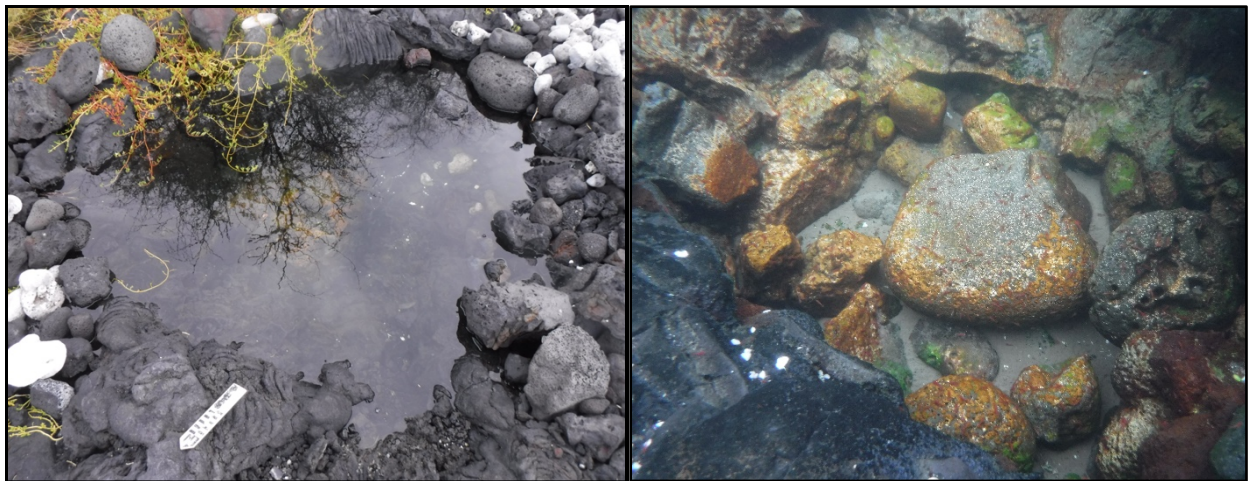


Figure 5. (left) Northern pool N-2, at a tide level of +1.65', and (right) *Halocaridina rubra* (‘ōpae ‘ula) and algae within the pool.



Figure 6. Northern pool N-3 at tide level +1.71'.



Figure 7. (left) Northern pool, N-4, at tide level +1.68 and (right) N-4 connected to N-3 and N-5.

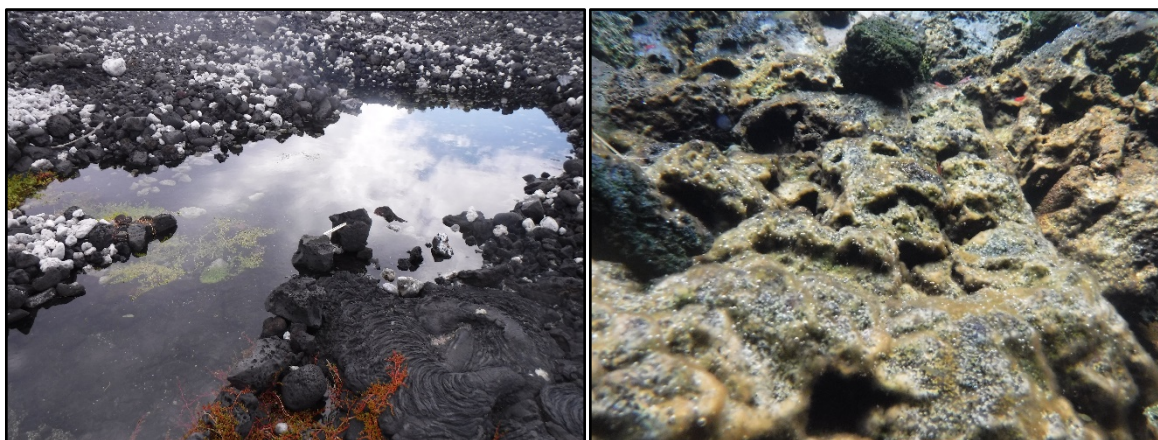


Figure 8. (left) Northern pool N-5, at tide level +1.75' and (right) *Halocaridina rubra* ('ōpae 'ula) and algae within the pool.



Figure 9. Southern pool, S-1, at a tide level of + 1.13'.



Figure 10. (left) Southern pool, S-3, at a tide level of +2.21' and (right) Southern pool, S-4, at a tide level of +2.20'.



Figure 11. Southern pool S-5 at a tide level of +1.09'.



Figure 12. (left) Southern pool S-9 at a tide level of +2.21'. (right) Southern pool, S-6 at a tide level of +2.21'.



Figure 13. (left) Southern pool, S-7, at a tide level of +0.96'. (right) Southern pool, S-8, at tide level +1.03'.



Figure 14. Southern pool, S-10 (left), at a tide level of +1.43'.

Table 1. List of species previously observed in anchialine pools within and surrounding the NELHA facility. (Compiled from previous annual reports).

	Taxon	Common/ Hawaiian Name	Classification
Anchialine pool: Native	<i>Halocaridina rubra</i>	Ōpae 'ula/ Ōpae hiki	Shrimp (Decapoda)
	<i>Metabetaeus lohena</i>		Shrimp (Decapoda)
	<i>Macrobrachium grandimanus</i>	Ōpae 'oeha'a	Shrimp (Decapoda)
	<i>Ruppia</i> sp.	Widgeon grass	Monocot plant (Ruppiaceae)
	<i>Assimineia</i> sp.	Snail	Aquatic Snail (Gastropoda)
	<i>Theodoxus cariosa</i>	Hihiwai	Limpet (Gastropoda)
	<i>Trichocorixa reticulata</i>	Water boatman	Aquatic insect (Arthropoda)
	<i>Pantala flavescens</i>	Globe skimmer	Dragonfly (Arthropoda)
	<i>Ajax junior</i>	Common green darner	Dragonfly (Arthropoda)
	<i>Oligochaeta</i> sp.	Worm	Aquatic worm (Oligochaeta)
	<i>Palaemon debilis</i>	'Ōpae hula, Glass shrimp	Shrimp (Decapoda)
	<i>Metopograpsus meson</i>	Kukupu	Crab (Decapoda)
	<i>Grasps tenuicrustatus</i>	A 'ama	Crab (Decapoda)
	<i>Cladophora</i> sp.	Limu hulu'ilio	Green algae (Chlorophyta)
	<i>Enteromorpha</i> sp.	Limu 'ele 'ele	Green algae (Chlorophyta)
	<i>Rhizoclonium</i> sp.	Limu	Green algae (Chlorophyta)
	<i>Lyngbya</i> sp.	Cyanophyte mat	Cyanobacteria (Cyanophyta)
	<i>Schizothrix clacicola</i>	Cyanophyte crust	Cyanobacteria (Cyanophyta)
Anchialine pool: Introduced	<i>Melanoides tuberculata</i>	Red-rimmed Melania snail, Thiarid	Thiarid Snail (Gastropoda)
	<i>Tarebia granifera</i>	Quilted Melania snail, Thiarid	Thiarid Snail (Gastropoda)
	<i>Poecilia</i> sp.	Guppy (Topminnow)	Fish (Poeciliidae)
	<i>Gambusia affinis</i>	Mosquitofish (Topminnow)	Fish (Poeciliidae)
	<i>Macrobrachium lar</i>	Tahitian Prawn	Prawn (Decapoda)
	<i>Argiope appensa</i>	Garden spider	Spider (Arthropoda)
	<i>Tramea lacerata</i>	Black saddlebags	Dragonfly (Arthropoda)
	<i>Ischnura posita</i>	Fragile forktail damselfly	Damselfly (Arthropoda)
Terrestrial plants	<i>Bacopa</i> sp.	Pickleweed (Invasive)	Plantaginaceae
	<i>Capparis sandwichiana</i>	Maiapilo (Endemic)	Capparaceae
	<i>Cladium</i> sp.	Sedge	Cyperaceae
	<i>Ipomoea pes-caprae</i>	Pōhuehue, Beach morning glory	Convolvulaceae
	<i>Morinda citrifolia</i>	Noni	Rubiaceae
	<i>Pennisetum setaceum</i>	Fountain grass (Invasive)	Poaceae
	<i>Pluchea odorata</i>	Pluchea	Asteraceae
	<i>Prosopis pallida</i>	Kiawe, mesquite tree	Mimoseae
	<i>Scaevola taccada</i>	Naupaka	Goodeniaceae
	<i>Schinus terebinthifolius</i>	Christmas berry (Invasive)	Anacardiaceae
	<i>Sesuvium portulacastrum</i>	'Ākulikuli, Pickleweed	Aizoaceae
	<i>Thespesia populnea</i>	Milo	Malvaceae
	<i>Tournefortia argentea</i>	Beach heliotrope	Boraginaceae

Table 2. Coordinates and sizes of anchialine pools located in the vicinity of the NELHA facility (calculated from measurements reported in Brock 2008*, and Whale Environmental Group 2015**).

Area	Pond number	Latitude (Decimal degrees)	Longitude (Decimal degrees)	Size (m ²)*
Northern Ponds	N-1	19.73137	-156.05681	93
	N-2	19.73142	-156.05659	1
	N-3	19.73143	-156.05658	22.5
	N-4	19.73141	-156.05653	4
	N-5	19.73153	-156.05656	22.5
Southern Ponds	S-1	19.71676	-156.04893	1.7
	S-2	19.71670	-156.04890	1
	S-3	19.71680	-156.04871	1
	S-4	19.71680	-156.04871	0.01
	S-5	19.71680	-156.04871	5
	S-6	19.71685	-156.04814	0.01
	S-7	19.71660	-156.04810	1.4
	S-8	19.71650	-156.04810	1
	S-9	19.71680	-156.04810	0.01
	S-10	19.71380	-156.04820	0.9**

Table 3. Faunal census data collected for the Northern pool complex of anchialine ponds at the NELHA facility. The pool surveys were conducted on April 25th, 2021, at a tidal level ranging from +1.61' to +1.75'. Poeciliids and *Ruppia maritima* were recorded as present or absent, and other organisms in the observed in each pool were noted in the comments. *Halocaridina rubra* densities are reported as a mean number of individuals per 0.1 square meters (\pm one standard error unit).

Area	Pool number	Survey Date	Survey Time	Water Quality		Substrate	Faunal Surveys			Comments/ Other Species
				Temp (C°)	Salinity (ppt)		<i>H. rubra</i> (Count/0.1m ²) (Mean \pm SE)	Poeciliids	<i>Ruppia maritima</i>	
Northern Ponds	N-1	4/25/2021	16:23	22.3	15.53	Sandy pebble substrate, some silt and shell fragments, rock wall mauka section	297 \pm 45	absent	absent	Lots of leaf litter, sticks, and seeds floating on surface. <i>M. lohena</i> , <i>Scaevola taccada</i> , <i>Cyrenus laevigatus</i> , <i>Prosopis pallida</i> , <i>Tournefortia argentea</i> , <i>Thespesia populnea</i> , <i>Sesuvium portulacastrum</i> , <i>Lyngbya sp.</i> ,
	N-2	4/25/2021	16:16	27.2	12.7	Basalt rubble, pahoehoe surroundings, some sediment and silt	188 \pm 54	absent	absent	<i>M. lohena</i> , <i>Sesuvium portulacastrum</i> , <i>Schizothrix clacicola</i> , <i>Lyngbya sp.</i> ,
	N-3	4/25/2021	16:01	24.8	13.17	Silt, sediment, and shell fragments, underlying cobble, pahoehoe surroundings	368 \pm 64	absent	present	<i>Lyngbya sp.</i> , <i>Sesuvium portulacastrum</i> , <i>Scaevola taccada</i> , <i>Cyrenus laevigatus</i> , <i>Kuhlia sandvicensis</i> (19cm – same from pool N-5)
	N-4	4/25/2021	16:09	28.9	12.71	Silt bottom with cobble and shells, pahoehoe surroundings	226 \pm 40	absent	absent	<i>M. lohena</i> , <i>Thiarid</i> snails, <i>Sesuvium portulacastrum</i> , <i>Cyrenus laevigatus</i> , <i>Schizothrix clacicola</i> , <i>Pennisetum setaceum</i> , <i>Prosopis pallida</i> , <i>Pluchea carolinensis</i> ,
	N-5	4/25/2021	15:51	25.2	15.55	Water-worn (rounded) basalt cobble and coral, some sediment and silt	285 \pm 49	absent	present	<i>M. lohena</i> , <i>Sesuvium portulacastrum</i> , <i>Thiarid</i> snails, <i>Kuhlia sandvicensis</i> (19cm)

Table 4. Faunal census data collected for the Southern pool complex of anchialine ponds at the NELHA facility. The pool surveys were conducted on March 16th and April 27th, 2021, at a tidal level ranging from +0.95' to +2.21'. Poeciliids and *Ruppia maritima* were recorded as present or absent, and other organisms observed in each pool were noted in the comments. *Halocaridina rubra* densities are reported as a mean number of individuals per 0.1 square meters (\pm one standard error unit).

Area	Pool number	Survey Date	Survey Time	Water Quality		Substrate	Faunal Surveys			Comments/ Other Species
				Temp (C°)	Salinity (ppt)		<i>H. rubra</i> (Count/0.1m ²) (Mean \pm SE)	Poeciliids	<i>Ruppia maritima</i>	
Southern Ponds	S-1	3/16/2021	15:39	22.0	10.1	Basalt rubble/ pebbles, shell fragments, pahoehoe surroundings	15 \pm 10	present	absent	<i>M. lohena</i> , <i>Pennisetum setaceum</i> , <i>Schinus terebinthifolius</i> , <i>Schizothrix clacicola</i> , <i>Poecilia</i> sp. or <i>Gambusia affinis</i> (~8 fish < 1cm)
	S-2	3/16/2021	15:37	-	-	-	-	-	-	Pond filled in with rocks
	S-3	4/27/2021	16:37	22.1	11.3	Basalt rubble/ pebbles, mixed pahoehoe surroundings	116 \pm 13	absent	absent	<i>M. lohena</i> , white amphipod, no surrounding vegetation
	S-4	4/27/2021	16:43	22.0	11.4	Basalt rubble, pahoehoe surroundings	118 \pm 22	absent	absent	No surrounding vegetation.
	S-5	3/16/2021	15:32	22.3	10.2	Basalt rubble and coral, mixed pahoehoe surroundings,	202 \pm 33	absent	absent	<i>Pennisetum setaceum</i> , <i>Schizothrix clacicola</i> , Minimal vegetation around pond. Signs of visitation – people and dogs swimming on 6/20/2020
	S-6	4/27/2021	16:28	21.5	10.8	Very narrow basalt crack, a'a surroundings.	58 \pm 12	absent	absent	<i>H. rubra</i> very small, <i>M. lohena</i> , no surrounding vegetation, <i>Capparis sandwichiana</i> nearby, Abundant ants at pond edge
	S-7	3/16/2021	15:08	21.0	10.3	Basalt rubble (some rounded), mixed pahoehoe surroundings	173 \pm 26	absent	absent	<i>M. lohena</i> , <i>Pennisetum setaceum</i> , <i>Capparis sandwichiana</i> , <i>Schizothrix clacicola</i> , green algae, unknown pink worm (2), Ophi shells observed. Rounded stones along basin and trail.
	S-8	3/16/2021	15:21	22.3	8.32	Basalt rubble with a few white coral stones, shell fragments, pahoehoe surroundings	130 \pm 22	absent	absent	<i>M. lohena</i> , <i>Pennisetum setaceum</i> , <i>Schizothrix clacicola</i> . Water-worn wall with rounded corals surrounding pond. Ophi shells observed. Trail to pond.
	S-9	4/27/2021	16:25	21.8	11.0	Basalt crack, a'a surroundings.	22 \pm 4	absent	absent	<i>H. rubra</i> very small. <i>M. lohena</i> , abundant ants at pond edge. No surrounding vegetation.
	S-10	4/25/2021	16:55	24.0	12.0	Pahoehoe with light organic material and some sand, small basalt pebbles	240 \pm 29	absent	absent	<i>M. lohena</i> (common), <i>Schinus terebinthifolius</i> cut and covered, <i>Pennisetum setaceum</i> , <i>Talinum fruticosum</i> , <i>Pluchea carolinensis</i> and <i>Leucaena leucocephala</i> nearby, green algae

MARINE BENTHIC BIOTA SURVEY

INTRODUCTION

The Natural Energy Laboratory of Hawaii Authority (NELHA) is a State of Hawaii agency that is administratively attached to the Department of Business, Economic Development, and Tourism (DBEDT). NELHA's mission is to develop and diversify the Hawaii economy by providing resources and facilities for energy and ocean-related research, education, and commercial activities in an environmentally sound and culturally sensitive manner. NELHA operates an ocean science and technology facility at Kailua-Kona on the West side of Hawaii Island. The facility operations are focused on research, education, and commercial activities that support sustainable industry development in Hawaii.

One of the utilities provided by NELHA is the pumping of cold seawater from deep ocean depths (~2,000 to ~3,000-fsw) to the surface through large pipes that have been installed on the benthic substrate in several locations along the coastal border of the facility. The pipelines run perpendicular to the shoreline to depths that enable delivery of nutrient rich water, which is used in a variety of aquaculture and sustainable energy activities on land. Concerns over water discharge from the various aquaculture and innovative energy operations, and the potentially negative impacts of this discharge to the adjacent reef communities, have prompted annual monitoring. Benthic communities are often sensitive indicators of environmental change (Gray and Pearson 1982). Conducting annual surveys allows for detecting any changes in the benthic substrate and associated reef organisms that may be indicative of larger changes occurring to the overall ecosystem structure and function.

Annual monitoring was initiated in 1989, and since then more than 30 surveys have been conducted to assess the ecological characteristics of both the nearshore and marine benthic communities adjacent to NELHA. Extensive reports were prepared that detail the results and findings of each survey, which are all publicly archived by NELHA. Results and summaries of the reports can be found in the following references: Surveys conducted from 1991-1995 are summarized by Marine Research Consultants (Marine Research Consultants 1995). Surveys conducted from 1995 and 1997 are summarized by Oceanic Institute (Oceanic Institute 1997). Surveys conducted from 1997-2002 are summarized by Marine Research Consultants (Marine Research Consultants 2002). Surveys conducted 2007-2008 surveys are summarized by Marine

Research Consultants (Marine Research Consultants 2008). Surveys conducted from October 2008-2010 are summarized by Ziemann (Ziemann 2008, Ziemann 2009, and Ziemann 2010). The 2012-2014 surveys are summarized by Bybee and colleagues (Bybee and Barrett 2012, Bybee et al. 2013, Bybee et al. 2014). The 2015 surveys are summarized by WHALE Environmental (WHALE Environmental 2015). The 2016, 2017, and 2018 surveys are summarized by Burns and Kramer (Burns and Kramer 2016, 2017, 2018). The 2019 and 2020 surveys are summarized by Burns and Annandale, and the results and findings for the 2021 surveys are reported here.

METHODS

Benthic surveys were conducted using SCUBA at six stations located along the NELHA coastline. Three 50-m transect surveys were completed for each station at deep (~50-fsw), moderate (~35-fsw), and shallow (~15-fsw) depths (Figure 13). This amounted to three surveys at each of the 6 stations, for a total of 18 transects. 10 quadrats, each 1.0 m x 0.6 m, were placed at pre-determined random locations along each of the surveyed transects. All abiotic and sessile biotic organisms within the quadrat boundaries were enumerated by divers and recorded as a measure of percent cover of the benthic substrate. Sessile organisms were taxonomically identified to the species level. Mobile invertebrates were also surveyed and measured in terms of counts of individuals present within the quadrat boundary. All mobile invertebrates were taxonomically identified to the species level. Surveys were conducted along the pre-determined isobaths at long-term monitoring pins installed in 2017. The long-term monitoring pins are located at the following coordinates. Coordinates are only recorded for the 50-fsw depth at sites with steep slopes due to the close linear proximity to the moderate and shallow survey depths. The pins can be found by swimming up-slope from the 50-fsw pin along the bearing indicated in the table below. Only the sites at Wawaloli have three coordinates as the pins are separated by substantial distances due to the minimal bathymetric slope at this site compared to the others. This is the only site that divers are unable to follow the slope and conduct all dives without surfacing and relocating:

Site	GPS	Notes
Ho'ona Bay	50: 19.73255, -156.0578	Mooring located at 30fsw. Pins align across depth gradient on 160-degree bearing and are adjacent to mooring. Surveys conducted along isobaths on west side of each pin.
NPPE	50: 19.73137, -156.0609	Pins align across depth gradient on 90-degree bearing. Surveys conducted along isobaths on west side of each pin.
12" Pipe North	50: 19.72825, -156.0625	Pins are just to south of pipe platform. Chain from pipe aligns with 30fsw pin, and bearing is consistent to 15fsw pin. Surveys conducted along isobaths on southwest side of each pin.
12" Pipe South	50: 19.72627, -156.06159	Pins are located to south of pipe. Follow 50-degree bearing from pipe at each isobaths to the pins. Surveys conducted along isobaths on south side of each pin.
18" Pipe	50: 19.72176, -156.05868	Pins are located to south side of pin at each isobaths. Surveys conducted along isobaths on south side of each pin.

Wawaloli	50: 19.71463, -156.05188 35: 19.7149, - 156.05136 15: 19.71535, - 156.05086	Pins are located at each bearing. Isobaths are much more separated than other sites. Surveys conducted along isobaths on south side of each pin.
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Photographs were taken of each quadrat using an underwater camera. The images were utilized for subsequent point count analysis to analyze benthic cover and provide an archival of images of the substrate. Each photograph was labeled and taken in succession with a picture of the enumerated datasheet, which allows the photos to be properly linked to each quadrat location (Appendix 4) and *in-situ* data recorded by the diver (Appendix 2). Estimates of the benthic composition, in terms of percent cover, were validated using the software CoralNet (Beijbom et al. 2015). Each photograph was cropped, and 100 points were randomly assigned within the quadrat area. The points were manually annotated to and assigned to the biotic or abiotic features they were digitized upon. Values for benthic cover were averaged among the quadrats, and one mean value was computed for each transect in order to avoid pseudo-replication. The data were statistically analyzed using the software package, R. If data met the assumptions necessary for parametric statistical tests (normality, independence, and equal variance), then one-way ANOVA and Tukey pairwise comparisons were used to compare values of benthic cover among the transects at different stations and depths. If the data did not meet the assumptions for parametric statistical tests, then non-parametric alternatives were used (Kruskal-Wallis). The alpha for statistical significance was 0.05, and this was used to determine if any significant differences exist among sites and depths in terms of benthic substrate characteristics (percent cover, species richness, and species diversity).



Figure 13. Six stations with three transects per station at deep (~50-fsw), moderate (~35-fsw), and shallow (~15-fsw) depths along the NELHA coastline. A total of 18 transects are completed for both the benthic monitoring and fish assemblage monitoring. An updated map with aerial imagery is provided on the right with North arrow for spatial reference.

RESULTS

BENTHIC SUBSTRATE CHARACTERIZATION

The biotic benthic features observed in this study included scleractinian stony corals, crustose coralline algae, fleshy macroalgae, echinoderms (sea urchins and sea cucumbers), and gastropod molluscs. The scleractinian stony corals comprised the majority of the benthic substrate among all stations. Abiotic features recorded along the transect surveys included sand and coral rubble. Percent cover, species richness, and species diversity of corals and other benthic biota, as well as abiotic substrate, are presented in detail in Appendix 2 and summarized in Table 5.

The overall percent coral cover among the six stations was 39%, and the most dominant corals were *Porites lobata* (29.5%), *Porites compressa* (17.2%), *Porites evermanni* (10.7%), *Montipora capitata* (5.8%), *Montipora patula* (5.1%), *Pocillopora meandrina* (4.2%), and *Pocillopora grandis* (3.5%). These coral species were present among all the stations. Other corals present were *Leptastrea purpurea*, *Leptastrea bewickensis*, *Montipora flabellata*, *Pavona varians*, *Porites brighami*, *Porites rus* and *Fungia scutaria*. These corals accounted for a small percentage of the overall relative benthic cover. Values of percent cover for the dominant coral species at each station and depth are provided in Table 5.

P. lobata was the most dominant coral among all three depths throughout the six monitoring stations. *P. lobata*, *P. evermanni*, *P. compressa* and *M. capitata* were the dominant corals in the shallow (~15-fsw) and moderate depths (~35-fsw) among the six stations. *P. lobata* and *P. compressa* were the most dominant corals at the deep depths (~50-fsw) among the six stations. *P. meandrina* was most abundant at the 12" Pipe stations. *P. evermanni* was most abundant at Ho'ona Bay, in equal abundance among the other stations and in lowest abundance at the NPPE station. *P. compressa* was most abundant at Ho'ona Bay and NPPE stations. *P. lobata* had the highest levels of abundance at Ho'ona Bay, NPPE, and 18" Pipe stations. *P. lobata* had the highest levels of coral cover among all six stations compared to the other observed species of coral. The distribution, abundance, and percent cover of the corals among all stations in 2021 were similar to 2020 and the previous survey years. Photographs of each photographed quadrat are included in Appendix 4.

Table 5 provides a detailed comparison of the percent cover, species richness, and species diversity of corals among all stations and survey depths. Similar to previous years, the Ho'ona Bay, NPPE, and 18" Pipe sites exhibited the highest levels of coral cover (51.8% 48%, and 36.5% respectively). Coral cover at these three sites was dominated by *P. lobata*, *P. evermanni*, and *P. compressa*. Species richness and species diversity was highest at 12" Pipe and Ho'ona Bay stations. The benthic substrate at these sites were predominantly occupied by *P. lobata*, *P. evermanni*, *P. compressa*, and *M. capitata* (Table 5). Values of coral cover exhibited statistically significant differences among the sites. Overall coral cover was significantly higher ($p < 0.05$, Kruskal-Wallis) at Ho'ona Bay and NPPE than the other sites. *P. lobata* exhibited significantly higher values of cover ($p < 0.05$, Kruskal-Wallis) at Ho'ona Bay, NPPE, and the 18" Pipe site in comparison to the other sites. *P. lobata* exhibited significantly higher values of cover ($p < 0.05$, Kruskal-Wallis) at Ho'ona Bay and NPPE compared to the other sites. *M. capitata* exhibited significantly higher values of cover ($p < 0.05$, Kruskal-Wallis) at both 12" Pipe and the 18" Pipe stations.

Values of overall coral cover were statistically similar among all depths. Moderate depths had the highest cover of 42.3%, which was closely followed by deep depth sites (40.3%) and shallow sites exhibiting exhibited the lowest average value of coral cover (34.4%). *P. compressa* showed significantly higher values of cover ($p < 0.05$, Kruskal-Wallis) at the deep sites compared to moderate and shallow. Among the deep stations, coral was most abundant at the Ho'ona Bay and NPPE sites (72.6% and 51.6%). These statistical patterns in coral cover are similar to the 2017 – 2020 survey years with the same species and depths exhibiting higher levels of coral cover compared to the other locations. The general patterns in coral cover and diversity among the surveyed depths and sites are similar to previous years and showed similar patterns in coral cover among sites in 2016-2020 (Burns and Kramer 2016-2018, Burns and Annandale 2019, Burns et al. 2020). Coral cover values and statistically significant trends in coral cover and species dominance were very similar to 2019 and 2020, which indicates stability in coral community structure among the survey locations in the last three years.

Mobile Benthic Invertebrates

Several mobile invertebrates were observed among all stations. Gastropod molluscs (*Conus spp.*), several species of sea urchins (e.g. *Diadema spp.*, *Echinometra spp.*, *Echinothrix spp.*, *Tripluvetes spp.*, *Acanthaster spp.*), sponges, flatworms, and sea cucumbers (*Holothurian spp.*) were observed among the study sites. Counts of all observed individual invertebrates that were within the survey quadrats were recorded and taxonomically identified to the species level. All data pertaining to the mobile invertebrates are provided in Appendix 2.

Table 5: Summary of benthic substrate data and comparative analyses from surveys conducted in May 2021.

Station	Wawaloli				18" Pipe				12" Pipe South		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Overall coral cover	43.10	48.30	12.00		37.50	41.00	30.90		26.60	38.20	28.10
<i>P. lobata</i>	34.50	34.50	10.00		34.00	36.00	27.50		20.80	29.00	21.50
<i>P. evermanni</i>	10.40	15.00			5.00	20.00				10.00	7.50
<i>P. compressa</i>							7.50			15.00	8.33
<i>P. meandrina</i>									14.00	2.00	5.50
<i>P. grandis</i>	1.50					1.00			1.00		1.50
<i>M. capitata</i>	4.20	9.20	5.00		5.00	6.00	5.70		2.00	8.33	
<i>M. patula</i>	3.00				5.00						
Species count	5.00	3.00	2.00		4.00	4.00	3.00		4.00	5.00	5.00
Species diversity (H)	1.20	1.29	0.80		1.13	1.18	1.09		1.17	1.23	1.12

Station	12" Pipe North				NPPE				Hoona Bay		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Overall coral cover	38.30	28.90	29.90		30.00	45.60	68.50		31.10	51.60	72.60
<i>P. lobata</i>	33.00	24.00	24.80		27.40	37.50	38.50		28.50	36.50	31.50
<i>P. evermanni</i>	10.00	10.00				10.00	6.00		5.00	18.00	15.00
<i>P. compressa</i>						13.75	27.80			15.00	30.70
<i>P. meandrina</i>	3.00	3.50			3.00				2.20	4.33	2.00
<i>P. grandis</i>	1.50		1.50								
<i>M. capitata</i>	3.00	10.00	5.20		4.00	3.70	6.00			3.33	6.75
<i>M. patula</i>		1.00	5.00		5.00		2.00		10.00	3.00	
Species count	5.00	5.00	4.00		4.00	4.00	5.00		4.00	6.00	5.00
Species diversity (H)	1.16	1.20	1.14		1.14	1.23	1.36		1.14	1.30	1.40

Mean value comparisons	Wawa	18" Pipe	12" Pipe S	12" Pipe N	NPPE	H - Bay	p-value	Shallow	Moderate	Deep	p-value
Overall coral cover	34.47	36.47	30.97	32.37	48.03	51.77	<0.01	34.43	42.27	40.33	0.06
<i>P. lobata</i>	26.33	32.50	23.80	27.30	34.50	32.30	<0.01	29.70	33.00	25.60	0.09
<i>P. evermanni</i>	12.70	10.00	9.25	10.00	6.70	15.45	0.46	8.70	14.20	10.00	0.07
<i>P. compressa</i>		7.50	10.00		23.50	28.25	<0.01		14.30	24.88	<0.05
<i>P. meandrina</i>	2.70		9.20	3.30	3.00	2.80	0.92	5.00	3.35	4.34	0.88
<i>P. grandis</i>	5.00	1.50	2.50	5.00			0.37	3.00		5.00	0.12
<i>M. capitata</i>	6.75	5.75	6.75	5.50	4.50	5.30	0.77	3.90	6.70	5.75	0.07
<i>M. patula</i>	3.00	5.00		7.50	3.50	6.50	0.55	5.20	6.50	3.50	0.68
Species count	6.00	6.00	6.00	6.00	6.00	6.00	0.90	6.00	6.00	7.00	0.88
Species diversity (H)	1.10	1.13	1.18	1.16	1.24	1.28	0.76	1.16	1.24	1.15	0.81

COMPARATIVE ANALYSIS OF TEMPORAL TRENDS IN BENTHIC DATA

The goal of this report is to provide a detailed characterization of the marine benthic communities at the six stations used for long-term monitoring adjacent to the NELHA facilities. Previous reports have performed extensive analyses to compare data from these sites from 1992-2012 (Ziemann 2010, Bybee and Barrett 2012). This report will discuss the key findings from these previous reports, as well as reports from 2013-2020, and how they compare to the current data from 2021.

Reports from previous years (1992-2008) showed a pattern of increase in overall coral cover ranging from 16.9% to 54.7%. Surveys conducted in the following years (2009-2015) reported estimates of overall coral cover fluctuating from 39.5% to 52.0%. While several of the changes in overall coral cover among these years were noted as significant (ANOVA, $p < 0.01$), the last six years have provided a consistent range (~25.0 – 50.0%) for which coral cover can be expected among the survey stations and depth gradients. The fluctuations in observed overall coral cover should be expected, as the surveys were not conducted at permanently marked locations and thus inherent variability in benthic cover will be evident among the survey years. The overall coral cover for 2021, 39%, is within this range and shows the benthic communities to exhibit consistent values of coral cover for the last 12 years.

Other studies conducted throughout the 30-year period of monitoring have found significant differences in overall coral cover among the six stations and among the three depth gradients (Ziemann 2010, Bybee et al. 2014). The statistical differences observed among the sites showed that coral cover increased from the Southern to Northern sites, with Ho'ona Bay and NPPE exhibiting statistically higher values of coral cover than the 12" Pipe and 18" Pipe sites, and all sites exhibiting higher coral cover than Wawaloli. *P. meandrina* has also been shown to have significantly higher coral cover at shallow depths compared to deep depths, and *P. compressa* to have higher coral cover at deep depths compared to shallow depths. The 2021 data supported this trend in overall coral cover with significantly higher mean values of overall coral cover observed at the Ho'ona Bay and the NPPE sites compared to the other four monitoring stations. The 2021 data also supported previous studies with *P. compressa* having significantly higher cover values at deeper sites. The 2021 data showed *P. lobata* to have

significantly higher values of cover at all sites among all three depths compared to the other observed coral species. The 2021 data show no significant differences in species richness or species diversity among the six stations and three depth profiles. The levels of overall coral cover and statistical patterns observed among sites and depths were very similar to 2020. These findings indicate all survey locations support coral assemblages of similar diversity and community structure with relatively high levels of coral cover.

Previous reports have documented a pattern of increase in percent cover of *P. lobata* among the six survey stations. The average percent cover of *P. lobata* increased from 10.0% to 30.7% from the years 1992-2012. The 2013 survey report documented significant increases (ANOVA, $p < 0.05$) in coral cover at the 18" Pipe station and NPPE station compared to the 2010 and 2012 data (Ziemann 2010). The average percent cover of *P. lobata* among all stations was 30.0%, 29.0%, and 25.8% for 2013, 2014, and 2015 respectively (Bybee et al. 2014, WHALE Environmental 2015). The average percent cover of *P. lobata* among all stations in 2021 was 29.5%. This value is similar to the average observed percent coral cover in 2020 (23.0%) and slightly elevated compared to the trend for previous years. While this value is comparable to values observed in the years 2013-2015, there was 10.7% cover attributed to *P. evermanni*, which was possibly not identified in previous years due to morphological similarity. This value of *P. evermanni* is similar to 2020 (10.3%). The values of ~10% *P. evermanni* cover in 2020 and 2021 is higher than reported for previous years, which again is likely due to the morphological similarity between these species. Overall this indicates a high level of mounding *Porites* corals among the survey stations, as the average percent cover of mounding *Porites* coral in 2021 is not statistically different to the previous five years. The differences in overall coral cover from 2013 to 2021 are less than 5.0%, which indicates consistency in this coral being the dominant coral genus and morphology among the long-term study sites. The 2021 values of coral cover for mounding *Porites* were also similar to prior surveys conducted during the previous 6-years, thus indicating these are the dominant coral colonies among these stations and this genus is exhibiting minimal changes in levels of coral cover.

The average values of *P. compressa* cover have not fluctuated significantly over the last several years and show a consistent trend of higher percent cover at deeper depths. The 2021 data also support this trend; with nearly all the *P. compressa* coral cover being observed at the

moderate and deeper depth sites. This is expected, as this coral has a delicate morphology and typically grows at deeper depths along the reef slope throughout Hawaii.

The average values of *P. meandrina* have also shown a general increase from 1992 – 2014 (Ziemann 2010). The percent cover of *P. meandrina* exhibited a wide range in coral cover in 2013 (3.9% - 21.6%) and was found to have statistically higher values in shallow sites in 2014 (Bybee et al. 2014). The 2021 data are similar to the generally lower values recorded in 2017 and 2018, and no colonies were observed at a few stations. The overall cover of *P. meandrina* cover did not exhibit statistically significant differences among sites compared to the past three years, with an average observed cover of 4.2%. Values of *P. meandrina* cover in 2021 were highest at shallow depths. The variability in *P. meandrina* coral cover over the last several years may be associated with the loss of *P. meandrina* corals along leeward coastlines at shallow depths throughout Hawaii due to regional increases in seawater temperature seen in 2014 and 2015. This coral species is fast growing and relatively short-lived, thus the fluctuations seen throughout the survey years are expected considering its life history traits. The relatively consistent levels of *P. meandrina* cover in shallow depths observed in 2021, compared to the past five years, suggests some recovery and recruitment of this species may be occurring. Conducting future surveys in the same locations will help to track the community structure of this coral.

The counts of mobile invertebrate species from the 2021 surveys were similar to observations documented throughout the duration of the NELHA marine biota monitoring program.

DISCUSSION

Coral reef ecosystems throughout Hawaii exhibit distinct zonation patterns with depth that are driven by physical parameters such as disturbance and light availability (Dollar 1975, Dollar and Tribble 1993, Ziemann 2010). Corals with high growth rates or robust morphologies, such as *P. meandrina*, *P. lobata*, and encrusting corals, tend to be dominant in shallow reef zones where disturbance is high due to water motion. Larger mounding corals (e.g., *P. lobata*, *P. evermanni*) and delicate branching corals (*P. compressa*) are more dominant at deeper depths where disturbance due to wave action is minimal. The coral assemblages along the nearshore coastline surrounding the NELHA facility exhibit these typical zonation patterns (Marine Research Consultants 2008, Ziemann 2010, Bybee et al. 2014).

The overall coral cover, and percent cover of the dominant coral species (*P. lobata*), have exhibited a trend of increasing coral cover from south to north and from shallow to deep in previous years (Ziemann 2010, Bybee et al. 2013). Studies in 2014 and 2015 showed no significant increase in coral cover, and only found a few statistically significant differences in coral cover among the sites and depth gradients (Bybee et al. 2014, WHALE Environmental 2015). The data collected in 2016 showed similar characteristics of coral community structure, with no significant differences among either sites or depths (Burns and Kramer 2016). The general range of coral cover among the dominant species has also remained relatively stable from 2009-2020. The data from 2021 exhibited a slight increase compared to 2018, but patterns in community structure were statistically similar, thus suggesting coral composition has remained similar at these sites. The 2021 data did support the previous findings of statistically significantly higher coral cover at the more northern sites, Ho'ona Bay and NPPE. The results of the statistical analyses found similar trends among species composition, diversity, and overall coral cover in 2021 compared to the 2020 survey data.

The mean values of *P. meandrina* cover have shown a significant decrease in abundance from shallow to deep and have been observed at all shallow and moderate depths (Bybee et al. 2014, WHALE Environmental 2015). As mentioned above, this coral has high growth rates and serves as a colonizer of disturbed habitat in areas with high water motion (Dollar 1982). The

2016 data showed a decrease in *P. meandrina* cover in shallow sites, which is likely due to the statewide episodic increase in seawater temperatures in 2014-2015. The values of coral cover of *P. meandrina* were highest at shallow sites in 2021, and within ~1% of the coral cover observed in 2020, which suggests potential recruitment and recovery of this species. Another positive indication of recovery is the observation of *P. meandrina* among all three depths and at all sites except the 18" Pipe station. Future surveys at the same spatial locations will enable documentation of how effectively *P. meandrina* can re-colonize at the shallow survey stations and how the community structure of this species may change following the prior disturbances.

The results and findings of the surveys conducted up until 2017 have shown statistically significant variability in the characterization of coral communities among the six stations. Considering that no permanent markers were used for the transects, there is an expected inherent variability due to the confounding factor of being unable to repeat surveys in the exact same spatial locations. Utilizing permanent markers will reduce this error and enhance the capability to track changes in reef structure over time. Permanent pins were established in 2017 to help mitigate this problem. Stainless steel pins were placed at the start location for transect surveys at each depth among the six sites. It is promising to see high similarity in values of coral cover from 2017 - 2021, the five years using the permanent pins. While variability will always exist due to the randomly selected locations for quadrats along the transect, the high similarity in values among the previous two years suggest the permanent sites are helping in accurately detecting changes in the benthic communities at these survey sites.

Despite variability in the mean values of coral cover among the survey stations and depths over time, the data has shown these corals exhibit patterns in zonation and community structure that are typical of Hawaiian reefs on leeward coastlines. The consistent values of species richness and diversity indicate the assemblages have not experienced any dramatic changes over the last two decades. The 2021 data show no significant variation in benthic composition among the stations and depths, and no significant changes compared to the last several years of monitoring. These findings indicate the nearshore marine benthic communities are not exhibiting any signs of detrimental impacts associated with the NELHA facility.

MARINE FISH BIOTA SURVEY

INTRODUCTION

The Natural Energy Laboratory of Hawaii Authority (NELHA) is a State of Hawaii agency that is administratively attached to the Department of Business, Economic Development, and Tourism (DBEDT). NELHA's mission is to develop and diversify the Hawaii economy by providing resources and facilities for energy and ocean-related research, education, and commercial activities in an environmentally sound and culturally sensitive manner. NELHA operates an ocean science and technology facility at Kailua-Kona on the West side of Hawaii Island. The facility operations are focused on research, education, and commercial activities that support sustainable industry development in Hawaii.

One of the utilities provided by the NELHA is the pumping of cold seawater from deep ocean depths (~2,000 to ~3,000-fsw) to the surface through large pipes that have been installed on the benthic substrate in several locations along the coastal border of the facility. The pipelines run perpendicular to the shoreline to depths that enable delivery of nutrient rich water, which is used in a variety of aquaculture and sustainable energy activities on land. Concerns over water discharge from the various aquaculture and innovative energy operations, and the potentially negative impacts of this discharge to the adjacent reef environments, have prompted annual monitoring of benthic and fish biota.

Keahole Point is known to support fish populations with high abundance and diversity compared to other sites throughout the Hawaiian Islands (Brock 1954, Brock, 1985; Brock, 1995). Productive fish assemblages are important resources to the State; thus conservation and management strategies are needed to avoid declines in the abundance and biomass of coastal fish populations. The NELHA facility is located along the shoreline of this point, thus annual monitoring has been conducted for the past 30 years to ensure that any impacts to water quality, associated with activities conducted on the NELHA facility, are not causing detrimental changes to the nearshore fish assemblages in this area.

The annual fish surveys utilize conventional techniques to detect any changes in the abundance, diversity, and biomass of all fish populations located at the same stations used for monitoring the benthic substrate. Utilizing this monitoring approach allows for detecting any detrimental reductions in the structure and overall productivity of these fish assemblages, which may be associated with anthropogenic activities on the adjacent land-tract.

METHODS

Surveys of the nearshore fish assemblages were conducted at the same six stations and depth gradients (18 total transect surveys) used for assessment of the benthic substrate (Figure 13). Surveys were conducted using SCUBA over the entire area of 4 x 25-m belt transects. Standard visual assessments were used to record the abundance and length of all fish present within the belt transects area (Brock 1954). The method used for this survey approach is the same belt-transect technique utilized by multiple agencies (e.g., NOAA, DAR, UH) for standardized monitoring and assessment of fish assemblages on Hawaiian coral reefs. Divers taxonomically identified all fish within the belt-transect area to the species level and also recorded the length of each fish (cm).

Previous studies had utilized permanent transects that were marked by subsurface floats to ensure repeatability in the same spatial location (Brock 2008). The markers have not been present since 2012, so surveys conducted during the last five years have been performed at the same locations and depths (~15-fsw, ~30-fsw, and ~50fsw) of the benthic characterization surveys. Divers work in a pair, with the fish surveyor deploying the transect-tape while visually assessing all fish present within the belt-transect area. The other diver waits behind the fish surveyor, in order to avoid disturbing the fish, and then performs the benthic characterization in the same spatial area. This approach allows for ensuring both habitat and fish assemblage data are collected from the same location, and thus can be collated if necessary.

The visual estimates of fish length (cm) are converted to biomass using the standard formula to compute values of biomass in g/m² ($M = a * L^b$). a and b are fitting parameters based on the specific fish species, L represents length in mm, and M represents mass in grams. Fitting parameters were obtained from the Fishbase online database (Froese and Pauley 2000). Diversity was calculated using the Shannon Index (H), as this index has been used in the previous monitoring reports (Ziemann 2010).

$$\hat{H} = - \sum_{i=1}^n \frac{n_i}{n} \ln \frac{n_i}{n}$$

The data were statistically analyzed using the software package, R. If data met the assumptions necessary for parametric statistical tests (normality, independence, and equal variance), then one-way ANOVA and Tukey pairwise comparisons were used to compare mean values of fish assemblage parameters among the transects at different stations and depths. If the data violated the assumptions for parametric statistical tests, then non-parametric alternatives were used (Kruskal-Wallis). The alpha for statistical significance was 0.05, and this was used to determine if any significant differences exist among sites and depths in terms of fish assemblage structure (species count, number of species, species diversity, biomass).

RESULTS

The resulting mean values for each of the parameters measured for this study (total fish count, number of species, species diversity, biomass) are provided in Table 6, and the complete dataset is provided in Appendix 3.

Total Number of Individuals

The total number of individual fishes was highest at 12" Pipe South and the lowest was at Wawaloli, which is similar to patterns seen from 2016-2020 where the northern sites have higher counts of individual fish. Hoona Bay, NPPE, and 18" Pipe all had similarly high average values of fish counts (291, 280.3, and 280 respectively), and the high average number observed at shallow and moderate depths at the 12" Pipe South station were due to large schools of *Chromis spp.* that were observed in 2021. The range in the number of individual fish observed among all survey transects was 72 to 702. Sites in shallow depths had the highest observed average fish counts (322.5), followed by moderate depths (276) and deep depths (229.3). While there were differences in the mean values, there were no statistically significant differences in the total number of individual fishes counted among all six stations ($p=0.08$) or among the three depth gradients ($p=0.29$). All values are reported in Table 6.

Number of Species

The mean number of species recorded was highest at the 12 Pipe North and lowest at Wawaloli. This range in mean number of species was 9 to 31. The shallow, moderate, and deep habitats had 21-24 species of fish recorded for surveys among these depths. While there were differences in mean values of the number of species recorded, there was no statistically significant difference among the six stations ($p=0.09$) or among the three depth gradients ($p=0.68$). All values are reported in Table 6.

The fish families that exhibited the highest abundance among all surveys were the *chaetodontids* (butterfly fish), *pomacentrids* (damsel fish), *cirrhitidae* (hawkfish), *labridae* (wrasses), and *acanthurids* (surgeon fish). The most abundant species represented among the surveys were *Z. falvenscens*, *A. nigrofuscus*, *T. duperrey*, *C. strigosus*, *C. sordidus*, *N. literatus*,

C. multicinctus, *C. agilis*, *C. vanderbilti*, *P. arcatus*, *H. ornatissimus*, *G. varius*, *C. jactator*, *S. bursa*, *C. vanderbilti*, *P. multifasciatus*, *C. agilis*, *A. olivaceus*, *C. hawaiiensis*, *P. jonstonianus*, *S. fasciolatus*, *C. ornatissimus*, *C. quadrimaculatus*, *P. octotania*, and *Z. cornutus*. These fish were represented among all stations and depths surveyed for the study. The patterns in abundance were similar to previous years.

Species Diversity and Biomass

Species diversity ranged from 1.79 at Wawaloli to 3.51 at 12" Pipe North. The mean species diversity among the deep depths was 2.60, 2.75 among moderate depths, and 2.71 among the shallow depths. There were no significant differences in species diversity among the six stations surveyed ($p=0.20$). There were also no significant differences in species diversity among the three depth gradients ($p=0.83$).

Fish biomass was highest at the 12" Pipe North (210.84 g/m²) and lowest at Wawaloli (92.06 g/m²). Biomass was lowest at moderate depths (151.67 g/m²), and highest at the deep depths (168.10 g/m²). No significant differences in mean biomass were detected among the depth gradients ($p=0.64$). Fish biomass was statistically significantly higher at Hoona Bay, NPPE, and the 12" Pipe North and South stations in comparison to the 18" Pipe and Wawaloli stations (Kruskal-Wallis, $p<0.05$). This trend indicates more biomass at the northern sites, which matches the statistically higher values in coral cover at the northern sites in comparison to the southern sites.

Table 6: Summary of fish survey data and comparative analyses from surveys conducted in May 2021.

Station	Wawaloli				18" Pipe				12" Pipe South		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Fish count	72.00	104.00	83.00		286.00	240.00	314.00		702.00	782.00	138.00
Number of species	11.00	20.00	9.00		31.00	23.00	24.00		24.00	20.00	22.00
Diversity	2.05	2.67	1.79		3.31	2.10	2.51		1.85	2.21	3.11
Biomass	67.60	114.99	93.58		152.98	107.71	128.22		179.67	160.31	199.16
Station	12" Pipe North				NPPE				Hoona Bay		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Fish count	113.00	155.00	264.00		445.00	184.00	212.00		317.00	191.00	365.00
Number of species	24.00	31.00	26.00		21.00	20.00	22.00		28.00	30.00	28.00
Diversity	3.51	3.34	2.55		2.47	3.05	2.68		3.07	3.16	2.98
Biomass	241.23	161.17	230.11		195.50	174.88	184.54		166.67	190.98	174.22
Mean value comparisons	Wawa	18" Pipe	12" Pipe S	12" Pipe N	NPPE	H - Bay	p-value	Shallow	Moderate	Deep	p-value
Fish count	86.33	280.00	540.67	177.33	280.33	291.00	0.08	322.50	276.00	229.33	0.29
Number of species	13.00	26.00	22.00	27.00	21.00	28.00	0.09	23.00	24.00	21.00	0.68
Diversity	2.17	2.64	2.39	3.13	2.73	3.07	0.20	2.71	2.75	2.60	0.83
Biomass	92.06	129.64	179.71	210.84	184.97	177.29	<0.05	167.43	151.67	168.10	0.64

COMPARATIVE ANALYSIS OF TEMPORAL TRENDS IN FISH DATA

The goal of this report is to provide a detailed characterization of the nearshore fish assemblages at the six stations and three depth gradients used for long-term monitoring of marine habitats adjacent to the NELHA facilities. Previous reports have performed extensive analyses to compare data from these sites from 1992-2016 (Ziemann 2010, Bybee and Barrett 2012, Bybee et al. 2013, 2014, Whale Environmental 2015, Burns and Kramer 2016). This report will discuss the key findings from these previous reports and how they compare to the current data from the 2021 surveys.

Previous studies have reported variation in fish assemblage structure over the past 30 years of the annual monitoring program, but no significant changes have been documented that are attributed to anthropogenic impacts or detrimental declines in fish productivity due to acute or prolonged disturbances (Ziemann 2010, Bybee et al. 2014).

Several years have exhibited substantial variation in mean values of fish counts and biomass. For example, 2012 had statistically significantly lower values of overall species count, species diversity, and biomass compared to data from 2010 (Bybee et al. 2014). A significant increase in these parameters was observed in 2013, and then values for all parameters were statistically similar in 2014 and 2015 (Bybee et al. 2014, WHALE Environmental 2015). All parameters showed a slight increase in 2015, and the 2016 data is not significantly different to the 2010 data. Results from the 2016 surveys showed a marked increase in abundance, diversity, and biomass of the fish assemblages among all stations and depths. The 2021 data exhibited similar patterns and values for all parameters observed from 2016 - 2020 (Burns and Kramer 2016, 2017, 2018, Burns and Annandale 2019, Burns et al. 2020). The data from the past six years suggests the sites support very abundant and diverse fish assemblages. The lack of statistically significant variation suggests all study sites support abundance and diverse fish assemblages. The 2021 data show a statistically significant increase in biomass at the northern sites (Hoona, NPPE, 12" North, 12" South) in comparison to the southern sites (18" Pipe, Wawaloli). This trend matches what was found for values of average coral cover, and suggests there may be more complex and dynamic habitat at the northern sites that supports higher values of coral cover and fish biomass in comparison to the southern sites.

DISCUSSION

Previous reports have suggested the variability in fish assemblage data is likely driven by large schools of reef-fish that sporadically enter into the belt-transect areas during the surveys (Ziemann 2010, Bybee et al. 2014). Reef fish communities are known to be highly variable in both spatial and temporal scales. Conducting the fish surveys on an annual basis provides a coarse resolution of temporal variability in fish assemblage structure, and likely contributes to the variability observed over the duration of this monitoring program. Furthermore, the different observers conducting the surveys will also introduce a level of variability in the data.

Small methodological changes were introduced in 2013 in order to minimize diver-based disturbance to the fish communities. Fish assemblage parameters exhibited a statistically significant increase that year yet was still lower than values obtained in 2010 (Bybee et al. 2014). Attempting to reduce observer bias is important but will not adequately allow for diminishing the confounding factors and determining the precise sources of variability in the data. The 2016 - 2021 surveys were conducted using the standardized approaches that are utilized by multiple agencies for monitoring and assessing fish assemblages throughout Hawaii (e.g., NOAA, DAR, UH). Values in 2021 were higher than some previous years, but in the same range as those observed from 2016 - 2020. These findings suggest that variability due to presence of the divers is minimal compared to the natural variability in fish assemblage structure. Fish are highly mobile, and their spatial habitat ranges in conjunction with a wide array of life-history traits create inherent variability in the parameters being assessed by this study. Therefore, the standardized approach utilized by this monitoring program should be expected to produce variable results yet is entirely capable of detecting dramatic loss of fish abundance and productivity. Examining data across the 30-year timespan of the monitoring program is effective for noticing any substantial detrimental changes that may be associated with acute or long-term disturbances.

A general pattern that has been detected in previous years was that fish assemblages exhibited higher abundance, diversity, and biomass near the Pipe sites and lower values off Wawaloli Beach. This pattern is still evident, as values at Wawaloli were lowest in 2014, 2015-2020, and

in the 2021 data (Bybee et al. 2014, WHALE Environmental 2015, Burns and Kramer 2016-2018, Burns and Annandale 2019, Burns et al. 2020, Table 6). The reason of this pattern is likely habitat differences. Both the northern sites and those adjacent to the pipes display steep topographic relief with highly complex basalt substrate. Complex habitat is a known driver of fish abundance and diversity. The Wawaloli Beach site is in an embayment, and the substrate not occupied by live coral is predominantly sand (Appendix 2 and 4). These differences in habitat composition may be driving the consistent differences in fish assemblages seen at Wawaloli, and they will likely remain evident in future surveys. The 2021 data continued to support this trend with statistically significantly higher values of biomass observed at the northern sites compare to the 18" Pipe and Wawaloli sites. Other than biomass, all other variables (fish count, number of species, diversity) were statistically similar among sites and exhibited similar ranges of values to 2020 and pervious survey years.

In summary, the reports conducted over the past 30 years show variability in fish assemblage data, but long-term trends indicate that the fish communities in the area are highly productive and diverse. There are no dramatic declines in abundance or changes in population structure that indicate any detrimental impacts are associated with proximity to the NELHA facility.

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APPENDICES

Appendix 1 – Pool Monitoring

Appendix 1.1. Physical characteristics of Northern and Southern complex anchialine pools, summarized from faunal surveys conducted from May 1989 to October 2008 (Brock 2008, Ziemann and Conquest 2008), and water quality surveys in 2009. Pool S-10 was not included during these surveys.

Area	Pond number	Dimensions (m)	Basin Characteristics	Salinity (2009) (ppt)
Northern Ponds	N-1	15.5 x 6	Deep mud substrate; in pahoehoe/basalt cobble	10
	N-2	1 x 1	Rubble basin substrate; in pahoehoe	10
	N-3	7.5 x 3	Cobble basin substrate; in pahoehoe	9
	N-4	2 x 2	Rubble and mud substrate; in pahoehoe	9
	N-5	7.5 x 3	Two inter-connected basins in cobble	10
Southern Ponds	S-1	1.4 x 1.2	Pahoehoe and rubble substrate	5
	S-2	1 x 1	Pahoehoe and rubble substrate	7
	S-3	1 x 1	Pahoehoe and rubble substrate	8
	S-4	0.075 x 0.075	Pahoehoe and rubble substrate	8
	S-5	2 x 2.5	Pahoehoe and rubble substrate	8
	S-6	0.2 x 0.05	Pahoehoe and rubble substrate	8
	S-7	1 x 1.4	Pahoehoe and rubble substrate	9
	S-8	1 x 1	Pahoehoe and rubble substrate	8
	S-9	0.2 x 0.05	Small a'a crack	8

Appendix 1.2. Faunal census data reported for Northern and Southern complex anchialine pools located within and surrounding the NELHA facility, during surveys conducted from May 1989 to August 2008 (Brock 2008). Introduced fish species (Poeciliids) were recorded as present (x) or absent (0).

Survey Date	Pond: N-1 (Count/0.1m ²)							Pond: N-2 (Count/0.1m ²)			Pond: N-3 (Count/0.1m ²)								
	Thiarid Snails (Melania sp.)		H. rubra a	Poecilia sp.	M. grandimanus	P. debilis	M. messor	T. cariosa	Thiarid Snails (Melania sp.)	H. rubra a	Poecilia sp.	Thiarid Snails (Melania sp.)			H. rubra		Poecilia sp.	M. lar	P. debilis
	a	b										a	b	c	a	b			
May 1989	78	71		x					36	22	0	62	21		1	15	0		0
Oct 1991	35	52		x					42	15	0	12	9	0	0	28	0		0
Mar 1992	49	31		x					72	3	0	67	23	0	0	0	x		0
May 1992	56	29		x					85	0	x	29	41	0	0	0	x		1
Oct 1992	24	62		x					41	72	0	24	15	6	15	38			1
May 1993	31	54		x					22	0	x	19	26	0	0	0	0		2
Dec 1993	42	59		x					27	0	x	31	17	8	0	0	x		1
May 1994	31	72		x					31	0	x	42	24	5	2	0	x		2
Jun 1994	43	68		x	2				28	4	x	51	33	6	0	0	x	1	1
Oct 1994	19	72		x	0				19	0	x	72	41	9	0	0	x	0	1
Mar 1995	40	52		x	0				31	42	0	40	23	9	0	0	x	1	2
Jun 1995	63	50		x	1	2			28	0	x	53	19	14	0	0	x	0	3
Dec 1997	39	67		x	0		4		33	0	x	49	31	18	0	0	x	0	0
Jun 1998	41	53		x	0		7	6	44	0	x	57	22	34	0	0	x	0	0
Nov 1998	38	52		x	0		9	5	56	0	x	28	26	14	0	0	x	0	0
May 1999	27	49		x	0		6	6	47	0	x	39	24	22	0	0	x	0	0
Dec 1999	36	68		x	0	0	8	3	47	0	x	37	31	12	0	0	x	0	0
June 2000	42	37		x	0	0	9	2	39	0	x	44	51	6	0	0	x	0	0
Nov 2000	34	55		x	0	0	5	4	51	0	x	34	29	9	0	0	x	0	0
May 2001	39	27		x	0	0	4	3	79	0	x	41	22	3	0	0	x	0	0
Nov 2001	37	23		x	0	0	6	2	66	0	x	39	33	3	0	0	x	0	0
May 2002	29	47		x	0	0	5	9	72	0	x	27	19	5	0	0	x	0	0
Dec 2002	21	17		x	0	0	7	5	37	0	x	41	38	5	0	0	x	0	0
Dec 2007	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug 2008	4	0		0	0	0	0	0	3	10	0	2	0	0	25	21	0	0	0

Appendix 1.2. (continued)

Survey Date	Pond: N-4 (Count/0.1m ²)						Pond: N-5 (Count/0.1m ²)					
	Thiarid Snails (Melania sp.)		<i>H. rubra</i>		Poecilia sp.	<i>M. grandimanus</i>	Thiarid Snails (Melania sp.)		<i>H. rubra</i>	Poecilia sp.	<i>M. grandimanus</i>	<i>M. messor</i>
	a	b	a	b			a	b	a			
May 1989	39	115	3	21	0		2	4	0	0		
Oct 1991	0	4	0	23	0		2	4	0	0		
Mar 1992	0	9	0	0	x		31	2	0	x		
May 1992	14	3	0	0	x		9	1	0	x		
Oct 1992	10	85	12	31	0		8	1	41	0		
May 1993	9	42	0	0	x		12	1	0	x		
Dec 1993	14	61	0	0	x		23	17	0	x		
May 1994	12	53	0	0	x		19	27	0	x		
Jun 1994	26	49	0	0	x		27	6	0	x		
Oct 1994	25	19	0	0	x		51	29	0	x		
Mar 1995	26	19	0	0	x	5	21	19	0	x	3	
Jun 1995	25	23	0	0	x	0	29	16	0	x	0	
Dec 1997	27	17	0	0	x	0	33	13	0	x	0	3
Jun 1998	33	21	0	0	x	0	42	27	0	x	0	5
Nov 1998	29	26	0	0	x	0	23	19	0	x	0	5
May 1999	27	19	0	0	x	0	24	12	0	x	0	4
Dec 1999	36	29	0	0	x	0	16	19	0	x	0	5
June 2000	29	17	0	0	x	0	12	26	0	x	0	5
Nov 2000	27	21	0	0	x	0	21	17	0	x	0	5
May 2001	dry						19	14	0	x	1	7
Nov 2001	29	17	0	0	x	0	17	12	8	x	0	5
May 2002	31	20	0	0	x	0	23	16	0	x	0	6
Dec 2002	27	18	0	0	x	0	17	21	0	x	0	3
Dec 2007	dry						0	0	0	0	0	0
Aug 2008	2	1	23	17	0	0	4	5	80	0	0	0

Appendix 1.2. (continued)

Survey Date	Pond: S-1 (Count/0.1m2)				Pond: S-2 (Count/0.1m2)			Pond: S-3 (Count/0.1m2)				Pond: S-4 (Count/0.1m2)			
	<i>H. rubra</i>	<i>Poecilia</i> sp.	<i>M. grandimanus</i>	<i>Amphipoda</i>	<i>H. rubra</i>	<i>Poecilia</i> sp.	<i>Amphipoda</i>	<i>H. rubra</i>	<i>Poecilia</i> sp.	<i>M. lohena</i>	<i>Amphipoda</i>	<i>H. rubra</i>	<i>Poecilia</i> sp.	<i>Abudefduf sordidus</i>	<i>Amphipoda</i>
May 1989	56		0	0	71		185	38			54	9			0
Oct 1991	29		0	0	31		32	21			14	42			0
Mar 1992	31		1	0	40		6	43			9	6			0
May 1992	61		1	6	14		2	64			12	9			2
Oct 1992	29		0	19	34		9	56			9	4			12
May 1993	49		0	12	54		2	dry				dry			
Dec 1993	37		1	15	dry			94			12	dry			
May 1994	47		2	21	dry			37			14	21			6
Jun 1994	52		0	18	dry			86	1		3	dry			
Oct 1994	84		0	26	dry			94	0		16	39			12
Mar 1995	61		0	23	dry		9	dry				dry			
Jun 1995	57		0	27				78		2	21	16			3
Dec 1997	73		0	24	dry			dry				dry			
Jun 1998	49		0	23			12	14		0	17	0			2
Nov 1998	81		0	14	dry			dry				dry			
May 1999	63		0	12			14	29		0	10	0			3
Dec 1999	65		0	14	dry			8		0	12	15			4
June 2000	35		0	16	6		0	17		0	9	31			8
Nov 2000	35		0	9	dry			filled w/ sand				dry			
May 2001	55		0	11	dry							dry			
Dec 2002	58		0	9	48		1	0		0	3	38			1
Dec 2007	0	x	0	0	0	x	0	0	x	0	0	8			0
Aug 2008	0	x	0	0	0	x	0	0	x	0	0	0		1	0

Appendix 1.2. (continued)

Survey Date	Pond: S-5 (Count/0.1m2)				Pond: S-6 (Count/0.1m2)				Pond: S-7 (Count/0.1m2)				Pond: S-8 (Count/0.1m2)			Pond: S-9 (Count/0.1m2)	
	<i>H. rubra</i>	<i>Poecilia</i> sp.	<i>M. grandimanus</i>	<i>Amphipoda</i>	<i>H. rubra</i>	<i>Poecilia</i> sp.	<i>Amphipoda</i>	<i>Amphipoda</i> (white)	<i>H. rubra</i>	<i>Poecilia</i> sp.	<i>M. grandimanus</i>	<i>Amphipoda</i>	<i>H. rubra</i>	<i>Poecilia</i> sp.	<i>M. grandimanus</i>	<i>H. rubra</i>	<i>Poecilia</i> sp.
May 1989	43			94	3		0	0	97		0.5	11					
Oct 1991	121			65	3		9	2	95		0.5	17					
Mar 1992	131			48	1		2	0	87		0.5	12					
May 1992	92			27	1		3	0	96		0.75	10	65		0.5		
Oct 1992	107			34	7		3	2	49		1	13	72		0.75	3	
May 1993	113		1	7	5		2	1	72		0.5	9	81		1	dry	
Dec 1993	0		0	0	4		3	1	68		1	10	71		1	dry	
May 1994	0		1	0	7		3	3	82		2	18	68		2	dry	
Jun 1994	0		4	0	4		3	1	94		1	23	81		1	dry	
Oct 1994	0		1	0	23		0	2	113		1	39	80		1	14	
Mar 1995	0		2	0	dry				77		1	25	52		1	dry	
Jun 1995	0		1	0	17		0	0	121		3	29	61		1	9	
Dec 1997	0		0	0	dry				86		0	21	55		0	dry	
Jun 1998	0		0	0	12		2	0	79		1	31	57		0	12	
Nov 1998	0		0	0	dry				87		2	20	63		0	dry	
May 1999	0		0	0	6		3	0	59		3	18	72		1	10	
Dec 1999	0		0	0	dry				43		2	14	30		0	4	
June 2000	0		0	0	4		0	0	41		1	22	38		0	1	
Nov 2000	0		0	0	dry				56		1	6	48		0	7	
May 2001	35		0	0	dry				47		1	9	80		0	dry	
Dec 2002	49		0	4	7		0	0	0	x	1	0	81		0	27	
Dec 2007	3		0	0	dry				0	x	0	0	0	x	0	0	x
Aug 2008	0	x	0	0	5		0	0	0	x	0	0	0	x	0	0	x

Appendix 2 - Nearshore marine habitat characterization data

Table 2.1 Benthic habitat characterization data - Algae

Site	Depth	Location	10to Narr	Sub-Categories																									
				Algae																									
				Asparagopsis taxiformis (Asptax)	Caulerpa racemosa (Caurac)	Caulerpa serrulata (Caulser)	Caulerpa sertularioides (Caulsert)	Codium arabicum (Codara)	Crustose Coralline (CCA)	Cyanophyta (BG)	Dasya iridescens (Dasyir)	Dichotomaria marginata (Dichmar)	Dictyosphaeria cavernosa (Dictcav)	Dictyosphaeria versluysii (Dictver)	Dictyota species (Dicty)	Gibbsmithia hawaiiensis (Gibhaw)	Halimeda opuntia (Halop)	Lobophora variegata (Lobvar)	Martensia flabelliformis (Marflab)	Martensia fragilis (Marfrag)	Neomeris annulata (Neoman)	Padina species (Padina)	Portieria homemanii (Porhor)	Predaea weidii (Prewel)	Sargassum (Sarg)	Turbinaria ornata (Turbor)	Turf (Turf)	Ventricaria ventricosa (venven)	red algae
12S	50	1																									75		
12S	50	2																									60		
12S	50	6																									75		
12S	50	9																									50		
12S	50	13																									80		
12S	50	14																									75		
12S	50	16																									80		
12S	50	18																									75		
12S	50	22																									90		
12S	50	24																									59		
12S	35	0																									75		
12S	35	3																									65		
12S	35	7																									53		
12S	35	8																									65		
12S	35	11																									40		
12S	35	13																									45		
12S	35	14																									57		
12S	35	18																									68		
12S	35	21																									60		
12S	35	22																									90		
12S	15	0																									73		
12S	15	2																									85		
12S	15	4																									70		
12S	15	5																									90		
12S	15	7																									58		
12S	15	11																									81		
12S	15	16																									93		
12S	15	18																									55		
12S	15	19																									45		
12S	15	20																									84		

Site	Depth	Location	10to Nam	Sub-Categories	
				Algae	
				Asparagopsis taxiformis (Asptax)	
				Caulerpa racemosa (Caurac)	
				Caulerpa serrulata (Caulser)	
				Caulerpa sertularioides (Caulsert)	
				Codium arabicum (Codara)	
				Crustose Coralline (CCA)	
				Cyanophyta (BG)	
				Dasya iridescens (Dasyir)	
				Dichotomaria marginata (Dichmar)	
				Dictyosphaeria cavernosa (Dictcav)	
				Dictyosphaeria versluysii (Dictver)	
				Dictyota species (Dicty)	
				Gibbsmithia hawaiiensis (Gibhaw)	
				Halimeda opuntia (Halop)	
				Lobophora variegata (Lobvar)	
				Martensia flabelliformis (Marflab)	
				Martensia fragilis (Marfrag)	
				Neomeris annulata (Neoman)	
				Padina species (Padina)	
				Portiera hornemanni (Portor)	
				Predaea weldii (Prewel)	
				Sargassum (Sarg)	
				Turbinaria ornata (Turbor)	
				Turf (Turf)	
				Ventricaria ventricosa (venven)	
				red algae	
12N	50	0			70
12N	50	2			78
12N	50	6			73
12N	50	7			65
12N	50	9			45
12N	50	12			67
12N	50	15			85
12N	50	18			78
12N	50	21			75
12N	50	23			65
12N	35	1			74
12N	35	4			62
12N	35	5			85
12N	35	8			70
12N	35	10			80
12N	35	13			55
12N	35	16			55
12N	35	19			80
12N	35	24			80
12N	35	25			70
12N	15	0			77
12N	15	3			67
12N	15	4			55
12N	15	9			60
12N	15	10			68
12N	15	11			58
12N	15	14			40
12N	15	18			57
12N	15	21			85
12N	15	22			50

Site	Depth	Location	10to Narr	Sub-Categories	
				Algae	
				Asparagopsis taxiformis (Asptax)	
				Caulerpa racemosa (Caurac)	
				Caulerpa serrulata (Caulser)	
				Caulerpa sertularioides (Caulsert)	
				Codium arabicum (Codara)	
				Crustose Coralline (CCA)	
				Cyanophyta (BG)	
				Dasya iridescens (Dasyir)	
				Dichotomaria marginata (Dichmar)	
				Dictyosphaeria cavernosa (Dictcav)	
				Dictyosphaeria versluysii (Dictver)	
				Dictyota species (Dicty)	
				Gibbsmithia hawaiiensis (Gibhaw)	
				Halimeda opuntia (Halop)	
				Lobophora variegata (Lobvar)	
				Martensia flabelliformis (Marflab)	
				Martensia fragilis (Marfrag)	
				Neomeris annulata (Neoman)	
				Padina species (Padina)	
				Portieria homemannii (Portior)	
				Predaea weldii (Prewel)	
				Sargassum (Sarg)	
				Turbinaria ornata (Turbor)	
				Turf (Turf)	
				Ventricaria ventricosa (venven)	
				red algae	
NPPE	50	0			25
NPPE	50	1			25
NPPE	50	6			25
NPPE	50	8			15
NPPE	50	9			42
NPPE	50	11			30
NPPE	50	12			35
NPPE	50	14			50
NPPE	50	18			33
NPPE	50	19			35
NPPE	35	3			64
NPPE	35	4			45
NPPE	35	6			40
NPPE	35	7			35
NPPE	35	8			75
NPPE	35	13			70
NPPE	35	16			55
NPPE	35	19			70
NPPE	35	20			35
NPPE	35	21			55
NPPE	15	2			65
NPPE	15	5			60
NPPE	15	7			66
NPPE	15	8			94
NPPE	15	10			73
NPPE	15	12			60
NPPE	15	13			82
NPPE	15	16			65
NPPE	15	17			75
NPPE	15	19			60

Site Depth Location			Sub-Categories	
			Algae	
			Asparagopsis taxiformis (Asptax)	
			Caulerpa racemosa (Caurac)	
			Caulerpa serrulata (Caulser)	
			Caulerpa sertularioides (Caulsert)	
			Codium arabicum (Codiara)	
			Crustose Coralline (CCA)	
			Cyanophyta (BG)	
			Dasya iridescens (Dasyir)	
			Dichotomaria marginata (Dichmar)	
			Dictyosphaeria cavernosa (Dictcav)	
			Dictyosphaeria versluysii (Dictver)	
			Dictyota species (Dicty)	
			Gibbsmithia hawaiiensis (Gibhaw)	
			Halimeda opuntia (Halop)	
			Lobophora variegata (Lobvar)	
			Martensia flabelliformis (Marflab)	
			Martensia fragilis (Marfrag)	
			Neomeris annulata (Neoman)	
			Padina species (Padina)	
			Portieria homemannii (Portior)	
			Predaea weldii (Prewel)	
			Sargassum (Sarg)	
			Turbinaria ornata (Turbor)	
			Turf (Turf)	
			Ventricaria ventricosa (venven)	
			red algae	
H-bay	50	0		35
H-bay	50	2		25
H-bay	50	7		35
H-bay	50	12		6
H-bay	50	15		73
H-bay	50	18		30
H-bay	50	24		20
H-bay	50	26		15
H-bay	50	28		22
H-bay	50	30		13
H-bay	35	1		53
H-bay	35	4		40
H-bay	35	8		27
H-bay	35	11		35
H-bay	35	14		40
H-bay	35	19		59
H-bay	35	21		40
H-bay	35	23		60
H-bay	35	25		70
H-bay	35	28		60
H-bay	15	0		57
H-bay	15	2		50
H-bay	15	6		73
H-bay	15	7		67
H-bay	15	8		69
H-bay	15	10		75
H-bay	15	13		85
H-bay	15	15		85
H-bay	15	18		78
H-bay	15	20		50

Site	Depth	Location	10to Narr		Sub-Categories																		
							Algae																
							Asparagopsis taxiformis (Asptax)																
							Caulerpa racemosa (Caurac)																
							Caulerpa serrulata (Caulser)																
							Caulerpa sertularioides (Caulsert)																
							Codium arabicum (Codara)																
							Crustose Coralline (CCA)																
							Cyanophyta (BG)																
							Dasya iridescens (Dasyir)																
							Dichotomaria marginata (Dichmar)																
							Dictyosphaeria cavernosa (Dictcav)																
							Dictyosphaeria versluysii (Dictver)																
							Dictyota species (Dicty)																
							Gibbsmithia hawaiiensis (Gibhaw)																
							Halimeda opuntia (Halop)																
							Lobophora variegata (Lobvar)																
							Martensia flabelliformis (Marflab)																
							Martensia fragilis (Marfrag)																
							Neomeris annulata (Neoman)																
							Padina species (Padina)																
							Portieria homemannii (Portior)																
							Predaea weldii (Prewel)																
							Sargassum (Sarg)																
							Turbinaria ornata (Turbor)																
							Turf (Turf)																
							Ventricaria ventricosa (venven)																
							red algae																
18	50	1																					
18	50	6																					
18	50	7																					
18	50	6																					
18	50	12																					
18	50	13																					
18	50	15																					
18	50	17																					
18	50	18																					
18	50	20																					
18	35	0																					
18	35	2																					
18	35	3																					
18	35	6																					
18	35	9																					
18	35	10																					
18	35	11																					
18	35	14																					
18	35	16																					
18	35	18																					
18	15	2																					
18	15	4																					
18	15	5																					
18	15	7																					
18	15	10																					
18	15	11																					
18	15	12																					
18	15	14																					
18	15	17																					
18	15	19																					

Site Depth Location			Sub-Categories	
1oto Narr			Algae	
			Asparagopsis taxiformis (Asptax)	
			Caulerpa racemosa (Caurac)	
			Caulerpa serrulata (Caulser)	
			Caulerpa sertularioides (Caulsert)	
			Codium arabicum (Codara)	
			Crustose Coralline (CCA)	
			Cyanophyta (BG)	
			Dasya iridescens (Dasyir)	
			Dichotomaria marginata (Dichmar)	
			Dictyosphaeria cavernosa (Dictcav)	
			Dictyosphaeria versluysii (Dictver)	
			Dictyota species (Dicty)	
			Gibbsmithia hawaiiensis (Gibhaw)	
			Halimeda opuntia (Halop)	
			Lobophora variegata (Lobvar)	
			Martensia flabelliformis (Marflab)	
			Martensia fragilis (Marfrag)	
			Neomeris annulata (Neoman)	
			Padina species (Padina)	
			Portieria homemannii (Portior)	
			Predaea weldii (Prewel)	
			Sargassum (Sarg)	
			Turbinaria ornata (Turbor)	
			Turf (Turf)	
			Ventricaria ventricosa (venven)	
			red algae	
Wawa	50	0		
Wawa	50	3		
Wawa	50	6		
Wawa	50	7		
Wawa	50	9		
Wawa	50	12		
Wawa	50	13		
Wawa	50	15		
Wawa	50	18		
Wawa	50	20		
Wawa	35	1		
Wawa	35	2		
Wawa	35	4		
Wawa	35	5		
Wawa	35	8		
Wawa	35	10		
Wawa	35	14		
Wawa	35	19		
Wawa	35	21		
Wawa	35	23		
Wawa	15	0		
Wawa	15	2		
Wawa	15	6		
Wawa	15	7		
Wawa	15	9		
Wawa	15	12		
Wawa	15	13		
Wawa	15	16		
Wawa	15	18		
Wawa	15	20		

Table 2.2 Benthic habitat characterization data – Sessile Invertebrates & Abiotic Substrate

Site	Depth	Location	Photo	Name	Sub-Categories		Fungia sutaria (Funsu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Montfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Podillopora damicornis (Poddam)	Podillopora eydouxi (Poceyd)	Podillopora ligulata (Podlig)	Podillopora meandrina (Pomea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
12S	50	1																														
12S	50	2																														
12S	50	6																10	5													
12S	50	9																														
12S	50	13																														
12S	50	14																														
12S	50	16																														
12S	50	18															15			5		10										
12S	50	22																														
12S	50	24																1				5										
12S	35	0																														
12S	35	3																														
12S	35	7																														
12S	35	8																														
12S	35	11								10																						
12S	35	13								5																						
12S	35	14								10																						
12S	35	18																2														
12S	35	21																		15		5										
12S	35	22																														
12S	15	0								2																						
12S	15	2																5														
12S	15	4																														
12S	15	5																														
12S	15	7																2														
12S	15	11														1	10															
12S	15	16													2																	
12S	15	18																														
12S	15	19																35														
12S	15	20																														

			Sub-Categories																												
			Coral																												
			Fungia scutaria (Fungscu)																												
			Leptastrea purpurea (Leppur)																												
			Leptoseris bewickensis (Lepbew)																												
			Montipora capitata (Moncap)																												
			Montipora flabellata (Monfla)																												
			Montipora patula (Monpat)																												
			Montipora species (Monsp)																												
			Pavona duerdeni (Pavdue)																												
			Pavona varians (Pavvar)																												
			Podilopora damicornis (Poddam)																												
			Podilopora eydouxi (Poceyd)																												
			Podilopora ligulata (Podlig)																												
			Podilopora meandrina (Pocmea)																												
			Porites compressa (Porcom)																												
			Porites brighami																												
			Porites evermanni (Porev)																												
			Porites lobata (Porlob)																												
			Porites rus																												
			Tubastrea coccinea (Tubcoc)																												
			Sarcothelia edmondsoni																												
			Inorganics																												
			Basalt (Basalt)																												
			Rubble																												
			Limestone (Limest)																												
			Quad (Quad)																												
			Sand (Sand)																												
Site	Depth	Location	hoto	Nam																											
12N	50	0						5													25										
12N	50	2						2													20										
12N	50	6						2													25										
12N	50	7						5													30										
12N	50	9						15													40										
12N	50	12																			33										
12N	50	15																			15										
12N	50	18						2													20										
12N	50	21													15						10										
12N	50	23								5											30										
12N	35	1															1				25										
12N	35	4															3				35										
12N	35	5															5				10										
12N	35	8								10											20										
12N	35	10											5								15										
12N	35	13																			45										
12N	35	16						10													35										
12N	35	19																			20										
12N	35	24															5				15										
12N	35	25																		10	20										
12N	15	0																			20										
12N	15	3						3													30										
12N	15	4																			20										
12N	15	9																		15	25										
12N	15	10																			40										
12N	15	11												2	15						15										
12N	15	14												2							40										
12N	15	18															1			5	35										
12N	15	21																			15										
12N	15	22																			50										

NELHA BENTHIC AND BIOTA MONITORING PROGRAM

			Sub-Categories																									
			Coral																									
			Fungia sutaria (Fungsu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Montfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Podillopora damicornis (Poddam)	Podillopora eydouxi (Poceydx)	Podillopora ligulata (Podlig)	Podillopora meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
Site	Depth	Location photo Nam																										
NPPE	50	0														55			20									
NPPE	50	1														35		10	30									
NPPE	50	6				10										10		5	50									
NPPE	50	8														50		5	30									
NPPE	50	9				3												5	50									
NPPE	50	11														30		5	35									
NPPE	50	12														25			40									
NPPE	50	14														5			45									
NPPE	50	18				5		2								20			40									
NPPE	50	19														20			45									
NPPE	35	3				1					5					5			30									
NPPE	35	4														20			50									
NPPE	35	6														20			40									
NPPE	35	7														20			45									
NPPE	35	8																10	15									
NPPE	35	13				5													25									
NPPE	35	16																	45									
NPPE	35	19																	30									
NPPE	35	20														10			55									
NPPE	35	21				5													40									
NPPE	15	2													5				30									
NPPE	15	5																	40									
NPPE	15	7													1				33									
NPPE	15	8																	6									
NPPE	15	10				2		5											20									
NPPE	15	12				5													35									
NPPE	15	13													3				15									
NPPE	15	16																	35									
NPPE	15	17				5													20									
NPPE	15	19																	40									

			Sub-Categories																									
			Coral																									
Site	Depth	Location photo Nam	Fungia scutaria (Fungia)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Leppew)	Montipora capitata (Moncap)	Montipora flabellata (Montfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Pocillopora damicornis (Podam)	Pocillopora eydouxi (Poceyd)	Pocillopora ligulata (Podlig)	Pocillopora meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
H-bay	50	0														20		5	40									
H-bay	50	2														30			45									
H-bay	50	7														35			30									
H-bay	50	12				2										42		35	15									
H-bay	50	15				2										10			15									
H-bay	50	18														40			30									
H-bay	50	24														55		5	20									
H-bay	50	26				10										35			40									
H-bay	50	28				13										10		10	45									
H-bay	50	30													2	30		20	35									
H-bay	35	1				2										20		20	25									
H-bay	35	4													5			10	45									
H-bay	35	8				5		3							5	20		20	40									
H-bay	35	11																20	45									
H-bay	35	14																20	40									
H-bay	35	19				3									3			20	35									
H-bay	35	21														10			50									
H-bay	35	23									5								35									
H-bay	35	25																20	10									
H-bay	35	28																	40									
H-bay	15	0													3				40									
H-bay	15	2																	50									
H-bay	15	6													2				25									
H-bay	15	7													3				30									
H-bay	15	8													1			5	25									
H-bay	15	10																	25									
H-bay	15	13																	15									
H-bay	15	15																	15									
H-bay	15	18													2				20									
H-bay	15	20						10											40									

			Sub-Categories																									
			Coral																									
Site	Depth	Location photo Nam	Fungia scutaria (Funsu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lebbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Pocillopora damicornis (Poddam)	Pocillopora eydouxi (Poceyd)	Pocillopora ligulata (Podlig)	Pocillopora meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tuboc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
18	50	1																	5									
18	50	6																	30									
18	50	7		2			2												45									
18	50	6																	30									
18	50	12					10												30									
18	50	13																	35									
18	50	15																	20									
18	50	17					5												25									
18	50	18														10			25									
18	50	20																	30									
18	35	0																	45									
18	35	2																	45									
18	35	3					5												30									
18	35	6					10												40									
18	35	9																	35									
18	35	10					5												30									
18	35	11																	25									
18	35	14					5												55									
18	35	16					5											20	20									
18	35	18																	35									
18	15	2					5												40									
18	15	4																5	50									
18	15	5																	45									
18	15	7																	30									
18	15	10																	45									
18	15	11																5	35									
18	15	12											10						20									
18	15	14																	20									
18	15	17																	20									
18	15	19																	35									5

			Sub-Categories																													
			Coral																													
			Fungia sutaria (Funsu)																													
			Leptastrea purpurea (Leppur)																													
			Leptoseris bewickensis (Leppew)																													
			Montipora capitata (Moncap)																													
			Montipora flabellata (Morfla)																													
			Montipora patula (Monpat)																													
			Montipora species (Monsp)																													
			Pavona duerdeni (Pavdue)																													
			Pavona varians (Pavvar)																													
			Podillopora damicornis (Poddam)																													
			Podillopora eydouxi (Poceydx)																													
			Podillopora ligulata (Podlig)																													
			Podillopora meandrina (Pocmea)																													
			Porites compressa (Porcom)																													
			Porites brighami																													
			Porites evermanni (Porev)																													
			Porites lobata (Porlob)																													
			Porites rus																													
			Tubastrea coccinea (Tubcoc)																													
			Sarcothelia edmondsoni																													
			Inorganics																													
			Basalt (Basalt)																													
			Rubble																													
			Limestone (Limest)																													
			Quad (Quad)																													
			Sand (Sand)																													
Site	Depth	Location	hoto	Nam																												
Wawa	50	0																														60
Wawa	50	3																														60
Wawa	50	6																														65
Wawa	50	7							5																							5
Wawa	50	9																														45
Wawa	50	12																														70
Wawa	50	13																														75
Wawa	50	15																														20
Wawa	50	18																														55
Wawa	50	20																														85
Wawa	35	1							10																							
Wawa	35	2							5																							
Wawa	35	4																														
Wawa	35	5							15																							
Wawa	35	8							10																							
Wawa	35	10																														
Wawa	35	14																														
Wawa	35	19							5																							
Wawa	35	21																														
Wawa	35	23							10																							
Wawa	15	0																														
Wawa	15	2																														
Wawa	15	6																														
Wawa	15	7																														
Wawa	15	9																														
Wawa	15	12																														
Wawa	15	13																														
Wawa	15	16																														
Wawa	15	18																														
Wawa	15	20																														

Table 2.3 Benthic habitat characterization data – Mobile Invertebrates

Sites	Sum of <i>D. paucispinus</i>	Sum of <i>Echinometra mathaei</i>	Sum of <i>Conus</i> sp.	Sum of flatworms	Sum of <i>Tripneustes gratilla</i>	Sum of <i>Holothuria atra</i>
18	7	12	1		1	1
15	2	6	1			
35	4	6				1
50	1				1	
12N	4	11		1	1	
15		2		1		
35	2	3				
50	2	6			1	
12S	2				2	
15						
35	1					
50	1				2	
H-bay	7	40	2	1	1	2
15	4	1	2			2
35	2	23		1		
50	1	16			1	
NPPE	10	33			11	
15	9	2				
35	1	21				
50		10			11	
Wawa	14	8	1			2
15	8	5	1			1
35	6	3				1
50						
Grand Total	44	104	4	2	16	5

Appendix 3: Nearshore fish assemblage data

Table 3.1 Abundance and length of all fish observed among sites and depths

Haona Bay			5/22/21								
50'						35'					
Species	Individuals	Size (cm)				Species	Individuals	Size (cm)			
<i>M. kuntee</i>	41	13				<i>A. nigrofuscus</i>	2	5			
<i>M. kuntee</i>	40	16				<i>A. nigrofuscus</i>	1	8			
<i>M. kuntee</i>	56	17				<i>A. nigrofuscus</i>	15	7			
<i>N. literatus</i>	1	15				<i>A. nigrofuscus</i>	6	4			
<i>N. literatus</i>	1	12				<i>C. agilis</i>	9	4			
<i>N. literatus</i>	1	17				<i>C. agilis</i>	14	5			
<i>N. literatus</i>	1	22				<i>C. strigosus</i>	8	9			
<i>C. agilis</i>	19	3				<i>C. strigosus</i>	8	7			
<i>C. agilis</i>	42	4				<i>C. strigosus</i>	4	4			
<i>C. agilis</i>	41	5				<i>C. vanderbiliti</i>	30	2			
<i>C. agilis</i>	20	6				<i>C. vanderbiliti</i>	28	3			
<i>C. strigosus</i>	3	6				<i>C. vanderbiliti</i>	36	4			
<i>C. strigosus</i>	7	9				<i>T. duperrey</i>	2	13			
<i>C. strigosus</i>	2	12				<i>T. duperrey</i>	1	15			
<i>C. strigosus</i>	1	13				<i>T. duperrey</i>	1	9			
<i>C. potteri</i>	1	6				<i>C. sordidus</i>	5	20			
<i>C. potteri</i>	1	8				<i>C. sordidus</i>	6	10			
<i>C. jactator</i>	2	4				<i>C. sordidus</i>	11	15			
<i>Z. flavescens</i>	4	8				<i>C. multicinctus</i>	1	3			
<i>Z. flavescens</i>	8	10				<i>C. multicinctus</i>	1	4			
<i>Z. flavescens</i>	8	7				<i>C. multicinctus</i>	3	9			
<i>Z. flavescens</i>	4	9				<i>G. varius</i>	1	19			
<i>Z. flavescens</i>	5	12				<i>G. varius</i>	1	11			
<i>C. sordidus</i>	1	15				<i>C. jactator</i>	1	4			
<i>C. sordidus</i>	1	11				<i>C. jactator</i>	1	3			
<i>C. sordidus</i>	2	16				<i>P. arcatus</i>	1	8			
<i>C. sordidus</i>	2	20				<i>P. arcatus</i>	2	7			
<i>C. sordidus</i>	2	13				<i>M. vidua</i>	1	17			
<i>C. sordidus</i>	3	18				<i>M. vidua</i>	2	19			
<i>A. nigrofuscus</i>	4	11				<i>N. literatus</i>	2	20			
<i>C. ornatus</i>	3	16				<i>N. literatus</i>	1	22			
<i>M. vidua</i>	6	15				<i>N. literatus</i>	1	21			
<i>M. vidua</i>	5	18				<i>A. abdominalis</i>	6	11			
<i>C. multicinctus</i>	1	10				<i>A. vaigiensis</i>	8	11			
<i>F. flavissimus</i>	2	12				<i>C. gaimard</i>	1	19			
<i>S. spiniferum</i>	1	19				<i>C. argus</i>	1	17			
<i>Z. comutus</i>	1	12				<i>C. argus</i>	1	29			
<i>A. olivaceus</i>	1	26				<i>H. ornatus</i>	1	4			
<i>C. hawaiiensis</i>	1	14				<i>H. ornatus</i>	1	8			
<i>G. varius</i>	1	17				<i>A. chinensis</i>	1	65			
<i>C. ovalis</i>	1	10				<i>Z. flavescens</i>	2	12			
<i>P. multifasciatus</i>	1	11				<i>Z. flavescens</i>	1	13			
<i>P. multifasciatus</i>	1	14				<i>A. blochii</i>	1	26			
<i>C. gaimard</i>	1	17				<i>C. carolinus</i>	1	21			
<i>H. ornatus</i>	1	9				<i>F. flavissimus</i>	1	13			
<i>S. rubroviolaceus</i>	2	30				<i>P. multifasciatus</i>	1	13			
<i>S. rubroviolaceus</i>	1	52				<i>P. multifasciatus</i>	1	16			
<i>A. chinensis</i>	1	48				<i>Z. comutus</i>	1	16			
<i>A. leucopareius</i>	3	15				<i>P. cyclostomus</i>	1	12			
<i>N. sammara</i>	1	16				<i>Kyphosus spp.</i>	1	26			
<i>F. commersonii</i>	1	121				<i>O. meleagris</i>	1	3			
<i>D. albisella</i>	3	13				<i>X. auromarginatus</i>	1	14			
<i>D. albisella</i>	1	10				<i>C. sandwichiensis</i>	1	13			
<i>G. meleagris</i>	1	90									

NPPE	5/23/21									
50'				35'				15'		
Species	Individuals	Size (cm)		Species	Individuals	Size (cm)		Species	Individuals	Size (cm)
<i>Z. flavescens</i>	17	6		<i>C. strigosus</i>	3	9		<i>A. nigrofuscus</i>	6	9
<i>Z. flavescens</i>	7	9		<i>C. strigosus</i>	4	13		<i>A. nigrofuscus</i>	14	10
<i>A. nigrofuscus</i>	4	7		<i>C. strigosus</i>	10	12		<i>A. nigrofuscus</i>	19	12
<i>C. strigosus</i>	13	8		<i>T. duperrey</i>	1	7		<i>C. strigosus</i>	4	6
<i>C. strigosus</i>	6	11		<i>T. duperrey</i>	1	10		<i>C. strigosus</i>	5	10
<i>C. strigosus</i>	1	10		<i>T. duperrey</i>	1	14		<i>C. strigosus</i>	8	12
<i>C. sordidus</i>	4	13		<i>T. duperrey</i>	1	12		<i>Z. flavescens</i>	34	11
<i>C. sordidus</i>	1	20		<i>A. nigrofuscus</i>	9	8		<i>Z. flavescens</i>	137	9
<i>C. sordidus</i>	2	15		<i>A. nigrofuscus</i>	9	10		<i>Z. flavescens</i>	40	12
<i>C. argus</i>	1	27		<i>A. nigrofuscus</i>	6	7		<i>Z. flavescens</i>	6	14
<i>C. omatissimus</i>	1	7		<i>A. nigrofuscus</i>	6	12		<i>Z. flavescens</i>	30	10
<i>T. duperrey</i>	1	5		<i>C. sordidus</i>	2	16		<i>T. duperrey</i>	1	5
<i>C. multicinctus</i>	1	9		<i>C. sordidus</i>	1	19		<i>T. duperrey</i>	3	12
<i>C. multicinctus</i>	1	4		<i>C. sordidus</i>	7	14		<i>T. duperrey</i>	2	9
<i>P. multifasciatus</i>	1	25		<i>C. sordidus</i>	2	21		<i>C. vanderbilti</i>	53	3
<i>P. arcatus</i>	1	12		<i>Z. flavescens</i>	5	14		<i>C. vanderbilti</i>	31	2
<i>C. hanui</i>	1	5		<i>Z. flavescens</i>	4	15		<i>H. omatissimus</i>	1	9
<i>C. hanui</i>	1	6		<i>C. jactator</i>	1	3		<i>F. lognirostris</i>	1	15
<i>C. agilis</i>	20	2		<i>G. varius</i>	1	9		<i>C. jactator</i>	1	6
<i>C. agilis</i>	41	3		<i>G. varius</i>	1	12		<i>M. vanicolensis</i>	4	17
<i>C. agilis</i>	42	4		<i>C. multicinctus</i>	2	9		<i>Z. comutus</i>	1	11
<i>L. phthiophagus</i>	1	8		<i>C. multicinctus</i>	2	11		<i>S. marginatus</i>	1	7
<i>L. phthiophagus</i>	2	7		<i>C. vanderbilti</i>	14	2		<i>A. guttatus</i>	6	14
<i>S. bursa</i>	1	7		<i>C. vanderbilti</i>	36	3		<i>C. hawaiiensis</i>	1	17
<i>S. bursa</i>	1	6		<i>C. vanderbilti</i>	11	4		<i>C. sordidus</i>	1	16
<i>C. potteri</i>	1	7		<i>H. omatissimus</i>	2	12		<i>C. sordidus</i>	2	13
<i>A. nigricans</i>	1	13		<i>H. omatissimus</i>	1	3		<i>Kyphosus spp.</i>	1	32
<i>A. nigricans</i>	1	8		<i>H. omatissimus</i>	1	7		<i>Kyphosus spp.</i>	1	35
<i>M. vidua</i>	1	13		<i>A. abdominalis</i>	18	13		<i>M. burditi</i>	26	17
<i>A. furca</i>	1	24		<i>A. vaigiensis</i>	11	13		<i>N. literatus</i>	1	16
<i>A. furca</i>	2	22		<i>N. literatus</i>	1	23		<i>P. insularis</i>	1	22
<i>H. polylepis</i>	23	12		<i>N. literatus</i>	1	28		<i>S. bursa</i>	1	15
<i>N. literatus</i>	3	18		<i>S. balteata</i>	1	9		<i>S. balteata</i>	2	8
<i>N. literatus</i>	2	16		<i>M. vidua</i>	1	18				
<i>N. unicomis</i>	2	32		<i>M. vidua</i>	2	21				
<i>P. octotaenia</i>	1	8		<i>Z. comutus</i>	1	14				
<i>Z. comutus</i>	1	14		<i>C. omatissimus</i>	1	15				
<i>A. achilles</i>	1	8		<i>P. johnstonianus</i>	1	6				
				<i>P. multifasciatus</i>	1	16				
				<i>P. aspricaudus</i>	1	11				

NELHA BENTHIC AND BIOTA MONITORING PROGRAM

12 Pipe South	5/22/21									
50'				35'				15'		
Species	Individuals	Size (cm)		Species	Individuals	Size (cm)		Species	Individuals	Size (cm)
<i>T. duperrey</i>	2	9		<i>N. literatus</i>	1	18		<i>Z. flavescens</i>	9	14
<i>T. duperrey</i>	1	14		<i>N. literatus</i>	1	17		<i>Z. flavescens</i>	6	15
<i>T. duperrey</i>	1	5		<i>Z. flavescens</i>	2	8		<i>A. nigrofuscus</i>	5	10
<i>A. nigrofuscus</i>	6	8		<i>Z. flavescens</i>	1	12		<i>C. vanderbilti</i>	202	2
<i>A. nigrofuscus</i>	7	13		<i>C. strigosus</i>	11	8		<i>C. vanderbilti</i>	200	3
<i>A. nigrofuscus</i>	12	9		<i>C. strigosus</i>	15	10		<i>C. vanderbilti</i>	190	4
<i>C. strigosus</i>	1	10		<i>C. strigosus</i>	1	12		<i>N. literatus</i>	1	17
<i>C. sordidus</i>	2	14		<i>A. nigrofuscus</i>	8	8		<i>C. sordidus</i>	3	14
<i>C. sordidus</i>	1	11		<i>A. nigrofuscus</i>	12	10		<i>C. sordidus</i>	3	18
<i>C. sordidus</i>	6	15		<i>C. sordidus</i>	1	21		<i>T. duperrey</i>	2	13
<i>C. multicinctus</i>	1	5		<i>C. sordidus</i>	1	19		<i>T. duperrey</i>	1	15
<i>C. multicinctus</i>	2	7		<i>C. sordidus</i>	2	12		<i>S. bursa</i>	1	17
<i>C. vanderbilti</i>	21	2		<i>T. duperrey</i>	1	9		<i>S. bursa</i>	3	14
<i>C. vanderbilti</i>	21	3		<i>T. duperrey</i>	1	6		<i>S. bursa</i>	1	12
<i>N. literatus</i>	2	19		<i>G. varius</i>	2	11		<i>F. flavissimus</i>	1	13
<i>N. literatus</i>	1	21		<i>P. multifasciatus</i>	1	12		<i>M. niger</i>	4	19
<i>N. literatus</i>	1	24		<i>C. jactator</i>	1	4		<i>M. niger</i>	3	23
<i>H. omatissimus</i>	1	7		<i>C. vanderbilti</i>	100	2		<i>M. niger</i>	4	20
<i>H. omatissimus</i>	1	10		<i>C. vanderbilti</i>	100	3		<i>Kyphosus spp.</i>	5	20
<i>H. omatissimus</i>	1	13		<i>H. omatissimus</i>	3	9		<i>C. strigosus</i>	4	10
<i>P. arcatus</i>	1	8		<i>P. arcatus</i>	2	7		<i>C. strigosus</i>	14	12
<i>G. varius</i>	1	9		<i>C. agilis</i>	120	2		<i>A. olivaceus</i>	1	18
<i>G. varius</i>	1	6		<i>C. agilis</i>	150	3		<i>C. amboinensis</i>	1	8
<i>F. flavissimus</i>	2	12		<i>C. agilis</i>	150	4		<i>C. amboinensis</i>	1	6
<i>P. evanidus</i>	2	6		<i>C. agilis</i>	80	5		<i>C. hawaiiensis</i>	13	16
<i>P. evanidus</i>	1	7		<i>C. hanui</i>	1	5		<i>C. hawaiiensis</i>	10	20
<i>P. evanidus</i>	1	9		<i>C. potteri</i>	1	6		<i>P. imparipennis</i>	1	14
<i>P. multifasciatus</i>	1	14		<i>P. ewaensis</i>	1	6		<i>S. rubroviolaceus</i>	1	40
<i>Z. flavescens</i>	6	14		<i>P. ewaensis</i>	1	5		<i>P. multifasciatus</i>	1	17
<i>Z. flavescens</i>	7	12		<i>S. balteata</i>	1	10		<i>A. blochii</i>	1	17
<i>A. blochii</i>	2	28		<i>S. rubroviolaceus</i>	6	21		<i>A. blochii</i>	1	23
<i>A. olivaceus</i>	2	19		<i>S. rubroviolaceus</i>	1	28		<i>A. guttatus</i>	2	14
<i>C. argus</i>	1	20		<i>A. xanthopterus</i>	1	29		<i>A. guttatus</i>	1	13
<i>C. gaimard</i>	1	19		<i>X. auromarginatus</i>	2	14		<i>C. quadrimaculatus</i>	1	11
<i>C. gaimard</i>	2	6						<i>M. grandoculis</i>	1	22
<i>C. gaimard</i>	1	14						<i>M. grandoculis</i>	1	26
<i>M. vidua</i>	1	18						<i>M. kuntee</i>	1	11
<i>P. johnstonianus</i>	1	5						<i>Z. comutus</i>	1	12
<i>S. rubroviolaceus</i>	1	24						<i>S. spiniferum</i>	1	17
<i>S. rubroviolaceus</i>	1	27								
<i>S. rubroviolaceus</i>	2	13								
<i>N. hexacanthus</i>	9	23								

12 Pipe N			5/22/21																	
50'						35'						15'								
Species	Individuals	Size (cm)				Species	Individuals	Size (cm)				Species	Individuals	Size (cm)						
<i>T. duperrey</i>	1	8				<i>N. literatus</i>	1	21				<i>A. nigrofuscus</i>	9	10						
<i>A. nigrofuscus</i>	3	6				<i>N. literatus</i>	2	16				<i>C. strigosus</i>	8	10						
<i>A. nigrofuscus</i>	2	7				<i>N. literatus</i>	2	22				<i>C. strigosus</i>	1	15						
<i>A. nigrofuscus</i>	10	9				<i>N. literatus</i>	2	18				<i>C. strigosus</i>	4	13						
<i>C. vanderbiliti</i>	72	2				<i>N. literatus</i>	1	26				<i>C. strigosus</i>	2	8						
<i>C. vanderbiliti</i>	60	3				<i>C. vanderbiliti</i>	21	2				<i>N. literatus</i>	1	18						
<i>Z. flavescens</i>	10	13				<i>T. duperrey</i>	4	8				<i>N. literatus</i>	2	19						
<i>Z. flavescens</i>	12	14				<i>T. duperrey</i>	1	2				<i>N. literatus</i>	1	23						
<i>P. octotaenia</i>	1	8				<i>T. duperrey</i>	2	6				<i>C. hawaiiensis</i>	3	14						
<i>H. omatissimus</i>	1	6				<i>T. duperrey</i>	2	4				<i>C. hawaiiensis</i>	2	13						
<i>H. omatissimus</i>	2	5				<i>T. duperrey</i>	2	7				<i>T. duperrey</i>	2	9						
<i>P. multifasciatus</i>	2	14				<i>H. omatissimus</i>	1	6				<i>T. duperrey</i>	1	13						
<i>P. multifasciatus</i>	1	17				<i>H. omatissimus</i>	1	10				<i>T. duperrey</i>	1	15						
<i>P. multifasciatus</i>	1	11				<i>A. nigrofuscus</i>	4	8				<i>S. rubroviolaceus</i>	1	26						
<i>N. literatus</i>	1	21				<i>A. nigrofuscus</i>	11	10				<i>S. rubroviolaceus</i>	1	16						
<i>N. literatus</i>	1	23				<i>Z. flavescens</i>	23	13				<i>S. rubroviolaceus</i>	1	41						
<i>N. literatus</i>	2	17				<i>C. strigosus</i>	5	8				<i>Z. flavescens</i>	7	10						
<i>M. vidua</i>	1	19				<i>F. flavissimus</i>	1	13				<i>Z. flavescens</i>	11	12						
<i>A. olivaceus</i>	1	18				<i>A. achilles</i>	1	10				<i>Kyphosus spp.</i>	2	18						
<i>F. flavissimus</i>	1	8				<i>C. sordidus</i>	1	17				<i>Kyphosus spp.</i>	1	21						
<i>Z. comutus</i>	1	12				<i>C. sordidus</i>	2	12				<i>Kyphosus spp.</i>	1	23						
<i>A. furca</i>	1	17				<i>C. sordidus</i>	2	21				<i>A. nigricans</i>	1	13						
<i>A. furca</i>	1	21				<i>C. sordidus</i>	3	10				<i>A. nigricans</i>	2	11						
<i>C. agilis</i>	3	3				<i>C. sordidus</i>	6	14				<i>S. psittacus</i>	1	19						
<i>C. hawaiiensis</i>	1	17				<i>C. sordidus</i>	1	24				<i>S. psittacus</i>	1	17						
<i>C. jactator</i>	1	4				<i>S. bursa</i>	1	16				<i>S. psittacus</i>	1	13						
<i>P. evanidus</i>	1	6				<i>C. jactator</i>	3	4				<i>S. balteata</i>	1	11						
<i>S. bursa</i>	1	18				<i>C. jactator</i>	2	5				<i>A. olivaceus</i>	1	16						
<i>S. bursa</i>	1	15				<i>S. spiniferum</i>	3	16				<i>S. bursa</i>	2	15						

NELHA BENTHIC AND BIOTA MONITORING PROGRAM

18 Pipe	5/23/21									
50'				35'				15'		
Species	Individuals	Size (cm)		Species	Individuals	Size (cm)		Species	Individuals	Size (cm)
A. nigrofuscus	7	6		N. literatus	1	23		C. jactator	2	5
A. nigrofuscus	19	8		Z. flavescens	7	12		C. jactator	1	4
C. agilis	20	3		Z. flavescens	5	14		A. nigrofuscus	10	8
C. agilis	23	4		A. nigrofuscus	18	8		A. nigrofuscus	15	10
C. agilis	20	5		A. nigrofuscus	5	6		A. nigrofuscus	10	12
C. strigosus	7	7		S. bursa	1	16		T. duperrey	1	15
C. strigosus	4	8		T. duperrey	3	7		T. duperrey	2	13
C. strigosus	4	6		T. duperrey	1	14		T. duperrey	2	16
C. vanderbiliti	84	2		T. duperrey	1	10		Z. flavescens	15	10
C. vanderbiliti	75	3		G. varius	2	14		Z. flavescens	15	14
N. literatus	1	20		C. sordidus	1	21		Z. flavescens	5	13
N. literatus	4	22		C. sordidus	1	18		Z. flavescens	3	12
N. literatus	5	19		C. sordidus	1	16		C. strigosus	15	12
T. duperrey	1	8		C. vanderbilti	91	2		C. strigosus	14	10
S. bursa	2	17		C. vanderbilti	70	3		C. strigosus	19	12
C. sordidus	2	21		H. omatissimus	1	7		C. vanderbilti	32	2
C. sordidus	1	24		H. omatissimus	1	8		C. vanderbilti	43	3
C. sordidus	1	22		P. multifasciatus	1	22		A. olivaceus	1	19
G. varius	1	8		P. multifasciatus	1	12		A. olivaceus	1	21
Z. flavescens	4	13		P. multifasciatus	1	10		A. olivaceus	1	23
Z. flavescens	3	12		P. arcatus	1	7		H. omatissimus	2	6
Z. flavescens	1	14		P. octotaenia	1	9		H. omatissimus	1	9
C. jactator	1	4		C. multicinctus	2	6		S. bursa	1	14
C. multicinctus	1	6		C. multicinctus	1	3		C. hawaiiensis	8	18
C. hanui	1	5		C. multicinctus	1	4		C. hawaiiensis	6	24
C. hanui	4	4		C. sordidus	4	17		N. literatus	1	21
P. ewaensis	2	7		C. sordidus	4	14		N. literatus	1	24
P. multifasciatus	1	13		P. evanidus	1	5		N. literatus	1	19
P. multifasciatus	1	15		S. rubroviolaceus	2	26		N. literatus	1	20
S. balteata	1	8		A. olivaceus	1	22		N. literatus	1	18
C. potteri	1	7		A. thompsoni	3	17		C. multicinctus	3	8
H. omatissimus	1	9		C. gaimard	1	24		C. multicinctus	1	10
H. omatissimus	1	8		C. gaimard	1	17		C. argus	1	31
L. phthirophagus	1	7		F. flavissimus	1	12		C. sordidus	1	14
L. phthirophagus	1	6		P. tetraetania	1	5		C. sordidus	1	19
M. vidua	1	21		Z. comutus	1	12		C. sordidus	1	19
M. vidua	1	17		M. vidua	1	21		T. duperrey	4	13
P. ewaensis	1	5						T. duperrey	2	10
S. balteata	1	8						A. blochii	1	24
X. auromarginatu	1	15						A. furca	1	17
Z. comutus	1	12						A. nigricans	1	8
Z. comutus	2	14						A. xanthopterus	1	28
								C. gaimard	1	6
								C. omatissimus	1	12
								C. quadrimaculata	1	9
								G. varius	1	11
								Kyphosus spp.	1	20
								L. phthirophagus	1	14
								M. vidua	1	20
								S. balteata	1	9
								M. niger	4	18
								M. niger	4	23
								M. niger	4	20
								M. niger	9	24
								P. imparipennis	1	5
								P. imparipennis	2	2
								P. insularis	1	22
								P. insularis	1	10
								P. insularis	1	15
								S. marginatus	3	15

Wawa	5/22/21									
50'				35'				15'		
Species	Individuals	Size (cm)		Species	Individuals	Size (cm)		Species	Individuals	Size (cm)
<i>P. heteroptera</i>	2	8		<i>C. vanderbiliti</i>	25	2		<i>A. nigrofuscus</i>	6	8
<i>C. strigosus</i>	1	3		<i>C. vanderbiliti</i>	20	3		<i>A. nigrofuscus</i>	4	10
<i>C. strigosus</i>	2	2		<i>Z. flavescens</i>	9	13		<i>T. duperrey</i>	1	9
<i>C. vanderbiliti</i>	36	3		<i>T. duperrey</i>	2	6		<i>T. duperrey</i>	6	7
<i>C. vanderbiliti</i>	25	4		<i>T. duperrey</i>	1	9		<i>T. duperrey</i>	4	5
<i>P. arcatus</i>	1	8		<i>A. nigrofuscus</i>	2	7		<i>T. duperrey</i>	3	6
<i>P. evanidus</i>	1	6		<i>A. nigrofuscus</i>	1	8		<i>Z. flavescens</i>	8	12
<i>P. evanidus</i>	2	3		<i>A. nigrofuscus</i>	1	9		<i>Z. flavescens</i>	4	10
<i>P. ewaensis</i>	2	5		<i>H. omatissimus</i>	1	8		<i>A. olivaceus</i>	1	18
<i>P. multifasciatus</i>	1	16		<i>H. omatissimus</i>	1	7		<i>C. jactator</i>	1	6
<i>S. bursa</i>	1	16		<i>P. octotaenia</i>	1	8		<i>C. jactator</i>	1	5
<i>S. bursa</i>	1	17		<i>A. olivaceus</i>	1	18		<i>A. nigroris</i>	1	15
<i>T. duperrey</i>	2	9		<i>A. olivaceus</i>	2	16		<i>C. lunula</i>	1	13
<i>N. taeniourus</i>	1	16		<i>A. olivaceus</i>	1	21		<i>C. vanderbiliti</i>	30	3
<i>N. taeniourus</i>	1	11		<i>A. olivaceus</i>	3	20		<i>P. imparipennis</i>	1	3
<i>N. taeniourus</i>	2	14		<i>G. varius</i>	1	9				
<i>S. variegatus</i>	1	3		<i>A. nigroris</i>	2	15				
<i>S. variegatus</i>	1	4		<i>C. agilis</i>	1	4				
				<i>N. literatus</i>	2	20				
				<i>N. literatus</i>	1	17				
				<i>N. literatus</i>	1	24				
				<i>N. literatus</i>	1	16				
				<i>C. jactator</i>	1	4				
				<i>P. ewaensis</i>	1	4				
				<i>Z. comutus</i>	1	13				
				<i>P. imparipennis</i>	2	4				
				<i>C. gaimard</i>	1	5				
				<i>P. evanidus</i>	1	6				
				<i>P. johnstonianus</i>	1	5				
				<i>P. ewaensis</i>	1	5				
				<i>Z. flavescens</i>	3	12				
				<i>Z. flavescens</i>	12	14				

Appendix 4. Digital images of quadrats used for benthic habitat characterization

