NELHA BENTHIC AND BIOTA MONITORING PROGRAM

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Annual Survey Report – 2023

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ANNUAL SURVEY REPORT – 2023

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 31 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 2023 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 May 16th to July 13th, 2023 during a high-tidal range (+1.14 to +2.02ft.). 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 2023 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 most of the pools. ‘Ōpae ‘ula was present in low numbers in pool, S-1 and absent in pools S-3 and S-5 where invasive fish were present. Overall species composition at each pool was similar to last year’s survey. Minimal turbidity was observed across sites in 2023, including the pools 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. Two 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 of 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 2023 was 39.9%, 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 2023 were quite consistent to data collected from 2017 – 2022 which indicates the pins are assisting with temporal monitoring of the study sites.

The overall percent coral cover among the six stations was 39.9%, the most dominant corals were *Porites lobata* (32.5%), *Porites evermanni* (20.0%)*, Montipora patula* (10.0%), *Porites compressa* (8.6%), *Pocillopora meandrina* (7.5%), *Montipora capitata* (5.8%), and *Pocillopora grandis* (4.2%). 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 2023 show similar values of abundance, diversity, and biomass to 2022. 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 has been conducted since 2020 as there was no habitat disturbance or species observations that warranted another site characterization, thus there is no discussion of intertidal surveys in the 2023 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.

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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 (ʻōpae ʻula) 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 Hawaiʻi, and also occur on Oʻahu, Maui, Molokaʻi, and Kahoʻolawe (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 Hawaiʻi 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* (ʻōpae ʻula) and indigenous *Metabetaeus lohena*, are common inhabitants in many of the anchialine ponds 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 (hypogeal) 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 ponds. 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 pool surroundings and substrate due to visitation and swimming. Additionally, models incorporating larger values of tidal fluctuation suggest that anchialine pools on Hawaiʻi 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 tidal fluctuation could alter anchialine pool ecology and thus must also be considered in addition to existing anthropogenic stressors. 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 Hawaiʻi (Santos 2006). This study showed that two distinct lineages of H. rubra exist on the East and West coasts of the Hawaiʻi 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 Hawaiʻi (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. 2021). Through this continued annual monitoring program at the ponds, changes in communities have been noted since 1989, with shrimp becoming absent in certain ponds 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. 2021).

Results of the 2023 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 nine 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 Hoʻona 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 2023 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, these pools start to form a single body of water (Burns and Kramer 2018). While the water level in the Southern group pools is also strongly tidally affected, pools were not observed to be interconnected during the 2023 survey.

Faunal surveys were conducted from May 16th to July 13th, 2023. Faunal observations for the 2023 survey were collected at tide levels greater than 1-ft to provide sufficient water for organismal observations. Sampling of the pools was conducted at tidal levels ranging from +1.14 to +2.02ft. 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 GoPro 10 Black waterproof camera. The *in-situ H. rubra* counts were conducted by randomly placing a ruler in the pool and counting in a 10x10cm area to calculate density. The number of replicate counts depended on pool area and depth and ranged from 5 to 10 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 m^2 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 2023 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 2023 survey was consistent with recent previous surveys (Burns and Annandale 2022). 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 and trash.

Southern pools were less saline and slightly cooler compared to the Northern pools. For the Southern pools S-1 through S-9, temperature ranged from 21.7 to 23.2 °C and salinity ranged from 9.61 to 10.03 ppt. Slightly higher temperature and salinity readings were recorded for distal pool S-10 (24.5 °C, 12.14 ppt., respectively) (Table 4). For the Northern pools, temperature and salinity were relatively higher than the Southern pools, ranging from 22.6 to 30.8 °C and from 11.83 to 12.62 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. 2021, Burns and Annandale 2022; 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. 2021, Burns and Annandale 2022). During the 2023 survey, *H. rubra* were observed at all the Northern Pools. *H. rubra* population densities in the Northern pools in 2023 was highly variable between pools. Pools N-1 and N-5 had densities over 200 shrimp/0.1, but like the 2022 survey, very few *H. rubra* were observed in pool N-4 (6 shrimp/0.1m2).

Within the Southern complex, the same three pools (S-7, S-8, and S-10) in 2022 had the highest densities of *H. rubra* in 2023 (Table 4). *H. rubra* were present in large densities in S-7 and S-8 where *H. rubra* had been absent and invasive fish were observed in surveys prior to 2020 (Burns and Kramer 2017, Burns and Kramer 2018, Burns and Annandale 2019). However, the densities in

S-7 and S-8 were not as high as in 2021 and 2022 (Burns et al. 2021, Burns and Annandale 2022). *H. rubra* are still absent in pools S-5 and S-3 since 2022 where they had been observed in high densities in 2021 (Burns and Annandale 2022).

During the 2023 survey, *M. lohena* was observed in one southern pool (S-1) and one Northern pool (N-4). *Macrobrachium grandimanus*, an uncommon indigenous species, was observed only at N-3 in 2023 where it was previously observed in the 2019 surveys (Burns and Kramer 2018, Burns and Annandale 2019).

Introduced *poeciliid* fish were observed at three of the southern area pools (S-1, S-3, and S-5) in 2023, compared to 2019 where they were observed at four of the southern area pools (S-1, S-5, S-7, and S-8) (Burns and Annandale 2019). After fish removal efforts, fish were only observed in pool S-1 during the 2020 and 2021 surveys (Burns et al. 2020, Burns et al. 2021). In the 2023 survey, *poeciliid* fish continued to be absent from pools S-7 and S-8 in which they were very abundant prior to the 2020 fish removal and have been recorded since 2007 and 2008, respectively (Burns and Kramer 2018, Burns and Kramer 2018, Burns and Annandale 2019). In pools S-1, S-3, and S-5, where introduced fish were present, shrimp populations, including *H. rubra* and *M. lohena*, were low (S-1) or absent (S-3 and S-5). As of the survey date in May 2023, 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 - 8). 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). Like previous surveys, very high densities of *Thiarid* 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).

Significant 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.

For the past several years of the surveys conducted at higher tides, two pools have been present about to 2.2m south of pool S-4 (Figure 15) (Burns et al. 2021, Burns and Annandale 2022). During the 2023 survey they were observed with *H. rubra*. Water quality and shrimp counts were conducted. They have similar water characteristics as the other southern pools, with slightly higher temperatures (23.6°C and 23.1°C). The smaller shallow pool had a total of 5 small, hidden *H. rubra* in the pool, where the larger pool had a density of 66 shrimp/0.1m2.

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 Hawaiʻi Island by tracking ecosystem changes overtime and evaluating causative factors.

The anchialine pools at NELHA were resurveyed in May and July 2023, and compared to previous censuses, spanning back to May 1989. The census results from 2023 show the anchialine pool ecology has remained relatively stable in the last several years except for the recent fluctuations in presence and absence of poeciliids and abundance of *H. rubra* in certain pools due to their removal and reintroduction (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. 2021, Burns and Annandale 2022). 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. Measurements collected in 2023 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. 2021, Burns and Annandale 2022; Appendix 1.1). Pool temperatures ranged from 21.7 to 30.8 °C and salinity ranged from 9.68 to 12.62 ppt. The Southern pools were cooler and less saline compared to the Northern pools during the 2023 survey. 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.

The presence of specialized native and endemic anchialine pools species, such as *H. rubra* and *M. lohena*, is a sign of a healthy pool. All the Northern pools hosted *H. rubra. H. rubra* population densities in the Northern pools were higher in some pools in 2023 than in 2022, however it had a similar pattern; the pools that had the highest densities were the same and the pools with the lowest densities were the same between the 2 years. However, pool N-3 continued to have a lower density of shrimp each year from 2021 to 2023. This year's decrease in *H. rubra* density in N-3 could be due to the presence of *M. grandimanus*, a large native prawn. The difference in the *H. rubra* counts over the years could also be due to the time of day the surveys were done, 16:00 in 2021 and 2023, and 11:00 in 2022. Even in fishless habitat *H. rubra* has higher densities at night than during the day, and, from observation, are usually in lower numbers in sun exposed areas of the pool (Havird et al. 2022, personal observation K. Annandale). Additionally, very few *H. rubra* were observed on the white rocks and vegetation on the bottom of the pool, as most were concentrated on the rocks along the sides. Again, this could be due to the exposed areas or food availability. There were no indicators of why N-4 the lowest *H. rubra* densities which was similar to the survey in 2022. However, this year many *M. lohena* were observed pool N-4.

The historical introduction of poeciliids within anchialine pools at NELHA has significantly affected pool ecology. 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 (CO_2) 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 four pools during the 2020 and 2021 surveys showed the success of the fish removal efforts. However, during the 2022 and 2023 survey, poecilids were observed in three pools (S-1, S-3, and S-5).

Fish are one of the greatest threats to anchialine pools and can be introduced into pools by people releasing their pets or bait, and tsunami events bringing in marine fish (Capps et al. 2009). Once introduced, fish can spread between pools that become connected during high tide events (Marrick and O'Grady 2014). Pool S-5 is the largest of the southern pools and possibly the most visited as it has been observed with people and dogs swimming. Fish could have been easily re-introduced into S-5 by visitors. Historically, fish had not been observed in pool S-3. However, with its proximity to S-5, fish could have been introduced during a seasonal high tide (king tide). Pool S-1 was the only pool with fish in 2020 and 2021, but it is unlikely to have introduced the fish into S-3 and S-5, due to its further distance from these pools.

Where introduced fish are present, shrimp populations, including *H. rubra* and *M. lohena*, were low or absent. *H. rubra* were observed cohabitating with the introduced poeciliids in pool S-1 during the 2023 survey and in past surveys (Burns et al. 2022). In pool S-1, *M. lohena* was observed and densities of *H. rubra* in 2023 were similar to 2022. Shrimp populations were absent in pools S-3 and S-5 where fish were recently introduced or re-introduced, respectively. 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 still not present in pools S-7 and S-8 after they were removed in 2019. With the absence of introduced poeciliid fish in pools the *H. rubra* populations in these pools remain high.

Fish removal is important for the restoration of anchialine pools as well as the protection of nearby pools. S-4 and two new pools nearby that hosts *H. rubra* are within close proximity to S-3 and S-5 and could easily be populated with poeciliids during another king tide event. The CO_2 treatment was not as successful in pool S-1, as poeciliids are still present and abundant, which could be due to the cracks and crevices in this pool being refuge for the fish during the treatment. However, with such success in the other three pools, it is recommended to continue fish removal efforts in pools with invasive fish. Additionally, education about not releasing pets and other introduced species into the wild is also important for the protection of anchialine pools and the native fauna that live in them.

Signs of visitor impacts were observed at several of the Southern pools in 2023. 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-3, S-4, S-5, and S-8). 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 may influence Hawaiian anchialine pool ecosystems by inducing changes to pool interconnectedness, depth, location, and water chemistry (Marrack and O'Grady 2014). These physical changes can in turn influence faunal composition within the pools, thus it is worth considering how factors such as tidal fluctuation could alter pool ecology outside of anthropogenic factors. The interconnectedness of pools 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 variability in sea-level. Surveys conducted over the past few years these changes have captured variability in tide levels and provide observational insight into how sea-level variability may influence pond connectivity. In the 2018 surveys, the northern pools were interconnected at tides >+2.1ft. During the 2021 survey the northern pools were interconnected at a tide of +1.7ft and a new pool to the south of N-2 was forming. In the southern complex, two pools just south of pool S-4 have formed. One of the pools, in 2023, hosted a larger density of *H. rubra* (66 shrimp/0.1m^2) compared to S-4 (12 shrimp/0.1 m^2) (Figure 15).

The results of the 2023 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 May 16 to July 13, 2023. (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. (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 on July 13, 2023. (Map generated using Google Earth Pro 7.3.3.7786).

Figure 4. (left) Northern pool, N - 1 at a tide level of +1.14’ with leaf litter floating on the surface of the pool and (right) vegetation around pool.

Figure 5. Northern pool N-2, at a tide level of +1.19’

Figure 6. Northern pool N-3 at tide level +1.28’

Figure 7. Northern pool, N-4, at tide level +1.38

Figure 8. Northern pool N-5, at tide level +1.45

Figure 9. Southern pool, S-1, at a tide level of +1.60

Figure 10. (left) Southern pool, S-3, at a tide level of +1.61' and (right) Southern pool, S-4, at a tide level of +1.74'

Figure 11. (left) Southern pool S-5 at a tide level of +2.32

Figure 12. (left) Southern pool S-6 at a tide level of +1.97. (right) Southern pool, S-9 at a tide level of +1.88

Figure 13. (left) Southern pool, S-7, at a tide level of +2.02’. (right) Southern pool, S-8, at tide level +1.96’

Figure 14. Southern pool, S-10 at a tide level of +1.53'

Figure 15. (left) New northern pool just south of pool N-4 at a tide level of +1.72 and (right) new small shallow pool just south of that at tide level of +1.69

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	*Halocaridina rubra*	Ōpae ʻula/ Ōpae hiki	Shrimp (Decapoda)
	Metabetaeus lohena		Shrimp (Decapoda)
	Macrobrachium grandimanus	Ōpae ʻoehaʻa	Shrimp (Decapoda)
	Ruppia sp.	Widgeon grass	Monocot plant (Ruppiaceae)
	Assiminea sp.	Snail	Aquatic Snail (Gastropoda)
	Theodoxus cariosa	Hihiwai	Limpet (Gastopoda)
	Trichocorixa reticulata	Water boatman	Aquatic insect (Arthropoda)
	Pantala flavescens	Globe skimmer	Dragonfly (Arthropoda)
	Ajax junior	Common green darner	Dragonfly (Arthropoda)
	Oligochaeta sp.	Worm	Aquatic worm (Oligochaeta)
	Palaemon debilis	ʻŌpae hula, Glass shrimp	Shrimp (Decapoda)
	Metopograspus meson	Kukupa	Crab (Decapoda)
	Grasps tenuicrustatus	A 'ama	Crab (Decapoda)
	Cladophora sp.	Limu hulu'ilio	Green algae (Chlorophyta)
	Enteromorpha sp.	Limu 'ele 'ele	Green algae (Chlorophyta)
	Rhizoclonium sp.	Limu	Green algae (Chlorophyta)
	Lyngbya sp.	Cyanophyte mat	Cyanobacteria (Cyanophyta)
	Schizothrix clacicola	Cyanophyte crust	Cyanobacteria (Cyanophyta)
Anchialine pool: Introduced	*Melanoides tuberculata*	Red-rimmed Melania snail, Thiarid	Thiarid Snail (Gastropoda)
	Tarebia granifera	Quilted Melania snail, Thiarid	Thiarid Snail (Gastropoda)
	Poecilia sp.	Guppy (Topminnow)	Fish (Poeciliidae)
	Gambusia affinis	Mosquitofish (Topminnow)	Fish (Poeciliidae)
	Macrobrachium lar	Tahitian Prawn	Prawn (Decapoda)
	Argiope appensa	Garden spider	Spider (Arthropoda)
	Tramea lacerata	Black saddlebags	Dragonfly (Arthropoda)
	Ischnura posita	Fragile forktail damselfly	Damselfly (Arthropoda)
Terrestrial plants	*Bacopa sp.*	Pickleweed (Invasive)	Plantaginaceae
	Capparis sandwichiana	Maiapilo (Endemic)	Capparaceae
	Cladium sp.	Sedge	Cyperaceae
	Ipomoea pes-caprae	Pōhuehue, Beach morning glory	Convolvulaceae
	Morinda citrifolia	Noni	Rubiaceae
	Pennisetum setaceum	Fountain grass (Invasive)	Poaceae
	Pluchea odorata	Pluchea	Asteraceae
	Prosopis pallida	Kiawe, mesquite tree	Mimoseae
	Scaevola taccada	Naupaka	Goodeniaceae
	Schinus terebinthifolius	Christmas berry (Invasive)	Anacardiaceae
	Sesuvium portulacastrum	ʻĀkulikuli, Pickleweed	Aizoaceae
	Thespesia populnea	Milo	Malvaceae
	Tournefortia argentea	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 May 16, 2023, at a tidal level ranging from +1.14' to +1.45'. 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 (± one standard error unit).

Area	Pool number	Survey Date	Survey Time	Water Quality		Faunal Surveys				
				Temp (C°)	Salinity (ppt)	Substrate	*H. rubra* (Count/0.1m²) (Mean ± SE)	Poeciliids	*Ruppia maritima*	Comments/ Other Species
Northern Ponds	**N-1**	5/16/2023	16:16	22.6	12.62	Sandy pebble substrate, some silt, shell and coral fragments, rock wall mauka section	265 ± 38	absent	absent	Lots of milo leaf litter, sticks, and seeds floating on surface. *Scaevola taccada, Cypenus laevigatus, Prosopis pallida, Tournefortia argentea, Thespesia populnea, Sesuvium portulacastrum, Lyngbya sp., Arigope spp*, 95% canopy cover
	N-2	5/16/2023	16:29	28.5	11.83	Basalt rubble, pahoehoe surroundings, some sediment and silt, shell fragments	73 ± 19	absent	absent	*Sesuvium portulacastrum, Schizothrix clacicola, Lyngbya sp.*, green and red algae, Thiarid snails, wasps
	N-3	5/16/2023	16:46	25.8	12.05	Silt, sediment, and shell fragments, underlying cobble, pahoehoe surroundings	62 ± 25	absent	present	*Lyngbya sp., Schizothrix clacicol, Sesuvium portulacastrum, Scaevola taccada, Cypenus laevigatus, Prosopis pallida, Arigope spp., Anax junius Macrobrachium grandimanus,*
	N-4	5/16/2023	17:00	30.8	11.94	Silt bottom with cobble and shells, pahoehoe surroundings	6 ± 6	absent	absent	*M. lohena*, Thiarid snails, *Sesuvium portulacastrum, Cypenus laevigatus, Schizothrix clacicol, Pennisetum setaceum, Prosopis pallida*
	N-5	5/16/2023	17:08	30.1	12.57	Water-worn (rounded) basalt cobble and coral, some sediment and silt	296 ± 70	absent	present	*Sesuvium portulacastrum*, Thiarid snails, *Schizothrix clacicol, Anax junius*, new path formed to pool

Table 4. Faunal census data collected for the Southern pool complex of anchialine ponds at the NELHA facility. The pool surveys were conducted on July 13, 2023, at a tidal level ranging from +1.53’ to +2.02’. 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 (± one standard error unit).

Area	Pool number	Survey Date	Survey Time	Water Quality		Faunal Surveys				
				Temp (C°)	Salinity (ppt)	Substrate	*H. rubra* (Count/0.1m²) (Mean ± SE)	Poeciliids	*Ruppia maritima*	Comments/ Other Species
Southern Ponds	S-1	7/13/2023	16:39	23.2	9.92	Basalt rubble/ pebbles, shell fragments, pahoehoe surroundings	70 ± 25	present	absent	Small poeciliids, *Pennisetum setaceum*, *Schinus terebinthifolius* (roots in pool), green algae, *M. Lohena*, broken glass and trash
	S-2	7/13/2023	16:30	-	-	-	-	-	-	Pond filled in with rocks
	S-3	7/13/2023	16:13	22.4	9.92	Basalt rubble/ pebbles, mixed pahoehoe surroundings	absent	present	absent	Lots of poecilids (mostly ~1cm), no surrounding vegetation
	S-4	7/13/2023	16:15	22.7	10.03	Basalt rubble, pahoehoe surroundings, sand	12 ± 4	absent	absent	No surrounding vegetation, green algae
	S-5	7/13/2023	16:00	22.9	9.68	Basalt rubble and coral, mixed pahoehoe surroundings,	absent	present	absent	*Pennisetum setaceum*,
	S-6	7/13/2023	15:34	21.7	10.40	Very narrow basalt crack, a'a surroundings.	16 ± 10	absent	absent	*H. rubra* very small, no surrounding vegetation, *Capparis sandwichiana* nearby
	S-7	7/13/2023	15:22	22.1	10.52	Basalt rubble (some rounded), mixed pahoehoe surroundings, shell (opihi) fragments	92 ± 20	absent	absent	*Pennisetum setaceum*, *Capparis sandwichiana*, *Schizothrix clacicola*, green algae
	S-8	7/13/2023	15:35	21.8	10.65	Basalt rubble with a few white coral stones, shell fragments, pahoehoe surroundings	96 ± 16	absent	absent	*Pennisetum setaceum*, green algae, *Pantala flavescens*, wasp
	S-9	7/13/2023	15:51	22.5	10.41	Basalt crack, a'a surroundings.	13 ± 6	absent	absent	*H. rubra* very small. No surrounding vegetation
	S-10	7/13/2023	16:50	24.4	12.07	Pahoehoe with light organic material and some sand, small basalt pebbles, shells	222 ± 58	absent	absent	*M. lohena*, *Pennisetum setaceum*, *Talinum fruticosum*, *Leucaena leucocephala*, 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 31 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, 2020, 2021 and 2022 surveys are summarized by Burns and Annandale, and the results and findings for the 2023 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
Hoʻona 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.

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 photographed 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 algae, 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 39.9%, the most dominant corals were *Porites lobata* (32.5%), *Porites evermanni* (20.0%)*, Montipora patula* (10.0%), *Porites compressa* (8.6%), *Pocillopora meandrina* (7.5%), *Montipora capitata* (5.8%), and *Pocillopora grandis* (4.2%). 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,* and *P. compressa* were the dominant corals in the shallow (~15-fsw) and moderate depths (~35-fsw) among the six stations. *P. lobata, P. evermanni, P. grandis* and *P. compressa* were the most dominant corals at the deep depths (~50-fsw) among the six stations. *P. lobata* was most abundant at the NPPE, Hoʻona Bay, 18” Pipe, and Wawaloli stations. *P. evermanni* was most abundant at Hoʻona Bay followed by the 12” Pipe N and 12” Pipe S stations. *P. meandrina* was most abundant at the 18” Pipe and Wawaloli stations. *P. compressa* was most abundant at NPPE, 18” Pipe and Hoʻona Bay 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 2022 were similar to 2022 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 NPPE, Hoʻona Bay, and 18” Pipe sites exhibited the highest levels of coral cover (55.7% 48.5%, and 40.5% 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 the 12” Pipe N and Wawaloli stations. The benthic substrate at these sites were predominantly occupied by *P. lobata, P. meandrina P. grandis*, *P. compressa*, and *M. capitata (*Table 5). Values of coral cover exhibited statistically significant differences among the survey sites. Overall coral cover was significantly higher (p<0.05, Kruskal-Wallis) at NPPE and Hoʻona Bay than the other sites. *P. lobata* exhibited significantly higher values of cover (p<0.05, Kruskal-Wallis) at NPPE, Hoona Bay, 18” Pipe, and Wawaloli compared to the 12” Pipe N and 12” Pipe South stations. *P. compressa* exhibited significantly higher values of cover (p<0.05, Kruskal-Wallis) at NPPE, Hoona Bay, and 18” Pipe compared to the other stations. *P. meandrina* exhibited significantly higher values of cover (p<0.05, Kruskal-Wallis) at the 18” Pipe and Wawaloli sites compared to the other stations. *M. capitata* exhibited significantly higher values of cover (p<0.05, Kruskal-Wallis) at NPPE and Wawaloli sites compared to the other stations. All other coral species, species riches, and species diversity did not exhibit any statistically significant differences among the survey locations.

Values of overall coral cover were statistically different among the survey depths (p<0.05, Kruskal-Wallis), with moderate depths having a higher average value of coral cover than shallow or deep survey depths. Moderate depths had an average coral cover value of 44.5%, which was followed by deep shallow sites (37.8%) and deep sites exhibiting exhibited the lowest average value of coral cover (37.4%). *P. lobata* showed significantly higher values of cover (p<0.05, Kruskal-Wallis) at the moderate sites compared to deep and shallow sites. Among the deep sites, coral was most abundant at the NPPE and Ho’ona Bay sites (76.0% and 57.7%). These statistical patterns in coral cover are like the 2017 – 2022 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 consistent with previous years and showed similar patterns in coral cover among sites in 2016-2022 (Burns and Kramer 2016- 2018, Burns and Annandale 2019-2023). Values of coral cover, species richness, and species diversity have remained relatively consistent for the past several years, which indicates stability in coral community structure among the survey locations in the last five 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., Tripnuestes 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 June 2023.

Station	Wawaloli				18" Pipe				12" Pipe South		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Overall coral cover	41.00	48.00	13.00		43.50	51.00	27.10		30.50	36.00	21.40
P. lobata	31.00	36.00	20.00		30.00	40.00	25.90		32.50	33.00	20.80
P. evermanni									5.00		5.00
P. compressa						20.00	30.00			1.00	10.50
P. meandrina	10.00		10.00		10.00		10.00		1.50	1.00	2.30
P. grandis					10.00	10.00	10.00				
M. capitata	10.00	15.00	10.00		9.00	10.00	10.00		4.60	4.20	10.00
M. patula									5.00		
Species count	7.00	3.00	2.00		6.00	3.00	4.00		5.00	6.00	4.00
Species diversity (H)	1.26	1.25	0.86		1.29	1.26	1.02		1.16	1.18	1.01
Station	12" Pipe North				NPPE				Hoona Bay		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Overall coral cover	36.90	28.50	29.00		42.00	49.00	76.00		32.90	54.80	57.70
P. lobata	32.50	28.30	22.00		40.00	40.00	42.50		31.50	39.50	27.10
P. evermanni	10.00		5.00							15.20	10.00
P. compressa			5.50			20.00	36.10			22.50	30.00
P. meandrina	3.70	5.00	5.00						5.00	3.00	1.00
P. grandis			10.00								10.00
M. capitata	4.70	7.50	5.30		10.00	10.00	10.00		1.00	5.50	
M. patula	2.70	10.00	1.50								
Species count	6.00	4.00	7.00		3.00	4.00	4.00		4.00	5.00	6.00
Species diversity (H)	1.17	1.11	1.18		1.10	1.21	1.35		1.10	1.27	1.34
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	34.00	40.50	29.30	31.50	55.70	48.50	**p<0.05**	37.80	44.50	37.40	**p<0.05**
P. lobata	32.30	32.60	29.10	27.60	40.80	32.70	**p<0.05**	32.90	36.30	27.70	**p<0.05**
P. evermanni			5.00	7.50		13.40	0.26	7.50	13.70	8.80	0.91
P. compressa		26.70	7.30	5.50	32.10	28.50	**p<0.05**		18.00	28.60	0.06
P. meandrina	10.00	10.00	1.60	4.20		3.40	**p<0.05**	6.30	6.90	2.60	0.12
P. grandis		10.00		10.00		10.00	0.90	10.00	10.00	10.00	0.90
M. capitata	11.80	9.50	5.30	5.60	10.00	2.80	**p<0.05**	6.25	9.40	9.20	0.07
M. patula			5.00	3.50			0.44	3.25	10.00	1.50	0.22
Species count	7.00	6.00	6.00	7.00	6.00	6.00	0.88	7.00	6.00	7.00	0.68
Species diversity (H)	1.12	1.19	1.12	1.15	1.19	1.24	0.72	1.17	1.21	1.12	0.91

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 2013-2022, and how they compare to the current data from 2023.

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 seven 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 2023, 39.9%, is within this range and shows the benthic communities to exhibit consistent values of coral cover for the last 14 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 Hoʻona 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 northern sites compared to southern sites, and *P. compressa* to have higher coral cover at deep depths compared to shallow depths. The 2023 data supported this trend in overall coral cover with significantly higher mean values of overall coral cover observed at the NPPE and Hoʻona Bay sites compared to the other four monitoring stations. The 2023 data also supported previous studies with *P. compressa* having significantly higher cover values at deeper sites. The 2023 data showed P. lobata to have higher values of cover at all sites among all three depths compared to the other observed coral species. The 2023 data show no significant differences in species richness or species diversity among the six stations and three depth profiles. Overall, the observed values of cover and statistical patterns detected among the survey sites and depths were similar to 2022. 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 2023 was 32.5%. This value is similar to the average observed percent coral cover in 2022 (34.3%) 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 20.0% 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 the last several years. The values of ~10% *P. evermanni* cover in 2020, 2021, and 2022 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 2023 is not statistically different to the previous five years. The differences in overall coral cover from 2013 to 2022 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 2023 values of coral cover for mounding *Porites* were also similar to prior surveys conducted during the previous 7-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 2023 data also support this trend; with the most *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 2023 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 four years, with an average observed cover of 7.5%, which is an increase of ~5% from 2022. Values of *P. meandrina* cover in 2023 were higher at moderate and 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 among all survey depths observed in the last several year, along with the ~5% increase observed this year, 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 2023 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 2009-2022. The data from 2023 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 2023 data did support the previous findings of statistically significantly higher coral cover at the more northern sites, NPPE and Hoʻona Bay. The results of the statistical analyses found similar trends among species composition, diversity and overall coral cover in 2023 compared to the 2022 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 and moderate sites in 2023 and showed an ~5% increase in cover compared to 2022, 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. This is an improvement in comparison to 2021 and 2022, which showed no observations of this species at the 18” Pipe station. Future surveys at the same spatial locations will enable documentation of *P. meandrina* recovery.

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 - 2023, the six 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 among these survey sites and depth categories.

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 2023 data show no significant variation in benthic composition (diversity and richness) 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/m^2 ($M = a * L^b$). 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 2016-2022 where the northern sites have higher counts of individual fish. Hoona Bay, NPPE, and 12" Pipe S exhibited average values of fish counts in a range of 251-455 (290, 251, and 455 respectively), which were the highest among the survey stations. *Chromis spp.* contributed to the high average value of observed fish count at shallow depth at the 12" Pipe South, which was also observed in the 2022 surveys. The range in the number of individual fish observed among all survey transects was 113 to 455. Sites in moderate depths had the highest observed average fish counts (376), followed by deep depths (167) and shallow depths (158). No statistically significant differences in the total number of individual fishes counted was detected among the six survey stations (p=0.38) or 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 South and lowest at Wawaloli, with values of 28 and 12 respectively. The range in mean number of species was 12 to 28. The shallow, moderate, and deep habitats had 22-24 species of fish recorded for surveys among these depths. There was no statistically significant difference among the six survey stations (p=0.06) or the three depth gradients (p=0.36). 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. falvescens, A. nigrofuscus, T. duperrey, C. strigosus, C. sordidus, N. literatus,* *C. multicinctus, C. agilis, C. vanderbilti, P. arcatus, H. ornatissimus, G. varius, C. jactotor, S. bursa, C. vanderbilti, P. multifasciatus, C. agilis, A. olivaceus, C. hawaiiensis, P. jonstonianus, S. fasciolatus, C. ornatissiums, 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 what has been reported in previous years.

Species Diversity and Biomass

Species diversity ranged from 2.84 at Hoona Bay to 3.89 at Wawaloli. This indicates an increase in observed diversity at Wawaloli compared to 2022, which is due to the larger number of species counted in 2023 in relation to the fish count. The mean species diversity among the deep depths was 3.69, 2.82 among moderate depths, and 3.58 among the shallow depths, which shows a slight increase in diversity observed in 2023 compared to 2022. There were no significant differences in species diversity among the six stations surveyed ($p=0.38$) or among the three depth gradients ($p=0.06$).

Fish biomass was highest at the 12" Pipe North (223.22 g/m2) and lowest at Wawaloli (111.16 g/m2). These sites also exhibited the highest and lowest mean values of biomass in 2021 and 2022. Biomass was lowest at deep depths (162.71 g/m2), and highest at the moderate depths (185.87 g/m2). No significant differences in mean biomass were detected among the depth gradients ($p=0.69$). The 12" Pipe North and 18" Pipe stations exhibited statistically significantly higher biomass values than the other survey stations ($p<0.05$). Similar to patterns found in previous survey years, the northern sites (12" Pipe N and S, NPPE, H-Bay) had numerically higher mean values compared to the southern sites (Wawaloli), which matches the statistically higher values in coral cover at the northern sites in comparison to the southern sites. However, in 2023 the mean value of biomass (199.87 g/m2) was more similar to the northern sites.

Table 6: Summary of fish survey data and comparative analyses from surveys conducted in June 2023.

Station	Wawaloli				18" Pipe				12" Pipe South		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Fish count	108.00	212.00	20.00		101.00	235.00	69.00		96.00	887.00	382.00
Number of species	16.00	16.00	5.00		28.00	21.00	29.00		25.00	29.00	30.00
Diversity	4.10	3.91	3.66		4.33	2.61	4.51		3.45	1.91	3.37
Biomass	148.12	136.65	48.73		163.53	224.05	212.04		146.64	176.57	191.88
Station	12" Pipe North				NPPE				Hoona Bay		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Fish count	201.00	99.00	170.00		170.00	516.00	66.00		269.00	306.00	296.00
Number of species	23.00	21.00	24.00		23.00	27.00	18.00		21.00	29.00	26.00
Diversity	3.33	3.17	3.41		3.46	2.47	4.34		2.82	2.85	2.86
Biomass	208.48	270.59	190.60		169.12	146.71	170.60		150.01	160.65	162.38
Mean value comparisons	Wawa	18" Pipe	12" Pipe S	12" Pipe N	NPPE	H - Bay	p-value	Shallow	Moderate	Deep	p-value
Fish count	113.33	135.00	455.00	156.67	250.67	290.33	0.39	157.50	375.80	167.20	0.14
Number of species	12.33	26.00	28.00	22.67	22.67	25.33	0.06	22.60	23.80	22.00	0.82
Diversity	3.89	3.82	2.91	3.30	3.42	2.84	0.38	3.58	2.82	3.69	0.06
Biomass	111.16	199.87	171.69	223.22	162.14	157.68	**p<0.05**	164.32	185.87	162.71	0.69

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 2023 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 2023 data exhibit the highest values in mean biomass at the northern sites (Hoona, NPPE, 12” North, 12” South) in comparison to the southern sites (Wawaloli), however the 18” Pipe station was more similar to the northern sites than has been documented in prior years. This general trend matches what was found for values of average coral cover and indicates 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. These trends of higher coral cover, higher fish count, number of species, diversity and biomass occurring at the northern sites match the patterns observed in the 2022 survey data.

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 - 2023 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 2023 were higher than some previous years, but in the same range as those observed from 2016 - 2022. 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 31-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 the values observed at Wawaloli were lower than the other five sites in surveys from 2014-2023 (Bybee et al. 2014, WHALE Environmental 2015, Burns and Kramer 2016-2018, Burns and Annandale 2019, Burns et al. 2020, Burns and Annandale 2021, Burns and Annandale 2022, Table 6). The reason of this pattern is likely habitat variability. 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 2023 data continued to support this trend with statistically significantly higher values of biomass observed at the northern sites compare to the Wawaloli site. Other than fish biomass, all other variables (fish count, number of species, diversity) were statistically similar among sites and exhibited similar ranges of values to 2022 and previous survey years.

In summary, the reports conducted over the past 31 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.

REFERENCES

Bailey-Brock, and J. H., Brock, R. E. 1993. Feeding, reproduction, and sense organs of the Hawaiian anchialine shrimp *Halocaridina rubra* (Atyidae). Pacific Science 47(4): 338-355.

Bailey-Brock, J. H., Brock, V. R., and Brock, R. E. 1999. Intrusion of anchialine species in the marine environment: the appearance of an endemic Hawaiian shrimp, *Halocaridina rubra*, on the south shore of O'ahu. Pacific Science 53: 367-369.

Benke, A. C. (1978). Interactions among coexisting predators--a field experiment with dragonfly larvae. The Journal of Animal Ecology, 335-350.

Brock, R. E. 1985. An assessment of the conditions and future of the anchialine pond resources of the Hawaiian Islands. Pp. C-1 – C-12. In: Us Army Corps of Engineers. Final Environmental Impact Statement, U. S. Department of the Army Permit Application. Waikoloa Beach Resort, Waikoloa, South Kohala District, Island of Hawaii. Honolulu.

Brock, R. E., Norris, J. E., Ziemann, D. A., and Lee, M. T. 1987. Characteristics of water quality in anchialine ponds of the Kona, Hawaii Coast. Pacific Science 41(1-4): 200-208.

Brock, R. E. 1995. Cooperative Environmental Monitoring Program for the Natural Energy Laboratory of Hawaii. Survey for Anchialine and Marine Fish Resources. 23 June 1995 Survey. Prepared for NELHA, Kailua-Kona, Hawaii. EAC Report No. 95-07. 56 pp.

Brock, R. E., Bailey-Brock, J. H. 1998. An unique anchialine pool in the Hawaiian Islands. International Review of Hydrobiology 83(1): 65-75.

Brock, R. E. 2002. Cooperative Environmental Monitoring Program for the Natural Energy Laboratory of Hawaii. Survey for Anchialine and Marine Fish Resources. May 2002 Survey. Prepared for NELHA, Kailua-Kona, Hawaii. EAC Report No. 2002-13A. 61 pp. plus Appendix.

Brock, R. E. 2008. Cooperative Environmental Monitoring Program for the Natural Energy Laboratory of Hawaii. Survey for Anchialine and Marine Fish Resources. Synopsis of 2007-2008 Surveys. Prepared for NELHA, Kailua-Kona, Hawaii. EAC Report No. 2008-16. 60 pp. plus Appendix.

Brock, V. E. 1954. A preliminary report on a method of estimating reef fish populations. J. Wildlife Mgmt. 18:297-304.

Burns, J. H. R., and K. L. Kramer (PlanB Consultancy, Inc.). 2016. NELHA Benthic and Biota Monitoring Study, May 2016. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 86 pp. + Appendices.

Burns, J. H. R., and K. L. Kramer (PlanB Consultancy, Inc.). 2017. NELHA Benthic and Biota Monitoring Study, May 2017. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 86 pp. + Appendices.

Burns, J. H. R., and K. L. Kramer (PlanB Consultancy, Inc.). 2018. NELHA Benthic and Biota Monitoring Study, May 2017. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 86 pp. + Appendices.

Burns, J. H. R., and Annandale K (PlanB Consultancy, Inc.). 2019. NELHA Benthic and Biota Monitoring Study, May 2017. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 86 pp. + Appendices.

Burns, J. H. R., Annandale K., Springer, K. (PlanB Consultancy, Inc.). 2020. NELHA Benthic and Biota Monitoring Study, May 2017. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 86 pp. + Appendices.

Burns, J. H. R., and Annandale K (PlanB Consultancy, Inc.). 2021. NELHA Benthic and Biota Monitoring Study, May 2017. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 86 pp. + Appendices.

Burns, J. H. R., and Annandale K (MEGA Lab) 2022. NELHA Benthic and Biota Monitoring Study, May 2017. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 86 pp. + Appendices.

Bybee, D.R., and Barrett, B. 2012. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority Keahole Point, District of North Kona Island of Hawaii. Survey Report April 2012. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 55 pp. + Appendices 1 - 4

Bybee, D.R., Hyde, S.K., Smith, B.L., Munton, C. 2013. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority Keahole Point, District of North Kona Island of Hawaii. Survey Report April 2013. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 52 pp. + Appendices 1 – 4

Capps, K. A., Turner, C. B., Booth, M. T., Lombardozzi, D. L., McArt, S. H., Chai, D., and Hairston, N. G., Jr. 2009. Behavioral responses of the endemic shrimp *Halocaridina rubra* (Malacostraca: Atyidae) to an introduced fish, *Gambusia affinis* (Actinopterygii: Poeciliidae) and implications for the trophic structure of Hawaiian anchialine ponds. Pacific Science 63(1): 27-37.

Catling, P. M. (2009). Dragonflies (Odonata) Emerging from Brackish Pools in Saltmarshes of Gaspé, Quebec. The Canadian Field-Naturalist, *123*(2), 176-177.

Chace, F. A., Jr., and Manning, R. B. 1972. Two new caridean shrimps, one representing a new family, from marine pools on Ascension Island (Crustacea: Decapoda: Natantia). Smithsonian Contributions to Zoology 131: 1-18.

Dollar, S. J. 1975. Zonation of reef corals off the Kona Coast of Hawaii. M.S. thesis, Dept. of Oceanography, University of Hawaii, Honolulu, 183 pp.

Dollar, S. J. 1982. Wave stress and coral community structure in Hawaii. Coral Reefs 1: 71-81.

Dollar, S. J. and G. W. Tribble. 1993. Recurrent storm disturbance and recovery: a long-term study of coral communities in Hawaii. Coral Reefs 12:223-233.

Froese, R. and D. Pauly, Editors. 2000. FishBase 2000: concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines. 344 p.

Google Inc. 2012. Google Earth. Version 6.2. Mountain View, CA.

Gray, J. H., and Pearson, J. H. 1982. Objective selection of sensitive species indicative of pollution-induced change in benthic communities. I. Comparitive methodology. Marine Ecology Progress Series 9: 111-119.

Hobbs, H. H. I. 1994. Biogeography of subterranean decapods in North and Central America and the Caribbean region (Caridea, Astacidae, Brachyura). Hydrobiologia 287(1): 95-104.

Holthuis, L. B. 1973. Caridean shrimps found in land-locked saltwater pools at four Indo-West Pacific localities (Sinai Peninsula, Funafuti Atoll, Maui and Hawaii Islands), with the description of one new genus and four new species. Zoologische Verhandelingen 128: 1-48.

Kohler, K. E. , and Gill, S. M. 2006. Coral Point Count with Excel extensions (CPCe): a visual basic program for the determination of coral and substrate coverage using random point count methodology. Computers and Geosciences, 32 (9) (2006), pp. 1259-1269.

Iliffe, T. M. 1991. Anchialine fauna of the Galapagos Islands. Topics in Geobiology 8: 209-231.

Maciolek, J. A., and Brock, R. E. 1974. Aquatic survey of the Kona coast ponds, Hawai'i Island. Sea Grant Advisory Report, UNIHISEAGRANT-AR-74–04.

U.S. Department of Commerce and Hawaii Cooperative Fishery Unit. Honolulu, HI,

Maciolek, J. A. 1983. Distribution and biology of Indo-Pacific insular hypogeal shrimp. Bulletin of Marine Science 33: 606-618.

Marrack, L. and P. O'Grady. 2014. Predicting impacts of sea level rise for cultural and natural resources in five National Park units on the Island of Hawai'i. Technical Report No. 188. Pacific Cooperative Studies Unit, University of Hawai'i, Honolulu, Hawai'i. 40 pp.

Marine Research Consultants. 1995. Benthic Marine Biota Monitoring Program at Keahole Point, Hawaii. Report XI, May 1995. Prepared for the Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 15 pp. + figs. and appendices.

Marine Research Consultants. 1998. Benthic Marine Biota Monitoring Program at Keahole Point, Hawaii. November 1997. Prepared for the Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 17 pp. + figs. and appendices.

Marine Research Consultants. 2002. Benthic Marine Biota Monitoring Program at Keahole Point, Hawaii. June 2002. Prepared for the Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 15 pp. + figs.and appendices.

Marine Research Consultants. 2008. Benthic Marine Biota Monitoring Program at Keahole Point, Hawaii. July 2008. Prepared for the Natural Enerty Laboratroy of Hawaii Authority, Kailua-Kona. 13 pp. + tables, figures and appendices.

Oceanic Institute. 1997. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority, Final Report - November 1995 - May 1997. Prepared for Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 35 pp. + Appendices A - E.

Oceanic Institute. 1997. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority, Final Report – November 1995-1997. Prepared for Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 35 pp. + Appendices A - E.

Oceanic Institute. 2005a. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority, Survey Report – July 2005. Prepared for Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 37 pp. + Appendices A - D.

Oceanic Institute. 2005b. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority, Survey Report – November 2005. Prepared for Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 37 pp. + Appendices A - D.

Oceanic Institute. 2006. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority, Survey Report - July 2006. Prepared for Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 38 pp. + Appendices A - D.

Oceanic Institute. 2007. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority, Final Report - January 2007. Prepared for Natural Energy Laboratory of Hawaii Authority, Kailua-Kona. 38 pp. + Appendices A - D.

Peck, S. B. 1994. Diversity and zoogeography of the non-oceanic Crustacea of the Galapagos Islands, Ecuador (excluding terrestrial Isopoda). Canadian Journal of Zoology 72(1): 54-69.

Santos, S. 2006. Patterns of genetic connectivity among anchialine habitats: a case study of the endemic Hawaiian shrimp *Halocaridina rubra* on the island of Hawaii. Molecular Ecology 15: 2699–2718.

School of ocean and earth science and Technology (SOEST), University of Hawaiʻi at Mānoa website. Accessed May 2017. http://www.soest.hawaii.edu/coasts/sealevel/.

Whale Environmental Services. 2015. NELHA Benthic and Biota Monitoring Study June 2015. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 35 pp. + Appendices 1 – 3

Yamamoto, M. N., and A. W. Tagawa. 2000. Hawaii's Freshwater Animals: Native & Exotic. Mutual Publishing: Honolulu Hawaii. 112 pp.

Yamamoto, M. N., T. Y. Iwai, and A. W. Tagawa. 2015. Hawaiian Anchialine Pools. Mutual Publishing: Honolulu Hawaii. 112 pp.

Ziemann, D. A., and Conquest, L. D. 2008. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority Keahole Point, District of North Kona Island of Hawaii. Survey Report October 2008. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 49 pp. + Appendices A - E.

Ziemann, D. A., and Conquest, L. D. 2008. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority Keahole Point, District of North Kona Island of Hawaii. Survey Report October 2008. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 49 pp. + Appendices A - E.

Ziemann, D. A., and Conquest, L. D. 2009. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority Keahole Point, District of North Kona Island of Hawaii. Survey Report May 2009. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 38 pp. + Appendices A - E.

Ziemann, D. A., and Conquest, L. D. 2010. Marine Biota Monitoring Program for Natural Energy Laboratory of Hawaii Authority Keahole Point, District of North Kona Island of Hawaii. Survey Report March 2010. Prepared for Natural Energy Laboratory of Hawaii Authority (NELHA), Kailua-Kona, HI. 38 pp. + Appendices A - E.

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/0.1m²)								Pond: N-2 (Count/0.1m²)			Pond: N-3 (Count/0.1m²)							
	Thiarid Snails (Melania sp.)		*H. rubra*	Poecilia sp.	*M. grandimanus*	*P. debilis*	*M. messor*	*T. cariosa*	Thiarid Snails (Melania sp.)	*H. rubra*	*Poecilia sp.*	Thiarid Snails (Melania sp.)			*H. rubra*		Poecilia sp.	*M. lar*	*P. debilis*
	a	b	a						a	a		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/0.1m²)						Pond: N-5 (Count/0.1m²)					
	Thiarid Snails (Melania sp.)		*H. rubra*		Poecilia sp.	*M. grandi-manus*	Thiarid Snails (Melania sp.)		*H. rubra*	Poecilia sp.	*M. grandi-manus*	*M. messor*
	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)			
	H. rubra	Poecilia sp.	*M. grandi-manus*	*Amphi-poda*	*H. rubra*	Poecilia sp.	*Amphi-poda*	*H. rubra*	Poecilia sp.	*M. lohena*	*Amphi-poda*	*H. rubra*	Poecilia sp.	*Abudefduf sordidus*	*Amphi-poda*
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

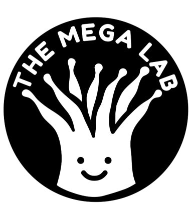
Appendix 1.2. (continued)

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)	
	H. rubra	Poecilia sp.	*M. grandi-manus*	*Amphi-poda*	*H. rubra*	Poecilia sp.	*Amphi-poda*	*Amphi-poda (white)*	*H. rubra*	Poecilia sp.	*M. grandi-manus*	*Amphi-poda*	*H. rubra*	Poecilia sp.	*M. grandi-manus*	*H. rubra*	Poecilia 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	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)	Dictyospaeria cavernosa (Dictcav)	Dictyosphaeria versluysii (Dictver)	Dictyota species (Dicty)	Gibsmithia hawaiiensis (Gibhaw)	Halimeda opuntia (Halop)	Lobophora variegata (Lobvar)	Martensia flabelliformis (Marflab)	Martensia fragilis (Marfrag)	Neomeris annulata (Neoman)	Padina species (Padina)	Portieria hornemanii (Porhor)	Predaea weldii (Prewel)	Sargassum (Sarg)	Turbinaria ornata (Turbor)	Turf (Turf)	Ventricaria ventricosa (venven)	red algae
12S	50	0								40																		40		
12S	50	2								50																		38		
12S	50	4								30																		50		
12S	50	6								40																		45		
12S	50	8								30																		50		
12S	50	10								30																		25		
12S	50	12								20																		40		
12S	50	14								20																		40		
12S	50	16								15																		64		
12S	50	18								25																		64		
12S	35	0								5																		70		
12S	35	2								10																		65		
12S	35	4								5																		65		
12S	35	6								5																		50		
12S	35	8								5																		43		
12S	35	10								5																		45		
12S	35	12								5																		40		
12S	35	14								1																		39		
12S	35	16																										38		
12S	35	18								1																		53		
12S	15	0																										58		
12S	15	2																										78		
12S	15	4																										48		
12S	15	6								20																		59		
12S	15	8								1																		83		
12S	15	10								30																		55		
12S	15	12								60																		29		
12S	15	14								10																		59		
12S	15	16								5																		50		
12S	15	18								1																		49		



Site	Depth	Location	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)	Dictyospaeria cavernosa (Dictcav)	Dictyosphaeria versluysii (Dictver)	Dictyota species (Dicty)	Gibsmithia hawaiiensis (Gibhaw)	Halimeda opuntia (Halop)	Lobophora variegata (Lobvar)	Martensia flabelliformis (Marflab)	Martensia fragilis (Marfrag)	Neomeris annulata (Neoman)	Padina species (Padina)	Portieria hornemanii (Porhor)	Predaea weldii (Prewel)	Sargassum (Sarg)	Turbinaria ornata (Turbor)	Turf (Turf)	Ventricaria ventricosa (venven)	red algae
12N	50	0								10																		60		
12N	50	2								5																		55		
12N	50	4								5																		65		
12N	50	6								1																		64		
12N	50	8								3																		69		
12N	50	10								1																		69		
12N	50	12								5																		60		
12N	50	14								1																		64		
12N	50	16								1																		69		
12N	50	18																										63		
12N	35	0								1																		69		
12N	35	2																										45		
12N	35	4								5																		70		
12N	35	6								10																		50		
12N	35	8																										70		
12N	35	10																										60		
12N	35	12								1																		54		
12N	35	14								10																		70		
12N	35	16								10																		75		
12N	35	18								2																		78		
12N	15	0								3																		65		
12N	15	2																										79		
12N	15	4								1																		50		
12N	15	6								1																		49		
12N	15	8																										70		
12N	15	10								5																		40		
12N	15	12																										70		
12N	15	14								13																		70		
12N	15	16																										40		
12N	15	18								20																		55		

Site	Depth	Location	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)	Dictyospaeria cavernosa (Dictcav)	Dictyosphaeria versluysii (Dictver)	Dictyota species (Dicty)	Gibsmithia hawaiiensis (Gibhaw)	Halimeda opuntia (Halop)	Lobophora variegata (Lobvar)	Martensia flabelliformis (Marflab)	Martensia fragilis (Marfrag)	Neomeris annulata (Neoman)	Padina species (Padina)	Portieria hornemanii (Porhor)	Predaea weldii (Prewel)	Sargassum (Sarg)	Turbinaria ornata (Turbor)	Turf (Turf)	Ventricaria ventricosa (venven)	red algae
NPPE	50	0																										20		
NPPE	50	2								10																		20		
NPPE	50	4								10																		20		
NPPE	50	6																										20		
NPPE	50	8								10																		20		
NPPE	50	10																										30		
NPPE	50	12								10																		10		
NPPE	50	14								10																		30		
NPPE	50	16								10																		0		
NPPE	50	18																										10		
NPPE	35	0																										50		
NPPE	35	2																										50		
NPPE	35	4																										60		
NPPE	35	6																										50		
NPPE	35	8																										70		
NPPE	35	10																										40		
NPPE	35	12																										30		
NPPE	35	14																										70		
NPPE	35	16																										40		
NPPE	35	18																										50		
NPPE	15	0																										50		
NPPE	15	2																										30		
NPPE	15	4																										80		
NPPE	15	6																										40		
NPPE	15	8																										80		
NPPE	15	10																										60		
NPPE	15	12																										70		
NPPE	15	14																										80		
NPPE	15	16																										40		
NPPE	15	18																										50		

Site	Depth	Location	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)	Dictyospaeria cavernosa (Dictcav)	Dictyosphaeria versluysii (Dictver)	Dictyota species (Dicty)	Gibsmithia hawaiiensis (Gibhaw)	Halimeda opuntia (Halop)	Lobophora variegata (Lobvar)	Martensia flabelliformis (Marflab)	Martensia fragilis (Marfrag)	Neomeris annulata (Neoman)	Padina species (Padina)	Portieria hornemanii (Porhor)	Predaea weldii (Prewel)	Sargassum (Sarg)	Turbinaria ornata (Turbor)	Turf (Turf)	Ventricaria ventricosa (venven)	red algae
H-bay	50	0								20																		20		
H-bay	50	2								20																		20		
H-bay	50	4								20																		30		
H-bay	50	6								20																		9		
H-bay	50	8								10																		0		
H-bay	50	10								25																		25		
H-bay	50	12								40																		5		
H-bay	50	14								20																		10		
H-bay	50	16								30																		0		
H-bay	50	18								10																		10		
H-bay	35	0								30																		19		
H-bay	35	2								45																		20		
H-bay	35	4								20																		8		
H-bay	35	6								20																		10		
H-bay	35	8								20																		10		
H-bay	35	10								20																		20		
H-bay	35	12								35																		0		
H-bay	35	14								35																		10		
H-bay	35	16								20																		35		
H-bay	35	18								10																		65		
H-bay	15	0								5																		70		
H-bay	15	2								5																		45		
H-bay	15	4								10																		50		
H-bay	15	6																										49		
H-bay	15	8																										84		
H-bay	15	10								5																		78		
H-bay	15	12								5																		70		
H-bay	15	14								10																		45		
H-bay	15	16								20																		35		
H-bay	15	18								16																		64		

Site	Depth	Location	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)	Dictyospaeria cavernosa (Dictcav)	Dictyosphaeria versluysii (Dictver)	Dictyota species (Dicty)	Gibsmithia hawaiiensis (Gibhaw)	Halimeda opuntia (Halop)	Lobophora variegata (Lobvar)	Martensia flabelliformis (Marflab)	Martensia fragilis (Marfrag)	Neomeris annulata (Neoman)	Padina species (Padina)	Portieria hornemanii (Porhor)	Predaea weldii (Prewel)	Sargassum (Sarg)	Turbinaria ornata (Turbor)	Turf (Turf)	Ventricaria ventricosa (venven)	red algae
18	50	0								10																		70		
18	50	2								20																		70		
18	50	4								10																		69		
18	50	6								20																		20		
18	50	8								30																		30		
18	50	10								10																		50		
18	50	12								30																		20		
18	50	14																										30		
18	50	16																										60		
18	50	18								10																		40		
18	35	0																										30		
18	35	2								10																		30		
18	35	4																										60		
18	35	6																										60		
18	35	8																										30		
18	35	10																										60		
18	35	12								10																		30		
18	35	14																										30		
18	35	16																										50		
18	35	18								10																		30		
18	15	0																										40		
18	15	2																										50		
18	15	4																										40		
18	15	6																										45		
18	15	8																										30		
18	15	10								10																		60		
18	15	12																										50		
18	15	14																										70		
18	15	16																										60		
18	15	18								10																		60		

Site	Depth	Location	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)	Dictyospaeria cavernosa (Dictcav)	Dictyosphaeria versluysii (Dictver)	Dictyota species (Dicty)	Gibsmithia hawaiiensis (Gibhaw)	Halimeda opuntia (Halop)	Lobophora variegata (Lobvar)	Martensia flabelliformis (Marflab)	Martensia fragilis (Marfrag)	Neomeris annulata (Neoman)	Padina species (Padina)	Portieria hornemanii (Porhor)	Predaea weldii (Prewel)	Sargassum (Sarg)	Turbinaria ornata (Turbor)	Turf (Turf)	Ventricaria ventricosa (venven)	red algae
Wawa	50	0																										0		
Wawa	50	2																										0		
Wawa	50	4																										20		
Wawa	50	6																										10		
Wawa	50	8																										10		
Wawa	50	10																										10		
Wawa	50	12																										0		
Wawa	50	14																										0		
Wawa	50	16																										0		
Wawa	50	18																										0		
Wawa	35	0																										40		
Wawa	35	2																										20		
Wawa	35	4																										20		
Wawa	35	6																										60		
Wawa	35	8																										60		
Wawa	35	10																										20		
Wawa	35	12																										50		
Wawa	35	14																										40		
Wawa	35	16																										40		
Wawa	35	18																										40		
Wawa	15	0																										60		
Wawa	15	2																										70		
Wawa	15	4																										30		
Wawa	15	6																										60		
Wawa	15	8																										70		
Wawa	15	10																										40		
Wawa	15	12																										50		
Wawa	15	14																										40		
Wawa	15	16																										70		
Wawa	15	18																										70		

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

Site	Depth	Location	Sub-Categories	Coral	Cirrhipathes spp	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Pavona varians (Pavvar)	Pocillopora grandis	Pocillopora meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites lutea	Porites lobata (Porlob)	Inorganics	Sand (Sand)	
12S	50	0																20			
12S	50	2													1			11			
12S	50	4												5				15			
12S	50	6																15			
12S	50	8																20			
12S	50	10													20			25			
12S	50	12																40			
12S	50	14							10											30	
12S	50	16												1				20			
12S	50	18							10					1							
12S	35	0							5									20			
12S	35	2							5									20			
12S	35	4															5	25			
12S	35	6							5									30		10	
12S	35	8										1		1				50			
12S	35	10							5									40		5	
12S	35	12																50		5	
12S	35	14																40		20	
12S	35	16							1					1				30		30	
12S	35	18													1			25		20	
12S	15	0							1					1				40			
12S	15	2							1					1				20			
12S	15	4							1					1				50			
12S	15	6												1				20			
12S	15	8												1				15			
12S	15	10							10					5							
12S	15	12							10					1							
12S	15	14												1				30			
12S	15	16									5							40			
12S	15	18															5	45			

Site	Depth	Location	Sub-Categories	Coral	Cirrhipathes spp	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Pavona varians (Pavvar)	Pocillopora grandis	Pocillopora meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites lutea	Porites lobata (Porlob)	Inorganics	Sand (Sand)	
12N	50	0							10									20			
12N	50	2																20		20	
12N	50	4																25		5	
12N	50	6							5									30			
12N	50	8									2			5	1			20			
12N	50	10											10					20			
12N	50	12											10		10			15			
12N	50	14											10				5	20			
12N	50	16																15		15	
12N	50	18							1		1							35			
12N	35	0																30			
12N	35	2																50		5	
12N	35	4																25			
12N	35	6							10											30	
12N	35	8							5					5				20			
12N	35	10																40			
12N	35	12									10							35			
12N	35	14																20			
12N	35	16																15			
12N	35	18																20			
12N	15	0							2									30			
12N	15	2										1		5				15			
12N	15	4							2		2							45			
12N	15	6																50			
12N	15	8																30			
12N	15	10							10		5							40			
12N	15	12																30			
12N	15	14									1			1				15			
12N	15	16															10	50			
12N	15	18												5				20			

Site	Depth	Location	Sub-Categories	Coral	Cirrhipathes spp	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Pavona varians (Pavvar)	Pocillopora grandis	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites lutea	Porites lobata (Porlob)	Inorganics	Sand (Sand)	
NPPE	50	0													40			40			
NPPE	50	2													20			50			
NPPE	50	4													25			45			
NPPE	50	6													25			55			
NPPE	50	8																70			
NPPE	50	10							10						30			30			
NPPE	50	12													30			50			
NPPE	50	14													35			25			
NPPE	50	16													75			15			
NPPE	50	18													45			45			
NPPE	35	0							10									40			
NPPE	35	2																50			
NPPE	35	4													20			20			
NPPE	35	6													20			30			
NPPE	35	8																30			
NPPE	35	10							10									50			
NPPE	35	12							10						20			40			
NPPE	35	14																30			
NPPE	35	16																60			
NPPE	35	18																50			
NPPE	15	0																50			
NPPE	15	2							10									60			
NPPE	15	4																20			
NPPE	15	6							10									50			
NPPE	15	8																20			
NPPE	15	10																40			
NPPE	15	12																30			
NPPE	15	14																20			
NPPE	15	16																60			
NPPE	15	18																50			

Site	Depth	Location	Sub-Categories	Coral	Cirrhipathes spp	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Pavona varians (Pavvar)	Pocillopora grandis	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites lutea	Porites lobata (Porlob)	Inorganics	Sand (Sand)
H-bay	50	0													30			30		
H-bay	50	2													20			40		
H-bay	50	4								5					15		10	20		
H-bay	50	6											15	1	25		10	20		
H-bay	50	8											5					11		74
H-bay	50	10													40			10		
H-bay	50	12															10	40		5
H-bay	50	14											10		20			40		
H-bay	50	16													40			30		
H-bay	50	18													50			30		
H-bay	35	0												1			20	30		
H-bay	35	2															5	30		
H-bay	35	4							1								36	35		
H-bay	35	6							10								20	40		
H-bay	35	8													30			40		
H-bay	35	10																60		
H-bay	35	12																65		
H-bay	35	14													15		5	35		
H-bay	35	16												5				40		
H-bay	35	18															5	20		
H-bay	15	0																25		
H-bay	15	2												5				45		
H-bay	15	4																40		
H-bay	15	6							1									50		
H-bay	15	8							1									15		
H-bay	15	10						1	1									15		
H-bay	15	12																20		5
H-bay	15	14																45		
H-bay	15	16												5				40		
H-bay	15	18																20		

Site	Depth	Location	Sub-Categories	Coral	Cirrhipathes spp	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Pavona varians (Pavvar)	Pocillopora grandis	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites lutea	Porites lobata (Porlob)	Inorganics	Sand (Sand)	
18	50	0							10											10	
18	50	2							10												
18	50	4																11		10	
18	50	6													20			20		20	
18	50	8																30		10	
18	50	10																20		20	
18	50	12																50			
18	50	14																20		50	
18	50	16																30		10	
18	50	18											10		40						
18	35	0											10		20			40			
18	35	2							10									50			
18	35	4							10					10				20			
18	35	6							10									20		10	
18	35	8							10									50		10	
18	35	10												10				30			
18	35	12												10				50			
18	35	14												10				50		10	
18	35	16																40		10	
18	35	18																50		10	
18	15	0							10									30		20	
18	15	2											10	10				30			
18	15	4							10									50			
18	15	6							5					10				40			
18	15	8							10					10				50			
18	15	10																20		10	
18	15	12										20						20		10	
18	15	14				10												20			
18	15	16							10					10				20			
18	15	18												10				20			

Site	Depth	Location	Sub-Categories	Coral	Cirrhipathes spp	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Pavona varians (Pavvar)	Pocillopora grandis	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites lutea	Porites lobata (Porlob)	Inorganics	Sand (Sand)	
Wawa	50	0							10											90	
Wawa	50	2							10											90	
Wawa	50	4							10											70	
Wawa	50	6							10											80	
Wawa	50	8							10									20		60	
Wawa	50	10																20		70	
Wawa	50	12							10											90	
Wawa	50	14							10											90	
Wawa	50	16							10											90	
Wawa	50	18							10											90	
Wawa	35	0							30									30			
Wawa	35	2							10									30		40	
Wawa	35	4							20									30		30	
Wawa	35	6																40			
Wawa	35	8							10					10				20			
Wawa	35	10							10					10				60			
Wawa	35	12																20		30	
Wawa	35	14												10				50			
Wawa	35	16																30		30	
Wawa	35	18							10									50			
Wawa	15	0												10				20			
Wawa	15	2												10				20			
Wawa	15	4							10									40		20	
Wawa	15	6												10				30			
Wawa	15	8												10				20			
Wawa	15	10												10				50			
Wawa	15	12							10									40			
Wawa	15	14												10				50			
Wawa	15	16												10				20			
Wawa	15	18												10				20			

Table 2.3 Benthic habitat characterization data – Mobile Invertebrates

SITES	Sum of D. paucispinum	Sum of Echinometra mathaei	Count of Echinometra oblonga	Sum of Echinothrix sp.	Sum of H. mammillatus	Sum of Tripneustes gratilla
⊟18	**4**	**1**				
15	2					
35	2					
50		1				
⊟12N		**12**		**3**		
15		1				
35		10		1		
50		1		2		
⊟12S		**7**		**2**		**3**
15		2		1		
35		4		1		
50		1				3
⊟H-bay		**46**		**7**		**2**
15		17				
35		18		2		
50		11		5		2
⊟NPPE	**2**	**26**		**1**	**1**	**10**
15		1				
35	2	20		1		1
50		5			1	9
⊟Wawa	**4**	**12**				
15		11				
35	4					
50		1				
Grand Total	**10**	**104**		**13**	**1**	**15**

Appendix 3: Nearshore fish assemblage data

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

Haona Bay	6/15/23									
50'				35'				15'		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		**Species**	Individuals	Size (cm)
N. literatus	1	17		*A. nigrofuscus*	1	5		*A. nigrofuscus*	13	8
N. literatus	1	14		*A. nigrofuscus*	5	9		*A. nigrofuscus*	7	12
C. potteri	2	6		*A. nigrofuscus*	1	4		*A. nigrofuscus*	18	10
C. potteri	1	7		*A. nigrofuscus*	3	10		*C. strigosus*	3	9
C. jactator	1	5		*C. agilis*	5	5		*C. vanderbilti*	40	4
A. nigrofuscus	4	8		*C. strigosus*	3	4		*C. vanderbilti*	32	2
A. nigrofuscus	5	7		*C. strigosus*	3	6		*C. vanderbilti*	50	3
A. nigrofuscus	10	9		*C. strigosus*	3	9		*T. duperrey*	5	9
C. ornatissimus	2	14		*C. strigosus*	4	10		*T. duperrey*	4	6
C. ornatissimus	1	9		*C. vanderbilti*	38	2		*Z. flavescens*	4	13
G. varius	1	8		*C. vanderbilti*	36	3		*Z. flavescens*	5	14
H. ornatissimus	1	7		*C. vanderbilti*	70	4		*C. multicinctus*	3	9
G. meleagris	1	43		*T. duperrey*	3	11		*S. balteata*	4	8
D. albisella	3	13		*T. duperrey*	1	7		*A. abdominalis*	10	9
D. albisella	2	9		*T. duperrey*	1	9		*A. abdominalis*	10	13
C. hawaiiensis	1	12		*T. duperrey*	1	12		*A. vaigiensis*	10	9
C. agilis	30	3		*C. sordidus*	2	16		*A. vaigiensis*	15	13
C. agilis	40	4		*C. sordidus*	2	9		*A. vaigiensis*	15	11
C. agilis	50	5		*C. sordidus*	3	12		*C. hawaiiensis*	1	14
P. multifasciatus	1	14		*C. sordidus*	1	22		*C. sordidus*	1	24
C. strigosus	10	8		*C. multicinctus*	1	8		*C. sordidus*	1	20
C. strigosus	5	9		*C. jactator*	2	4		*C. sordidus*	1	32
Z. flavescens	7	8		*C. jactator*	1	5		*C. sordidus*	1	38
Z. flavescens	11	6		*M. vidua*	1	21		*F. flavissimus*	1	12
Z. flavescens	5	5		*N. literatus*	2	20		*M. niger*	1	19
T. duperrey	2	10		*N. literatus*	1	22		*P. arcatus*	1	11
Z. cornutus	2	9		*N. literatus*	2	17		*P. multifasciatus*	1	14
M. kuntee	40	16		*N. literatus*	1	23		*P. multifasciatus*	1	11
M. kuntee	27	13		*A. vaigiensis*	10	11		*Kyphosus spp.*	1	28
C. sordidus	1	12		*A. vaigiensis*	22	12		*Kyphosus spp.*	1	31
C. sordidus	1	13		*C. gaimard*	1	7		*Kyphosus spp.*	1	22
C. sordidus	7	11		*C. gaimard*	2	6		*A. olivaceus*	1	14
C. sordidus	7	15		*C. gaimard*	1	4		*C. carolinus*	1	13
L. phthirophagus	1	6		*H. ornatissimus*	1	9		*C. ornatissimus*	2	14
O. unifasciatus	1	7		*H. ornatissimus*	1	12		*P. imparipennis*	2	2
P. evanidus	1	4		*Z. flavescens*	2	6		*P. johnstonianus*	1	3
P. evanidus	1	6		*Z. flavescens*	1	7		*S. marginatus*	1	6
P. johnstonianus	1	6		*A. blochii*	1	19				
P. johnstonianus	1	7		*F. flavissimus*	2	11				
P. octotaenia	1	10		*P. multifasciatus*	1	14				
S. balteata	3	7		*P. multifasciatus*	1	17				
L. kasmira	1	19		*Z. cornutus*	2	11				
A. achilles	1	40		*X. auromarginatus*	1	14				
M. grandoculis	1	13		*C. hanui*	1	5				
				M. niger	21	22				
				P. imparipennis	2	4				
				S. balteata	2	8				
				S. rubroviolaceus	1	24				
				C. vanderbilti	20	2				
				P. evanidus	1	6				
				S. psittacus	1	22				
				P. aspricaudus	1	11				

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50'		
Species	**Individuals**	**Size (cm)**
Z. flavescens	4	4
Z. flavescens	6	6
Z. flavescens	4	7
A. nigrofuscus	1	4
C. strigosus	5	9
C. strigosus	7	8
C. strigosus	2	7
C. sordidus	1	12
C. sordidus	2	14
C. sordidus	3	15
C. sordidus	2	17
T. duperrey	1	7
T. duperrey	2	12
C. multicinctus	1	8
C. multicinctus	1	6
P. multifasciatus	1	14
C. hanui	1	4
C. agilis	3	2
C. agilis	3	3
C. agilis	14	4
C. agilis	2	5
C. agilis	1	6
L. phthirophagus	1	9
H. polylepis	1	13
N. literatus	1	16
H. ornatissimus	1	3
H. ornatissimus	1	8
A. thompsoni	1	11
C. jactator	2	3
F. flavissimus	1	14
F. flavissimus	2	13
M. burdti	1	12
M. burdti	11	15
M. burdti	6	16
N. hexacanthus	1	17
S. psittacus	1	16
S. psittacus	5	11

35'		
Species	**Individuals**	**Size (cm)**
C. strigosus	4	4
C. strigosus	8	5
C. strigosus	2	10
C. strigosus	10	8
C. strigosus	6	6
T. duperrey	1	13
T. duperrey	1	15
T. duperrey	1	17
T. duperrey	1	7
T. duperrey	3	9
T. duperrey	1	3
T. duperrey	1	11
A. nigrofuscus	10	9
A. nigrofuscus	8	6
A. nigrofuscus	14	10
C. sordidus	1	21
C. sordidus	1	15
C. sordidus	2	20
C. sordidus	5	14
C. sordidus	2	17
Z. flavescens	3	10
Z. flavescens	5	5
Z. flavescens	3	8
Z. flavescens	3	13
Z. flavescens	1	6
C. jactator	2	4
C. jactator	1	5
G. varius	1	4
G. varius	1	11
C. multicinctus	2	9
C. vanderbilti	100	2
C. vanderbilti	180	3
C. vanderbilti	150	4
H. ornatissimus	2	6
H. ornatissimus	1	9
N. literatus	2	21
N. literatus	2	24
P. multifasciatus	1	16
A. chinensis	1	39
M. geoffroy	1	4
M. geoffroy	1	5
P. ewaensis	1	6
P. imparipennis	1	4
P. imparipennis	1	3
P. insularis	1	17
P. johnstonianus	1	5
P. octotaenia	1	6
P. tetrataenia	1	6
P. arcatus	1	8
P. evanidus	1	5
P. evanidus	1	8
S. bursa	1	16
M. flavolineatus	55	20

15'		
Species	**Individuals**	**Size (cm)**
A. nigrofuscus	5	10
A. nigrofuscus	5	12
C. strigosus	13	10
C. strigosus	6	13
C. strigosus	12	12
Z. flavescens	14	13
Z. flavescens	15	12
Z. flavescens	10	10
Z. flavescens	5	14
T. duperrey	2	9
T. duperrey	1	13
T. duperrey	1	5
T. duperrey	1	16
T. duperrey	1	14
T. duperrey	2	11
C. vanderbilti	63	3
C. vanderbilti	30	4
C. vanderbilti	40	2
H. ornatissimus	1	5
H. ornatissimus	1	6
F. flavissimus	1	15
S. marginatus	1	7
C. hawaiiensis	1	16
C. sordidus	1	14
C. sordidus	7	16
S. bursa	1	14
A. achilles	1	8
A. chinensis	1	43
C. quadrimaculatu	1	12
L. kasmira	1	17
M. niger	1	22
P. imparipennis	1	3
P. multifasciatus	1	16
A. leucopareius	1	12
C. melampygus	1	40
P. cyclostomus	1	19
P. insularis	1	13
P. insularis	1	16
C. chanos	6	60

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50'

Species	Individuals	Size (cm)
T. duperrey	1	9
T. duperrey	1	7
A. nigrofuscus	3	7
A. nigrofuscus	16	8
A. nigrofuscus	8	9
C. strigosus	15	9
C. strigosus	5	7
C. strigosus	16	10
C. strigosus	10	13
C. strigosus	8	5
C. multicinctus	1	9
C. multicinctus	1	6
C. vanderbilti	190	2
C. vanderbilti	91	3
N. literatus	2	19
H. ornatissimus	1	7
H. ornatissimus	1	11
G. varius	1	9
G. varius	1	11
F. flavissimus	1	10
P. evanidus	1	5
P. evanidus	1	7
P. multifasciatus	2	11
Z. flavescens	6	9
Z. flavescens	3	12
Z. flavescens	7	10
P. multifasciatus	1	14
S. rubroviolaceus	1	43
S. balteata	2	12
C. potteri	1	7
C. hanui	1	4
C. agilis	150	3
C. agilis	126	4
C. agilis	40	5
S. balteata	2	7
C. jactator	1	4
C. jactator	1	5
C. sordidus	2	16
H. polylepis	1	13
P. cyclostomus	2	22
P. forestri	1	16
P. octotaenia	1	6
Z. cornutus	1	12
P. octotaenia	1	9
P. ewaensis	1	6
S. spiniferum	1	26
X. auromarginat	2	16
P. insularis	1	21
N. hexacanthus	5	27
N. hexacanthus	6	20
N. hexacanthus	4	25
N. hexacanthus	3	23

35'

Species	Individuals	Size (cm)
N. literatus	1	21
Z. flavescens	5	13
C. strigosus	3	5
C. strigosus	3	8
A. nigrofuscus	8	9
A. nigrofuscus	4	11
A. nigrofuscus	6	7
C. sordidus	1	30
C. sordidus	2	15
C. sordidus	2	16
C. sordidus	1	18
T. duperrey	3	10
T. duperrey	2	12
T. duperrey	1	6
T. duperrey	1	9
T. duperrey	3	7
T. duperrey	5	8
T. duperrey	2	5
G. varius	1	7
G. varius	1	12
G. varius	1	4
P. multifasciatus	1	11
C. jactator	3	6
C. jactator	1	5
C. agilis	30	2
C. agilis	30	3
H. ornatissimus	1	6
H. ornatissimus	2	8
H. ornatissimus	1	11
C. vanderbilti	240	2
C. vanderbilti	340	3
C. vanderbilti	200	4
S. balteata	1	7
S. rubroviolaceus	1	25
X. auromarginat	1	16
C. multicinctus	1	7
C. quadrimaculat	1	6
C. quadrimaculat	1	9
C. quadrimaculat	1	10
C. quadrimaculat	3	12
M. vidua	1	19
M. vidua	1	21
N. hexacanthus	1	28
N. hexacanthus	2	32
P. arcatus	1	11
P. arcatus	1	6
P. imparipennis	1	4
P. tetrataenia	1	4
A. olivaceus	1	18
C. gaimard	1	11
F. flavissimus	3	12
F. flavissimus	1	9
L. fulvus	1	4
L. fulvus	1	7
H. thompsoni	1	14

15'

Species	Individuals	Size (cm)
Z. flavescens	6	12
Z. flavescens	4	14
Z. flavescens	6	10
Z. flavescens	5	14
C. vanderbilti	40	2
C. vanderbilti	60	3
C. vanderbilti	45	4
N. literatus	2	26
C. sordidus	1	17
T. duperrey	5	11
T. duperrey	3	7
T. duperrey	6	14
S. bursa	1	16
F. flavissimus	1	14
F. flavissimus	1	13
Kyphosus spp.	1	21
C. strigosus	8	7
C. strigosus	14	10
C. strigosus	7	8
C. strigosus	7	14
C. amboinensis	1	7
C. hawaiiensis	5	19
C. hawaiiensis	2	16
C. strigosus	7	12
C. quadrimaculatus	1	12
M. grandoculis	1	32
S. spiniferum	1	14
C. jactator	1	5
A. leucopareius	1	15
A. nigricans	1	13
A. nigrofuscus	4	9
A. nigrofuscus	8	10
A. nigrofuscus	5	6
H. ornatissimus	1	11
H. ornatissimus	1	6
H. ornatissimus	1	10
H. ornatissimus	1	4
H. ornatissimus	1	14
C. gaimard	1	6
L. phthirophagus	1	5
L. phthirophagus	1	3
P. ewaensis	1	6
P. insularis	1	12
S. marginatus	2	8
T. duperrey	3	11
T. duperrey	2	16
T. duperrey	4	10
F. commersonii	1	48

12 Pipe N	6/15/23									
50'				35'				15'		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**
T. duperrey	4	6		*N. literatus*	2	17		*A. nigrofuscus*	6	8
T. duperrey	1	4		*C. vanderbiliti*	85	2		*A. nigrofuscus*	15	10
T. duperrey	1	9		*C. vanderbiliti*	65	3		*C. strigosus*	12	12
T. duperrey	2	12		*C. vanderbiliti*	40	4		*C. strigosus*	7	8
T. duperrey	1	15		*T. duperrey*	1	12		*T. duperrey*	5	5
A. nigrofuscus	6	8		*T. duperrey*	2	7		*T. duperrey*	2	12
A. nigrofuscus	16	6		*T. duperrey*	1	5		*T. duperrey*	1	8
A. nigrofuscus	16	9		*T. duperrey*	2	14		*Z. flavescens*	22	10
A. nigrofuscus	2	12		*T. duperrey*	1	6		*Z. flavescens*	11	14
C. vanderbiliti	10	2		*T. duperrey*	2	9		*Z. flavescens*	6	13
C. vanderbiliti	32	3		*H. ornatissimus*	1	7		*Kyphosus spp.*	4	25
Z. flavescens	5	13		*H. ornatissimus*	1	5		*Kyphosus spp.*	8	30
Z. flavescens	4	13		*H. ornatissimus*	2	6		*A. nigricans*	2	13
Z. flavescens	4	14		*A. nigrofuscus*	9	9		*S. psittacus*	2	14
Z. flavescens	3	10		*Z. flavescens*	3	13		*S. psittacus*	1	17
P. octotaenia	1	9		*Z. flavescens*	8	11		*A. olivaceus*	1	16
H. ornatissimus	2	6		*Z. flavescens*	4	10		*A. olivaceus*	1	20
H. ornatissimus	1	12		*Z. flavescens*	6	12		*S. bursa*	1	17
P. multifasciatus	4	14		*Z. flavescens*	8	15		*S. bursa*	1	12
P. multifasciatus	1	12		*F. flavissimus*	1	13		*Z. cornutus*	2	15
P. multifasciatus	1	17		*C. sordidus*	2	14		*A. leucopareius*	1	13
N. literatus	2	19		*C. sordidus*	2	18		*C. multicinctus*	2	9
N. literatus	1	20		*S. bursa*	1	14		*C. dumerilii*	1	17
N. literatus	1	23		*S. bursa*	1	16		*C. ornatissimus*	1	14
A. olivaceus	1	23		*A. furca*	1	26		*C. sordidus*	1	24
A. olivaceus	1	20		*A. olivaceus*	1	24		*C. sordidus*	1	14
A. olivaceus	2	19		*C. multicinctus*	1	8		*C. vanderbilti*	22	2
F. flavissimus	3	11		*C. strigosus*	4	9		*C. vanderbilti*	55	3
F. flavissimus	3	13		*C. strigosus*	8	13		*C. vanderbilti*	25	4
C. agilis	3	6		*C. strigosus*	3	10		*M. niger*	7	20
C. agilis	6	4		*M. kuntee*	6	14		*M. niger*	1	19
S. bursa	1	13		*M. kuntee*	6	13		*N. literatus*	1	24
F. lognirostris	1	12		*M. niger*	1	18		*T. duperrey*	3	14
C. strigosus	9	9		*P. cyclostomus*	1	18		*T. duperrey*	2	6
C. strigosus	7	11		*P. multifasciatus*	2	17		*T. duperrey*	2	8
C. strigosus	4	5		*P. multifasciatus*	1	15		*A. chinensis*	1	40
C. strigosus	4	8		*P. multifasciatus*	1	18		*N. brevirostris*	1	26
A. thompsoni	1	13		*C. hanui*	1	4		*H. ornatissimus*	2	4
C. hanui	1	3		*C. melampygus*	1	28		*H. ornatissimus*	1	6
C. multicinctus	1	9		*P. arcatus*	1	10		*H. ornatissimus*	5	5
C. ornatissimus	1	6		*P. imparipennis*	2	3		*H. ornatissimus*	1	7
C. ornatissimus	1	12		*S. spiniferum*	1	16				
G. varius	2	12								
M. vidua	1	21								
O. unifasciatus	1	18								
P. ewaensis	1	7								
P. imparipennis	1	3								
P. tetrataenia	1	5								
S. balteata	1	7								

18 Pipe 6/15/23

50'

Species	Individuals	Size (cm)
A. nigrofuscus	8	5
A. nigrofuscus	8	7
A. nigrofuscus	8	6
C. agilis	45	4
C. agilis	15	5
C. agilis	40	3
C. strigosus	3	6
C. strigosus	12	8
C. vanderbiliti	70	2
C. vanderbiliti	80	3
C. vanderbiliti	30	4
N. literatus	3	22
N. literatus	1	24
N. literatus	1	29
T. duperrey	1	8
S. bursa	1	14
C. sordidus	1	21
Z. flavescens	3	4
C. multicinctus	1	5
C. multicinctus	2	4
C. hanui	3	4
P. ewaensis	1	8
S. balteata	2	7
H. ornatissimus	1	7
H. ornatissimus	1	10
L. phthirophagus	1	7
M. vidua	1	20
Z. cornutus	2	13
A. olivaceus	2	20
A. olivaceus	2	3
A. olivaceus	1	4
A. olivaceus	1	6
C. gaimard	1	7
C. gaimard	1	9
C. gaimard	1	4
C. gaimard	1	8
F. flavissimus	1	4
F. flavissimus	1	8
S. rubroviolaceus	1	46
S. rubroviolaceus	2	38
T. duperrey	1	7
T. duperrey	2	5
T. duperrey	2	10
T. duperrey	1	13
T. duperrey	1	16
Z. flavescens	6	10
Z. flavescens	4	5
Z. flavescens	1	12
Z. flavescens	1	13
C. melampygus	1	34
C. melampygus	1	36
C. melampygus	3	45
C. melampygus	3	50
C. melampygus	2	40
N. hexacanthus	1	24
N. hexacanthus	2	35
P. evanidus	1	7
P. evanidus	1	6
P. octotaenia	1	9
A. leucopareius	1	5
G. meleagris	1	42
S. lysan	2	50

35'

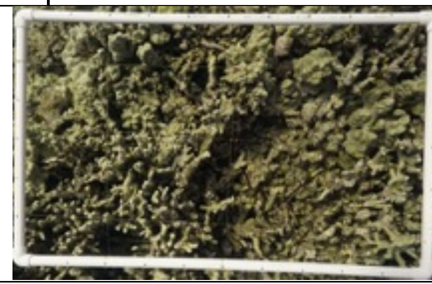
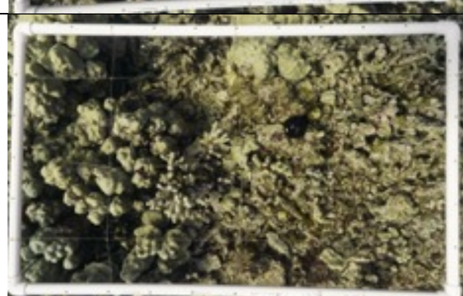
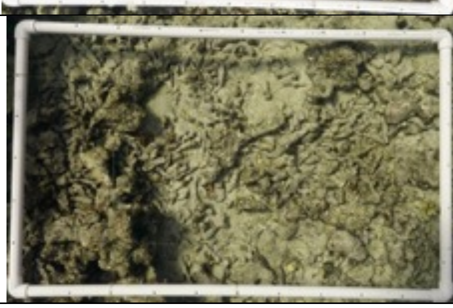
Species	Individuals	Size (cm)
N. literatus	1	23
N. literatus	1	18
N. literatus	1	19
N. literatus	1	20
Z. flavescens	2	14
Z. flavescens	2	13
A. nigrofuscus	8	8
A. nigrofuscus	3	9
A. nigrofuscus	1	11
A. nigrofuscus	5	13
A. nigrofuscus	3	6
S. bursa	2	17
S. bursa	1	16
T. duperrey	1	5
T. duperrey	2	7
T. duperrey	2	12
G. varius	1	10
G. varius	1	3
G. varius	1	5
C. sordidus	1	18
C. sordidus	1	10
C. sordidus	3	14
C. vanderbilti	63	2
C. vanderbilti	90	3
C. vanderbilti	40	4
P. multifasciatus	1	12
P. multifasciatus	1	14
P. multifasciatus	1	5
P. multifasciatus	1	9
P. arcatus	1	8
C. multicinctus	1	3
C. multicinctus	2	4
C. multicinctus	1	6
C. gaimard	1	10
C. gaimard	1	5
H. ornatissimus	1	5
H. ornatissimus	1	6
H. ornatissimus	2	7
A. thompsoni	5	14
C. agilis	3	3
C. jactator	3	5
C. jactator	1	7
C. quadrimaculatus	3	9
L. kasmira	2	20
P. imparipennis	1	4
S. marginatus	1	10
S. marginatus	1	11
S. marginatus	1	7

15'

Species	Individuals	Size (cm)
A. nigrofuscus	9	8
A. nigrofuscus	6	12
A. nigrofuscus	10	7
T. duperrey	5	6
T. duperrey	6	12
T. duperrey	4	14
T. duperrey	1	16
Z. flavescens	14	10
Z. flavescens	10	14
Z. flavescens	18	12
Z. flavescens	3	16
C. strigosus	4	10
C. strigosus	4	8
C. strigosus	2	15
C. strigosus	2	16
C. strigosus	8	11
C. vanderbiliti	36	2
C. vanderbiliti	50	3
C. vanderbiliti	35	4
H. ornatissimus	1	9
H. ornatissimus	3	7
H. ornatissimus	1	5
H. ornatissimus	2	8
S. bursa	1	16
C. hawaiiensis	1	17
C. hawaiiensis	2	18
C. hawaiiensis	3	23
C. hawaiiensis	2	26
N. literatus	1	17
C. multicinctus	1	8
C. multicinctus	2	11
C. argus	1	28
C. sordidus	1	16
M. vidua	2	18
M. niger	1	17
M. niger	1	14
M. niger	1	20
P. imparipennis	1	3
P. insularis	2	17
P. insularis	1	22
P. insularis	2	13
P. insularis	1	21
S. marginatus	1	8
S. marginatus	1	7
C. lunula	1	13
C. ornatissimus	1	11
C. ornatissimus	2	15
C. ornatissimus	2	14
Kyphosus spp.	1	28
P. imparipennis	1	3
P. multifasciatus	2	16
C. gaimard	1	7
C. gaimard	2	4
F. commersonii	1	54
L. phthirophagus	1	8
L. phthirophagus	1	6
M. kuntee	4	12
M. kuntee	4	14
N. hexacanthus	2	42
Z. cornutus	4	14

Wawa	6/15/23									
50'				35'				15'		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**
Synodus spp.	1	6		*C. vanderbiliti*	80	2		*A. nigrofuscus*	8	11
Synodus spp.	1	5		*C. vanderbiliti*	62	3		*A. nigrofuscus*	6	10
P. evanidus	1	2		*C. vanderbiliti*	40	4		*A. nigrofuscus*	6	14
P. evanidus	1	3		*Z. flavescens*	6	11		*T. duperrey*	2	6
N. taeniourus	1	1		*Z. flavescens*	4	15		*T. duperrey*	3	10
N. taeniourus	1	11		*Z. flavescens*	6	13		*T. duperrey*	1	16
N. taeniourus	2	17		*T. duperrey*	1	6		*T. duperrey*	2	8
I. umbrilatus	1	17		*T. duperrey*	1	14		*T. duperrey*	1	4
C. vanderbiliti	7	2		*T. duperrey*	1	11		*C. jactator*	1	5
C. vanderbiliti	4	3		*T. duperrey*	1	13		*C. jactator*	1	4
				T. duperrey	1	5		*C. vanderbilti*	52	2
				T. duperrey	1	7		*C. vanderbilti*	20	3
				A. nigrofuscus	2	8		*P. imparipennis*	1	3
				H. ornatissimus	2	5		*N. literatus*	1	20
				H. ornatissimus	1	7		*N. literatus*	1	24
				P. octotaenia	1	6		*N. literatus*	1	19
				A. olivaceus	2	21		*S. bursa*	1	15
				A. olivaceus	2	24		*S. psittacus*	1	21
				N. literatus	1	20		*S. psittacus*	3	12
				C. gaimard	1	7		*C. quadrimaculatus*	2	14
				P. ewaensis	1	6		*H. ornatissimus*	1	7
				P. ewaensis	1	5		*P. insularis*	1	16
				C. hanui	1	3		*S. spiniferum*	1	17
				C. ornatissimus	1	16		*Z. cornutus*	1	14
				F. flavissimus	1	13		*A. abdominalis*	1	11
				F. flavissimus	1	10		*A. sordidus*	1	15
				P. arcatus	1	11		*R. rectangulus*	1	14
				S. bursa	1	15				
				S. psittacus	1	21				
				S. psittacus	1	23				

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

Site: Ho‘ona Bay	Depth: 50fsw
	
	
	
	
	

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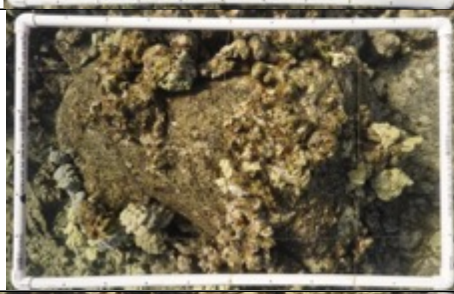	
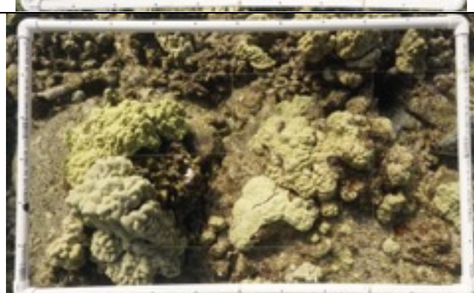	
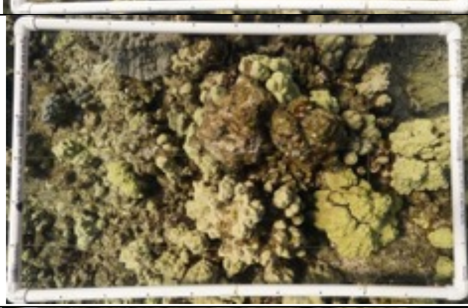	
	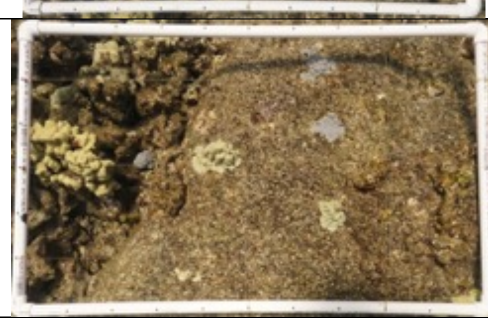

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	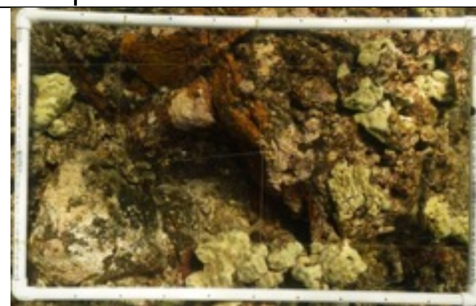
	
	
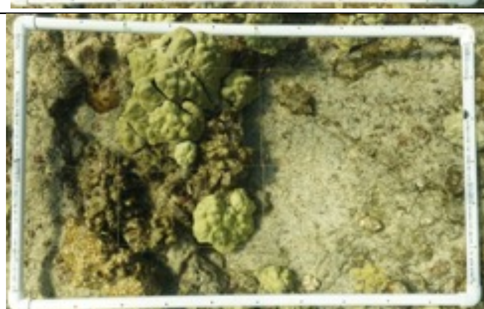	
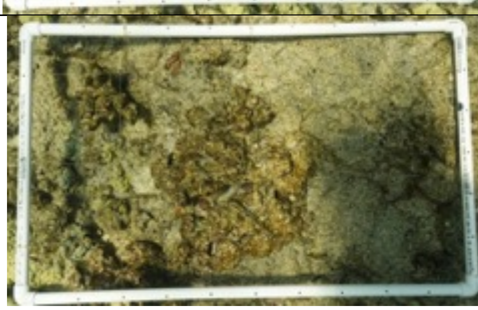	

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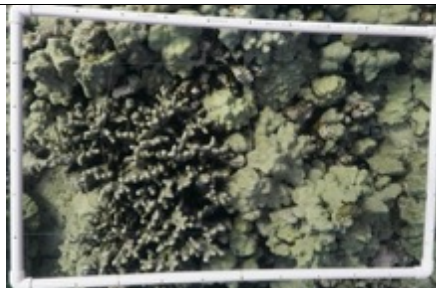	
	
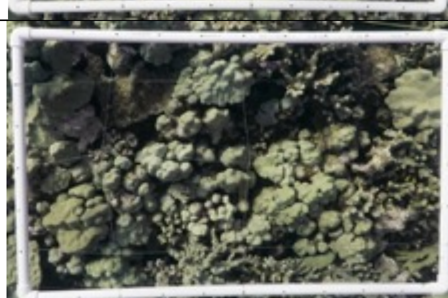	
	
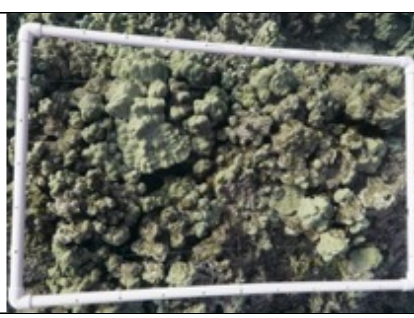	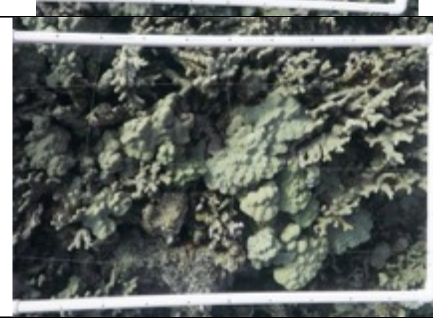

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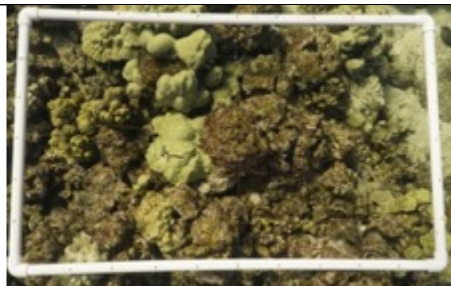	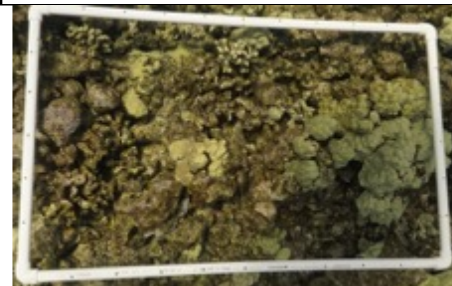
	
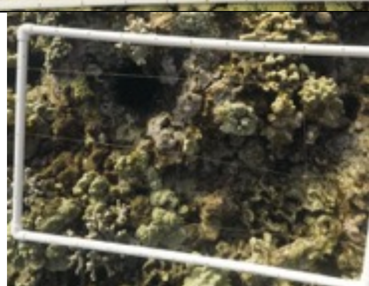	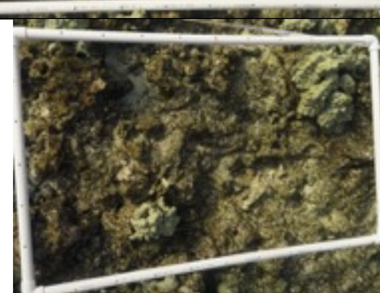
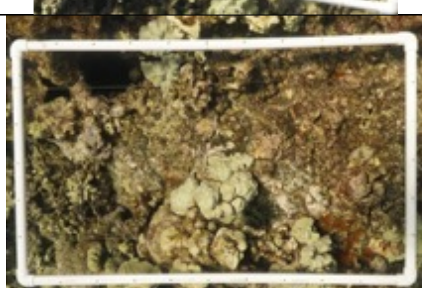	
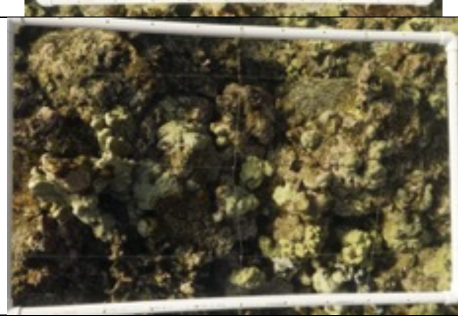	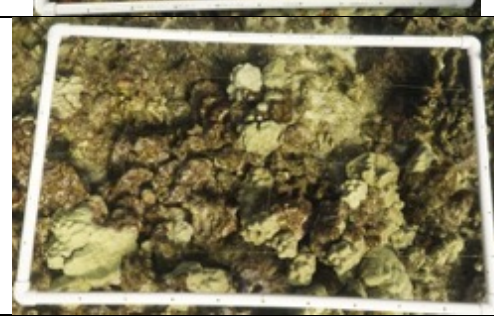

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	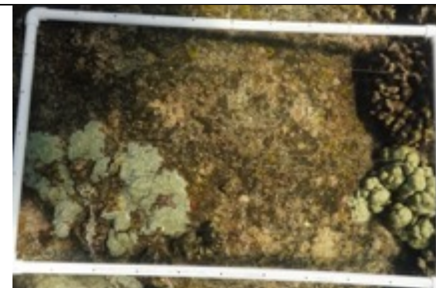
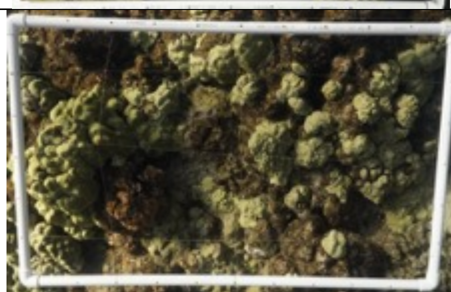	
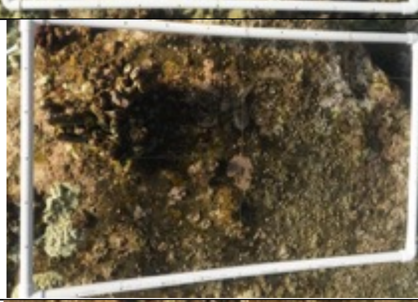	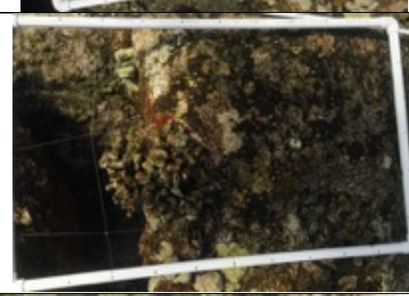
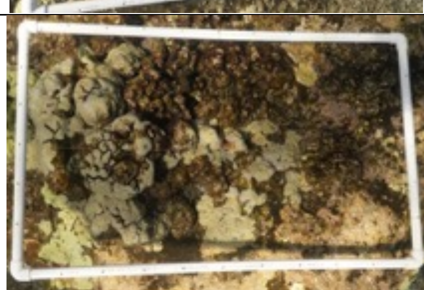	
	

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	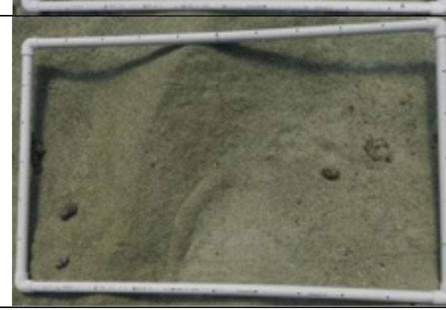

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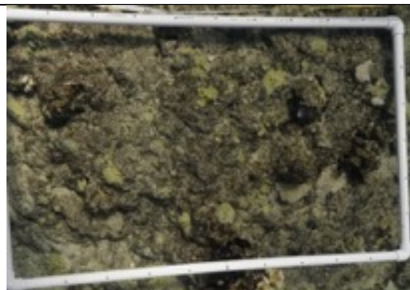	
	
	
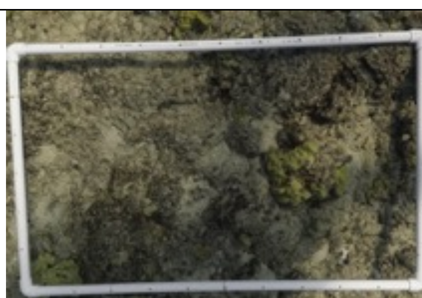	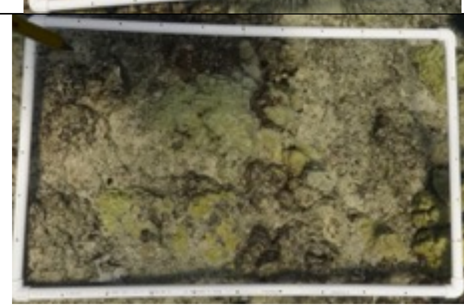
	

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	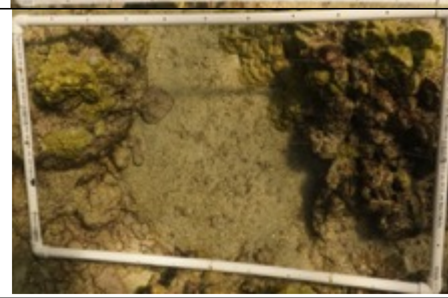
	
	
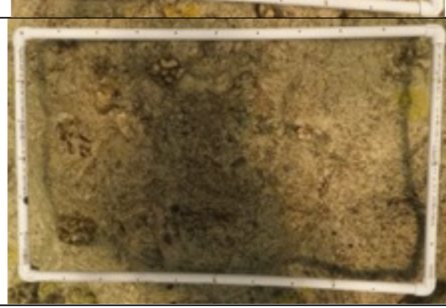	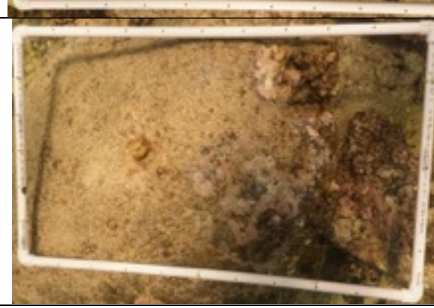

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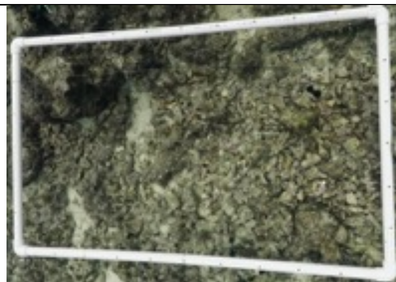	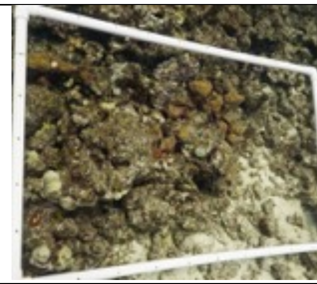
	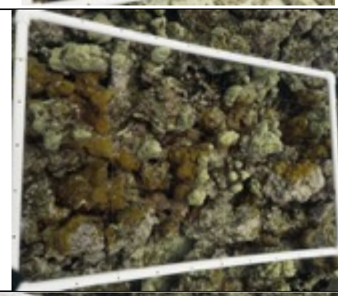
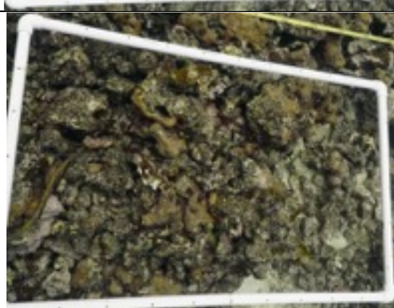	
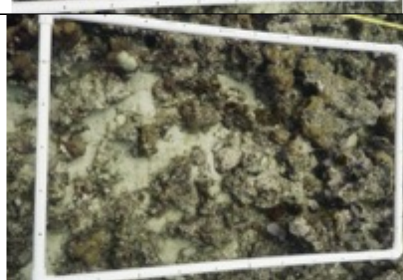	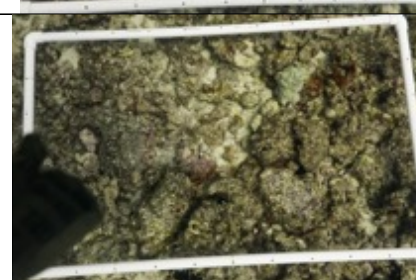
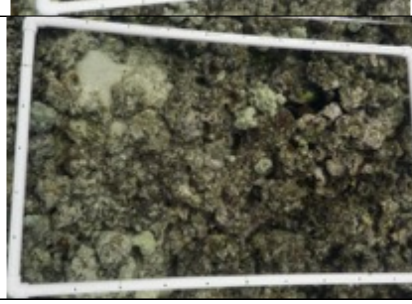	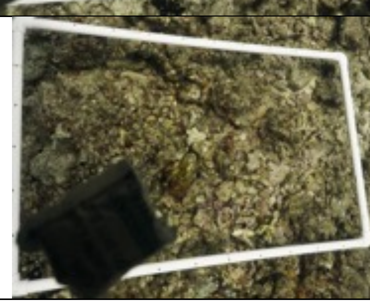

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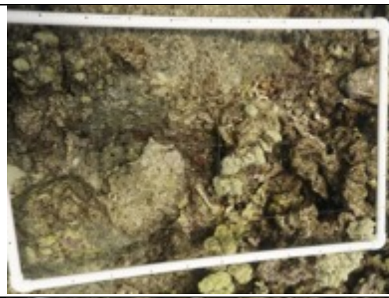	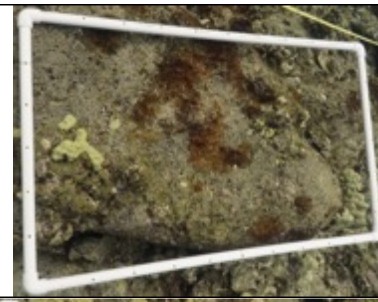
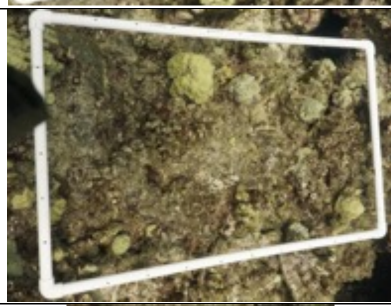	
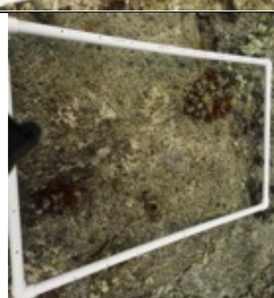	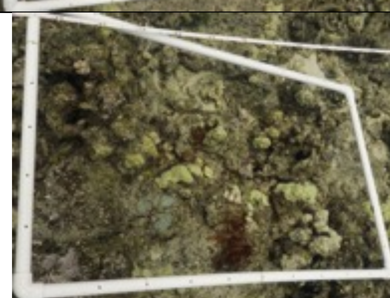
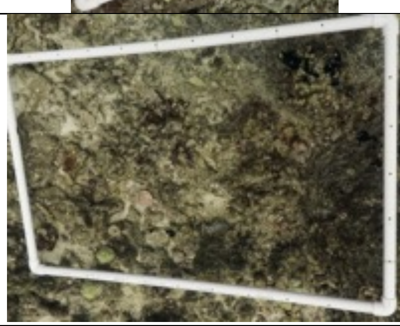	
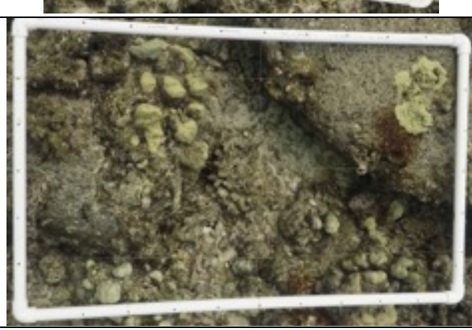	

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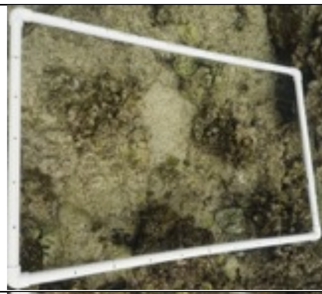	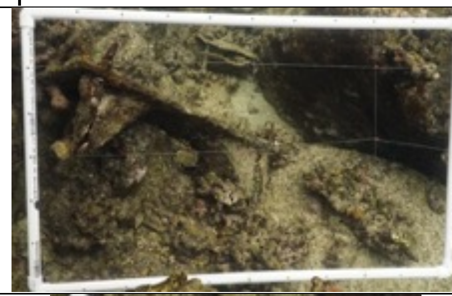
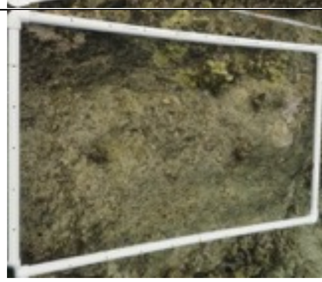	
	
	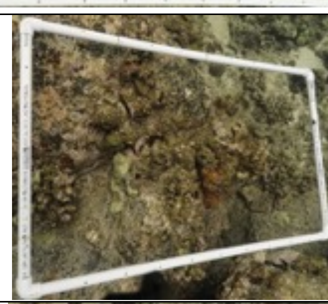
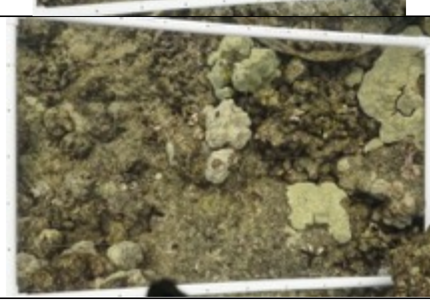	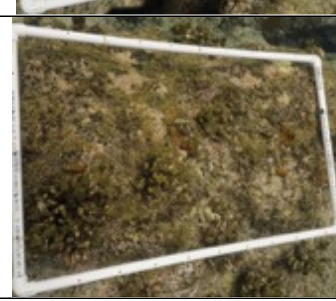

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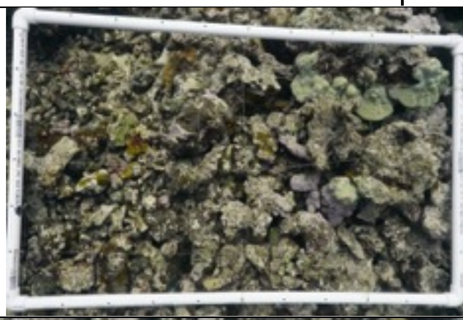
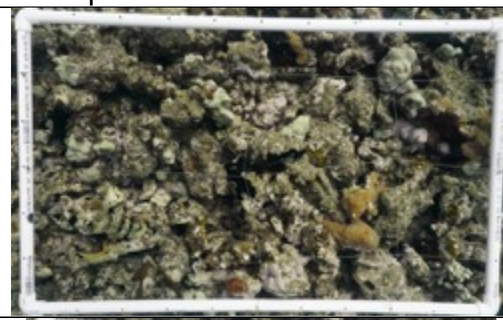
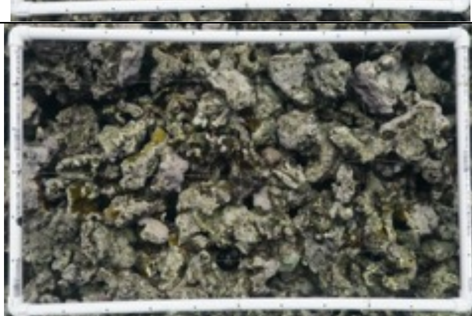
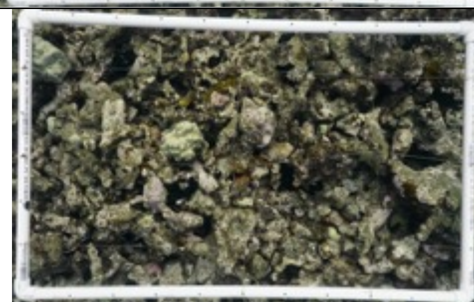
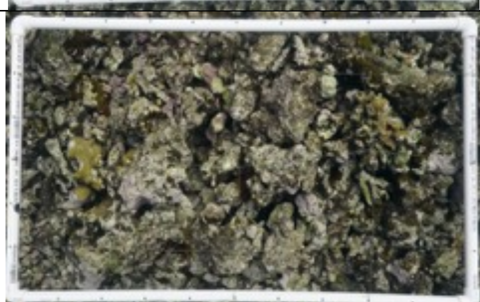
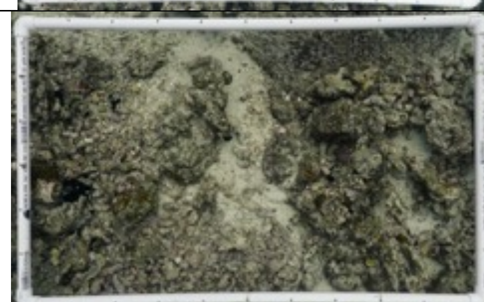
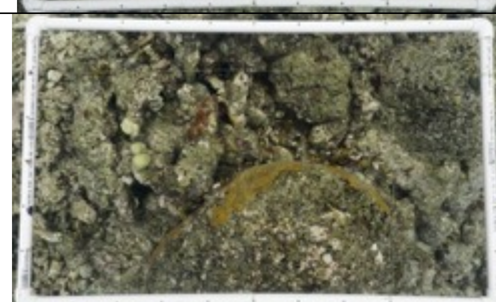
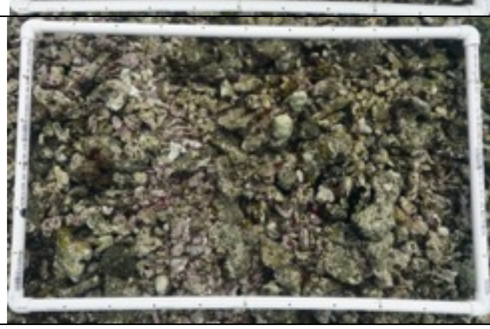
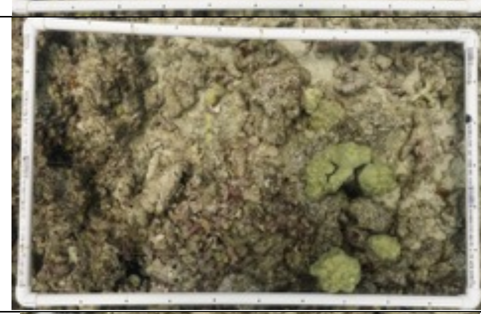
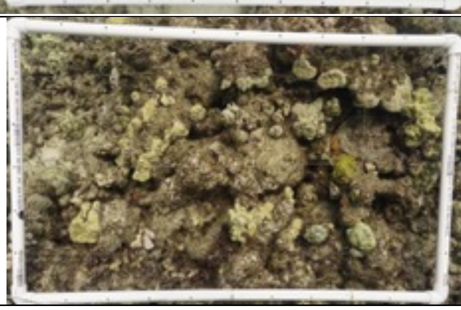
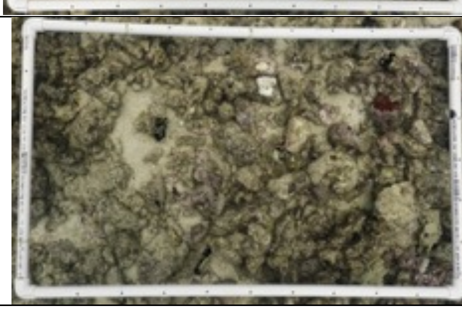
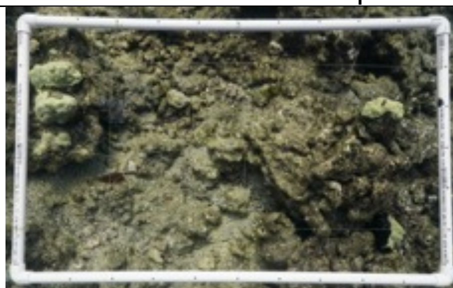
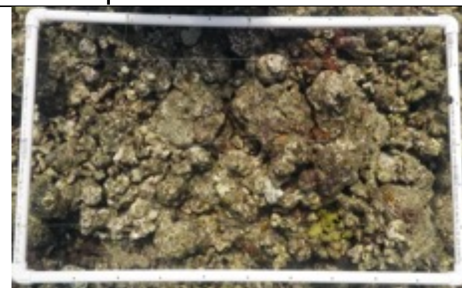
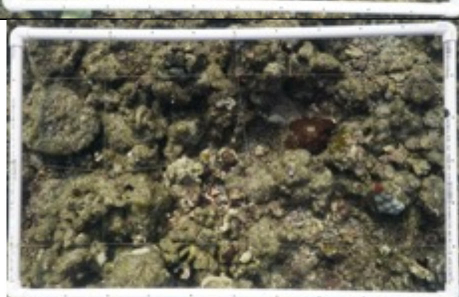
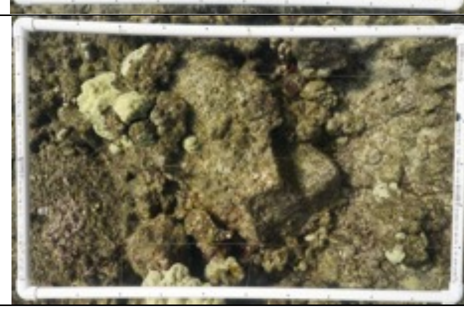
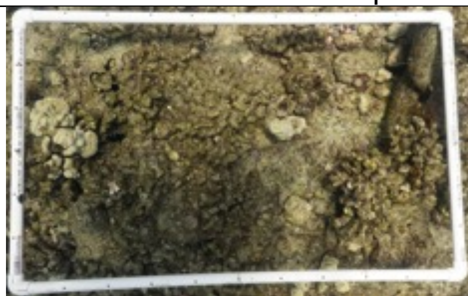
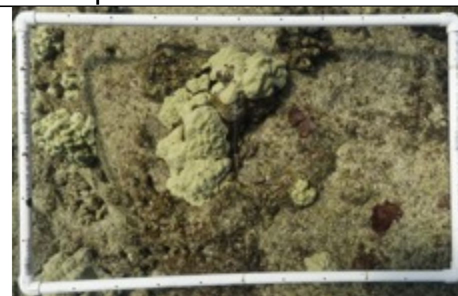
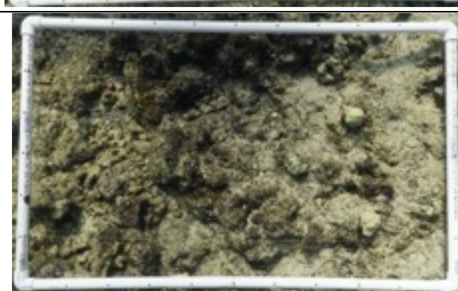
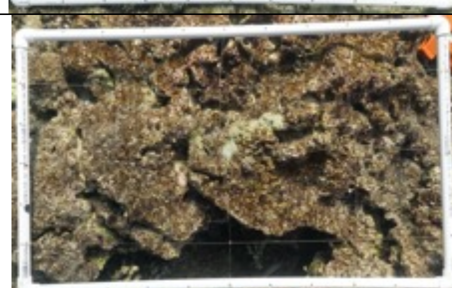
	
	
	
	
	

Site: 12 Pipe South	Depth: 30fsw
	
	
	
	
	

Site: 12 Pipe South	Depth: 15fsw
	
	
	
	
	

Site: 12 Pipe North	Depth: 50fsw
	
	
	
	
	

Site: 12 Pipe North	Depth: 30fsw
	
	
	
	
	

Site: 12 Pipe North	Depth: 15fsw