NELHA BENTHIC AND BIOTA MONITORING PROGRAM

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Annual Survey Report – 2019

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ANNUAL SURVEY REPORT – 2019

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EXECUTIVE SUMMARY

The Natural Energy Lab 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 47 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 2019 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, with the exception of pool S-10, which is situated south of the main Southern complex. A faunal census of each pool was completed from February 24th to March 21st, 2019 during a mid-tidal range (+0.8’ to +1.6’). 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 2019 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 pools where invasive fish were absent, with the exception of one Northern area pools (N-3). Similarly, the presence of invasive fish within the pools almost always precluded or limited native shrimp presence. Overall species composition at each pool was similar to previous surveys. Minimal turbidity was observed across sites in 2019, despite the presence of introduced fish in a portion of the pools. Relative to 2017, fewer signs of public visitation were observed at the Southern complex pools adjacent to the Wawaloli Beach park. 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. The relatively small size and enclosed nature of several of the Southern pools make them ideal candidates for invasive fish removal programs, which would likely further enhance the presence of *H. rubra* and other native shrimp species within the pools.

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 eight years have found the coral cover to stabilize in the range of ~30-50%. The overall coral cover for 2018 was 37.05%, which is within this range and shows the benthic communities to have exhibited relatively consistent values of coral cover for the last nine 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 2019 were quite consistent to 2017 and 2018 which indicates the pins will assist with temporal monitoring of the study sites.

The overall percent coral cover among the six stations was 37.05%, the most dominant corals were *Porites lobata* (25.23%), *Porites compressa (6.07%), Porites evermanni* (1.53%), *Montipora capitata* (2.67%), *Montipora patula* (0.65%) and *Pocillopora meandrina* (0.83%). These coral species were present among all the stations. Other corals present were *Pocillopora grandis (*previously *eydouxi)*, *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 28-year period of this monitoring program. The findings from 2019 show similar values of abundance, diversity, and biomass to 2018. Ultimately, data from the duration of the monitoring program shows the nearshore habitats surrounding NELHA support highly diverse and productive fish assemblages.

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

ANNUAL SURVEY REPORT – 2019 1

EXECUTIVE SUMMARY 2

ANCHIALINE POOL SURVEY 6
INTRODUCTION 6
METHODS 9
RESULTS 11
DISCUSSION 13
FIGURES AND TABLES 17

MARINE BENTHIC BIOTA SURVEY 29
INTRODUCTION 29
RESULTS 34
COMPARATIVE ANALYSIS OF TEMPORAL TRENDS IN BENTHIC DATA 37
DISCUSSION 40

MARINE FISH BIOTA SURVEY 42
INTRODUCTION 42
METHODS 43
RESULTS 45
COMPARATIVE ANALYSIS OF TEMPORAL TRENDS IN FISH DATA 48
DISCUSSION 49
REFERENCES 51

APPENDICES 57
Appendix 1 – Pond Monitoring 57
Appendix 2 - Nearshore marine habitat characterization data 62
Appendix 3: Nearshore fish assemblage data 75
Appendix 4. Digital images of quadrats used for benthic habitat characterization81

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*

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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 to pool surroundings and substrate due to visitation and swimming. Additionally, recent sea-level rise forecast models suggest that anchialine pools on Hawai‘i Island and throughout the state will eventually form larger pool complexes and have more frequent surface connections to the ocean in the coming decades (Marrack and O’Grady 2014). Concurrently, new anchialine pools may emerge further inshore, depending on elevation and groundwater connectivity. These anticipated changes associated with predicted sea-level rise could dramatically impact anchialine pool ecology. Fortunately, submarine connections between pools will likely allow *H. rubra* and other shrimp species to populate new higher elevation pools.

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

The two groups of pools adjacent to the NELHA facility have been surveyed for more than 30 years (Brock 1995, Brock 2008, Oceanic Institute 1997, Oceanic Institute 2007, Ziemann and Conquest 2008, Bybee *et al.* 2012, Bybee *et al.* 2013, Bybee *et al.* 2014, Whale Environmental Services 2015, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018). 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).

Results of the 2019 survey as part of NELHA's Comprehensive Environmental Monitoring Program (CEMP) are reported subsequently.

METHODS

Anchialine pools located within the NELHA facility form localized complexes, including five pools in the “Northern complex” and ten pools in the “Southern complex” (Figures 1 - 3). The Northern pool complex, including pools N-1 through N-5, is located approximately 100m inland of the cobble beach at 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 February/March 2019 survey based on previously recorded latitudes and longitudes. In 2017, site coordinates were updated to a five-decimal system for improved ease of pool relocation (Table 2). Upon arrival at each site, pool diameter was confirmed from measurements first reported by Brock 2008 (Table 2), except for pool S-10 which was first surveyed in 2015 (Whale Environmental Services 2015). Pool dimensions and basin characteristics for historically surveyed pools are included in Appendix 1.1 (Brock 2008).

Water level, water chemistry, and appearance of the anchialine pools vary with tidal level during the survey. The effect of tidal level is particularly apparent for the Northern pool complex, including pools N-2, N-3, N-4, and N-5. At low tide, these pools are separated by basalt substrate outcrops, however at high tide (> +2.1ft), these pools form a single body of water (Burns and Kramer 2018). This interconnectivity is particularly apparent during annual peak tides (also known as King’s tides) during which tidal levels exceed 2.4 ft. While the water level in the Southern group pools is also strongly tidally affected, pools were not observed to be interconnected during the 2019 survey.

Faunal observations for the 2019 survey were collected at tide levels below the daily maximum to provide sufficient water for organismal observations and photo-quadrat sampling if possible, while avoiding pool interconnection. Sampling of the pools was conducted at tidal levels ranging from +0.8 to +1.6ft to ensure each pool was surveyed only when it was physically separated from other adjacent pools.

Faunal surveys were conducted from February 24th to March 21st, 2019. Temperature and salinity measurements were collected concurrently using a hand-held YSI Pro-Series Quatro water quality meter and data logger. Flora and fauna within and surrounding each pool was documented using visual observations and photographs taken with a FujiFilm FinePix XP130 digital waterproof camera. Photo-quadrats were conducted by photographing a randomly placed ruler in the pool. In each photograph *H. rubra* were counted within a random 10x10cm area to calculate density. The number of replicate photo-quadrats depended on pool area and depth, and ranged from 4 to 7 replicates. *H. rubra* density was determined for each recorded photo-quadrat, then averaged for each pool. Pools with low water levels (S-6, S-9) and low/absent *H. rubra* densities (N-3, S-1, S-5, S-7) were surveyed visually *in-situ*. *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).

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RESULTS

Water quality measurements and faunal census results from the 2019 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 2019 survey was generally consistent with recent previous surveys (Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018). 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 - 12).The Southern pools tended to be surrounded by non-vegetated or very sparsely vegetated basalt, and were more likely to host introduced fish (Figures 9 - 12). Some Southern pools also had more signs of visitation, such as moved rocks, and trash.

Southern pools (with the exception of pool S-10) were less saline and slightly cooler compared to the Northern pools. For the Southern pools S-1 through S-9, temperature ranged from 21.3 to 21.7 °C and salinity ranged from 11.1 to 12 ppt. Slightly lower temperature readings and higher salinity readings were recorded for distal pool S-10 (19.8 °C, 14.13ppt., respectively) (Table 4). For the Northern pools, temperature and salinity were relatively higher, ranging from 21.7 to 24.6 °C and from 12.7. to 14.7ppt. (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, 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) (Figures 5, 8, and 10). During the 2019 survey, *H. rubra* were not observed at the Northern Pool N-3. *H. rubra* were present in N-4 in 2019, where they were previously absent in the 2018 surveys (Burns and Kramer 2018). *H. rubra* were still observed at a very high density at pool N-5 similar to 2018 surveys, where they were previously absent due to intensive substrate disturbance in 2016 (Figure 8) (Burns and Kramer 2016, Burns and Kramer 2018).
Within the Southern complex, two pools (S-9 and S-10) had very high densities of *H. rubra* (> 100 individuals/ 0.1 m^2), and three pools had moderate densities of *H. rubra* (S-3, S-4, and S-6) (Table 4). In the four pools where invasive fish were present in the Southern complex, *H. rubra* were absent (S-7) or had very low densities (S-1, S-5, S-8) (Figures 9 - 10). *H. rubra*

were observed in pools S-5 and S-8 where they had not been observed in previous surveys (Burns and Kramer 2018).
During the 2019 survey, *M. lohena* was observed within several Southern pools, including S-4, S-6, S-9, and S-10, and were noted to be particularly abundant at pool S-10 (Figure 12). *M. lohena* was also observed at all the Northern pools except N-3, compared to 2018 where *M. lohena* was absent from the Northern complex (Burns and Kramer 2018). Seven individuals of the uncommon indigenous species, *Macrobrachium grandimanus*, were observed at pool S-8 and one individual was observed at pool N-3 (Table 3 and 4, Figure 6). Historically and in more recent surveys, *M. grandimanus* had also been observed in pools S-1, S-5, and S-7 (Bybee *et al.* 2014, Burns and Kramer 2017, Appendix 1.2). Similar to previous surveys, Northern pools N-1, N-3, and N-5 hosted assemblages of the aquatic grass, *Ruppia maritima* (Figures 6 and 8).

Introduced Poeciliid fish, including *Gambusia affinis* and *Poecilia* spp. were observed in four of the Southern area pools, S-1, S-5, S-7, and S-8 (Table 4). For pool S-3, Poeciliids were not noted in the 2018 or 2019 surveys, but were recorded previously in 1994, 2007, 2008, and 2017 surveys (Burns and Kramer 2017, Burns and Kramer 2018, Appendix 1.2). Where introduced fish were present, shrimp populations, including *H. rubra* and *M. lohena*, were dramatically reduced or absent. As of the survey date in March 2019, introduced fish were not observed in any of the Northern pools (Table 3). However, two individuals of nearshore fish species, *Kuhlia* spp. (āholehole) and *Abudefduf* spp., were observed in pool N-3.

Tables 3 and 4 list additional species observed within and around each pool during *in-situ* visual observations. Generally, higher species diversity was observed for the Northern pools, which were typically surrounded by dense vegetation (Figures 4 - 7). Thiarid snails (*Melanoides tuberculata* and *Terbia grainers*) were observed in two of the five Northern pools, with just a few individuals observed in one Southern pool. Similar to previous surveys, very high densities of Thiarid snails were observed within the Northern pool N-4 (Table 3, Figure 7) (Bybee *et al.* 2014, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018, Appendix 1.2).

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.

DISCUSSION

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

The anchialine pools at NELHA were resurveyed in February/March 2019, and compared to previous censuses, spanning back to May 1989. The census results from 2019 were relatively similar to previous recent yet highlighted specific changes in the pools when compared to historical data surveys (Bybee *et al.* 2013, Bybee *et al.* 2014, Whale Environmental Services 2015, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018). The major drivers of pool ecology were: 1. pool location, either Northern or Southern areas, 2. groundwater influence reflected in temperature and salinity readings, 3. the presence or absence of introduced fish, and 4. the intensity of human visitor impacts to the pools (Tables 3 and 4).

Water quality is a key indicator in assessing anchialine pool ecosystem health and measurements collected in 2019 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, Appendix 1.1). Pool temperatures ranged from 20 to 25 °C and salinity ranged from 11 to 15ppt. The Southern pools were cooler and less saline during the 2019 survey compared to the Northern pools. This suggests Southern pools have a relatively higher groundwater influence or the Northern pools have a greater ocean influence due to the pools' proximity to the shoreline.

All the Northern pools hosted *H. rubra* and *M. lohena* assemblages except N-3. *H. rubra* was last observed in pool N-3 in 2017. In 2018, an unusually dense and partially decaying assemblage of *R. maritima* was observed in pool N-3, which may have altered water quality (e.g. depleted oxygen levels) within the pool and deterred *H. rubra*. (Approximately 5 gallons of decaying *R. maritima* material were removed from the pool following the survey). Less *R.*

maritima was present in the 2019 surveys, however *H. rubra* were still not present. The presence of two nearshore fish may also be a factor in *H. rubra* not returning to N-3. A very high density of *H. rubra* was observed in 2019, like the 2018 surveys. A dramatic increase in *H. rubra* density was noted in 2018 compared to the 2016 survey in which *H. rubra* was absent and to the 2017 survey in which a moderate population was observed. In April 2016, obvious signs of visitation and severe physical disturbance were documented (Burns and Kramer 2016). N-5 sustaining a high population of *H. rubra* suggests that visitation and physical disturbance were minimal within the past three years (Burns and Kramer 2017, Burns and Kramer 2018).

At very high tides, pools N-2, N-3, N-4 and N-5 become interconnected, which provides a simple mechanism for organismal exchange following depletion events (in addition to submarine/ hypogeal pool connections). This interconnectivity suggests that *H. rubra* can easily move from pool to pool, and *H. rubra* presence at N-3 is likely in future surveys. This interconnectivity also likely promoted the rapid replenishment of *H. rubra* within pool N-5 and the return of *H. rubra* to pool N-4. As documented in previous years, Poeciliid fish were not observed in any Northern pools which allows for the continued diurnal presence of *H. rubra* (Bybee *et al.* 2014, Burns and Kramer 2016, Burns and Kramer 2017, Burns and Kramer 2018, Appendix 1.2).

The historical introduction of Poeciliid fish within anchialine pools at NELHA has significantly affected pool ecology, and continues to alter four Southern area pools, S-1, S-5, S-7, and S-8 (Figures 9 - 11). Poeciliids were not observed in pool S-3 during the 2019, 2018, and 2016 surveys, but were recorded in previous surveys (Burns and Kramer 2017, Burns and Kramer 2018, Appendix 1.2). For pool S-7, *H. rubra* and *M. lohena* were not observed in the 2019 surveys despite the presence of these shrimp in nearby pools. For pools S-5 and S-8, *H. rubra* was present in the 2019 surveys, which had not been observed in past surveys (Burns and Kramer 2017, Burns and Kramer 2018, Appendix 1.2). However, the populations of *H. rubra* were very low, with only a few individuals observed in S-5 and only a few large individuals clustered on the northeast side of S-8. For pool S-1, a few individuals *H. rubra* and *M. lohena* were observed within deep cracks and crevices in the pools. These pools likely provided some spatial refuge from predation by the Poeciliids present. Additionally, the larger size of *H. rubra* in S-8 may preclude consumption.

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.

Pools S-7 and S-8 are good candidates for introduced Poeciliid removal in order to restore native shrimp populations, due to their small overall size and secluded nature (minimal signs of recent visitation were observed). However, any proposed fish removal activities must consider the effects of treatments on *Macrobrachium grandimanus* present in the pools. Two individuals of nearshore fish species, *Kuhlia* spp. (āholehole) and *Abudefduf* spp. were observed in pool N-3, and may correspond with the absence *H. rubra* in the pool. Removal of these nearshore fish from the pool is recommended to promote *H. rubra* recovery.

Despite the presence of introduced fish in certain pools, water clarity was high and invasive macroalgae was absent within the invaded pools, according to visual, qualitative surveys (Tables 3 and 4). This suggests that water quality characteristics have remained relatively consistent, and/or that grazing activities within the invaded pools are still able to adequately control any macroalgal growth

To a lesser extent than observed in the 2016 and 2017 surveys, signs of visitor impacts were observed at several of the Southern pools in 2019. Affected pools were generally near access points, including Wawaloli Beach Park and Makako Bay Drive, and were also relatively visible due to minimal surrounding vegetation. Signs of recent visitor impacts were observed at four of the surveyed pools in the Southern complex (S-1, S-3, S-4, and S-5). Modifications in and around the pools included the addition of rocks to pool basins, litter, and the possible removal/addition of Poeciliid fish and *H. rubra* for fishing bait and other uses. On a visit to the pools in November 2019 two large traps were observed in pool S-5 (Figure 10). The traps were deployed by NELHA for the ongoing removal of invasive fish that are present in S-1, S-5, S-7, and S-8. The traps appear to be effective as invasive fish have not been observed in S-7 and S-8 since the traps were deployed (per comms). Overall, visitation and disturbance can cause damaging physical changes to the pools. Substrate and surrounding rock movements can influence overall pool ecology, by altering light, water depth, turf algal growth, and food availability for *H. rubra* and other shrimp species. Trash and other refuse present may affect the water quality of the pools.

Predicted sea-level rise is a significant future threat to Hawaiian anchialine pool ecosystems will likely drive substantial changes to pool interconnectedness, depth, location, and water chemistry (Marrack and O’Grady 2014). These physical changes will have a critical influence on faunal composition within the pools. The interconnectedness of pools with sea-level rise can allow poecilids to invade nearby pools that currently do not have introduced fish. King Tides or seasonal high tides offer a preliminary view of potential anchialine pool ecosystem changes associated with rising sea-level.

The results of the 2019 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 February 24th through March 21st 2019. (Map generated using Google Earth 7.1.7).

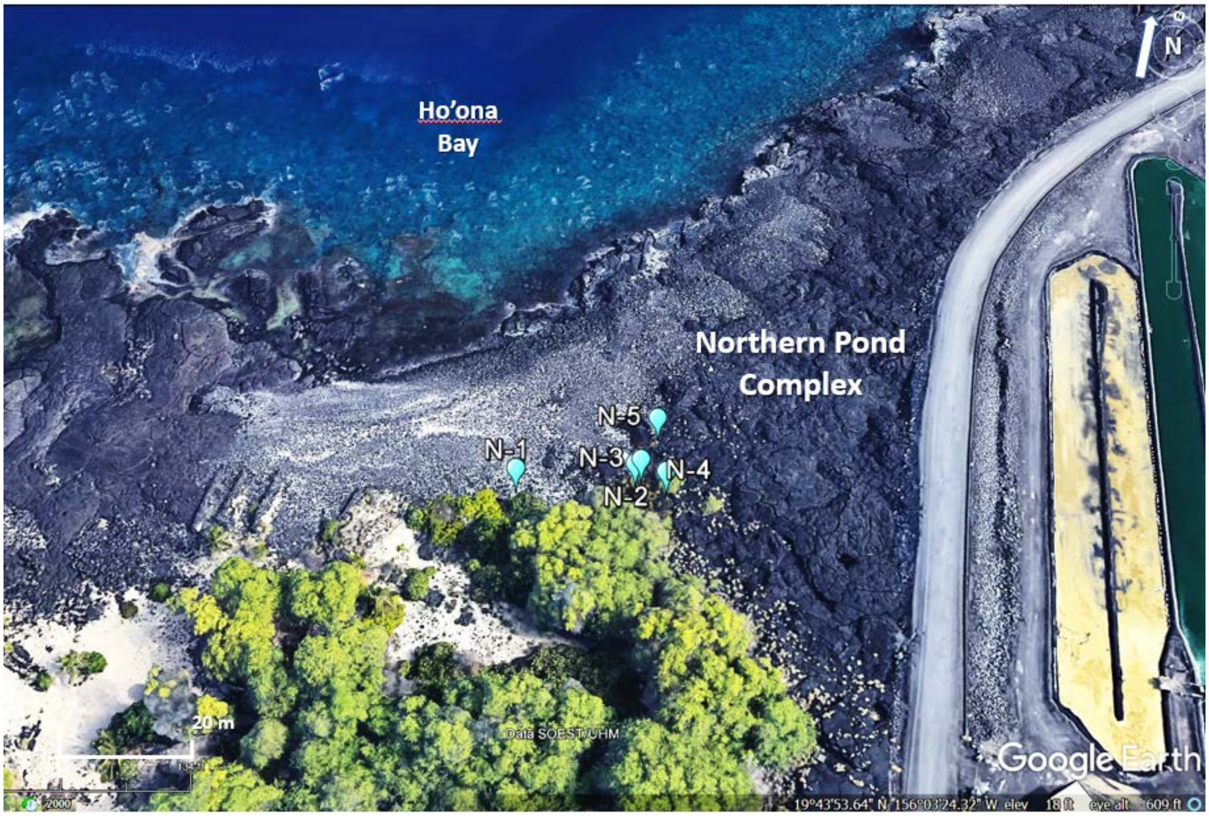

Figure 2. Locations of the Northern complex of anchialine pools (N – 1 through N –5), located inland of the cobble beach at Ho'ona Bay. The Northern pools were surveyed on February 25th through March 21st 2019. (Map generated using Google Earth 7.1.7).

Figure 3. The Southern complex of anchialine pools (S-1 through S-10), located inshore and south of the Wawaloli Beach Park facility at NELHA. The Southern pools were surveyed from February 25th through March 21st, 2019. (Map generated using Google Earth 7.1.7).

Figure 4. (left) Northern pool, N - 1 at a tide level of +1.53', and (right) leaf litter floating on the surface of the pool. Pools in the Northern group were typically characterized by relatively diverse faunal assemblages and dense surrounding vegetation. Surrounding vegetation has continued to encroach pool N – 1, and Ruppia maritima comprises a portion of the pond basin.

Figure 5. (left) Northern pool N-2, at a tide level of +0.97', and (right) *Halocaridina rubra* ('ōpae 'ula) within the pool.

Figure 6. (left) Northern pool N-3 at tide level +0.97' in February 2019 and (right) *Macrobrachium grandimanus* observed in the pool.

Figure 7. (left) Northern pool, N-4, at tide level +1.59' in March 2019 and (right) abundance of Thiarid snails on the pool substrate.

 

Figure 8. (left) Northern pool N-5, continued to show signs of improved health after intensive physical disturbance noted during the 2016 survey. (left) High density of H. rubra and *Ruppia maritima* in pool N-5.

Figure 9. Southern pool, S-1, at a tide level of + 1.02‘.

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Figure 10. Southern pool S-5 at a tide level of +1.09 in February 2019 (left). Pool S-5 with traps in November 2019.

Figure 11. Southern pool, S-8, at a tide level of +1.19’ in February 2019.

Figure 12. Southern pool, S-10 (left), at a tide level of +0.89'. Christmas berry (*Schinus terebinthifolius*) encroaches the pond basin and introduces substantial organic matter to the pond, which hosts an abundant assemblage of *Halocaridina rubra* and *Metabetaeus lohena* (right).

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

	Taxon	Common/ Hawaiian Name	Classification
Anchialine pond: 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 pond: 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 ponds 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 pond complex of anchialine ponds at the NELHA facility. The pond surveys were conducted from February 24, 2019 to March 21, 2019, at a tidal level ranging from +0.8' to +1.6'. Poeciliid fish and *Ruppia maritima* were recorded as present or absent, and other organisms in the observed in each pond 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). If the water level was too shallow for the photo-quadrat placement, the presence or absence of *H. rubra* was noted with a density estimate based on *in-situ* visual surveys.

Area	Pond 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	3/21/2019	17:33	23.1	14.7	Sandy pebble substrate, some silt and shell fragments, rock wall mauka section	252 ± 58	absent	absent	Lots of leaf litter, sticks, and seeds floating on surface. *M. lohena, Scaevola taccada, Cypenus laevigatus, Prosopis pallida, Tournefortia argentea, Thespesia populnea, Sesuvium portulacastrum, , Lyngbya sp., Argiope appensa*
	N-2	2/25/2019	8:07	21.7	13.1	Basalt rubble, pahoehoe surroundings, some sediment and silt	255 ± 25	absent	absent	*M. lohena, Sesuvium portulacastrum, Schizothrix clacicola,*
	N-3	2/25/2019	8:15	22.3	12.7	Silt, sediment, and shell fragments, underlying cobble, pahoehoe surroundings	absent	absent	present	Thiarid snails, *Lyngbya sp., Sesuvium portulacastrum, Prosopis pallida, Pantala flavescens, , Scaevola taccada, Kuhlia sp.*(1), *Abudefduf sp.* (1), *Macrobrachium grandimanus* (1)
	N-4	3/21/2019	17:12	24.6	14.1	Silt bottom with cobble and shells, pahoehoe surroundings	8.3 ± 4.0	absent	absent	*M. lohena*, Thiarid snails (high density), *Sesuvium portulacastrum, Cypenus laevigatus, Schizothrix clacicol*
	N-5	2/25/2019	8:40	22.5	13.58	Water-worn (rounded) basalt cobble and coral, some sediment	427 ± 213	absent	present	*M. lohena, Sesuvium portulacastrum, Pantala flavescen, Ischnura posita*

Table 4. Faunal census data collected for the Southern pond complex of anchialine ponds at the NELHA facility. The pond surveys were conducted from February 24, 2019 to March 21, 2019, at a tidal level ranging from +0.8' to +1.6'. Poeciliid fish and Ruppia maritima were recorded as present or absent, and other organisms in the observed in each pond 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). If the water level was too shallow for the photo-quadrat placement, the presence or absence of H. rubra was noted with a density estimate based on in-situ visual surveys.

Area	Pond number	Survey Date	Survey Time	Water Quality		Faunal Surveys				
				Temp (C°)	Salinty (ppt)	Substrate	*H. rubra* (Count/0.1m²) (Mean ± SE)	Poeciliids	*Ruppia maritima*	Comments/ Other Species
Southern Ponds	S-1	2/24/2019	9:00	21.7	12	Basalt rubble/ pebbles, pahoehoe surroundings	1.3	present	absent	*M. lohena*, *Pennisetum setaceum*, *Schinus terebinthifolius*, *Schizothrix clacicola*, *Poecilia* sp., *Gambusia affinis*
	S-2	2/24/2019	9:30	-	-	-	-	-	-	Pond filled in with rocks
	S-3	3/21/2019	18:15	21.6	11.8	Basalt rubble/ pebbles, mixed pahoehoe surroundings	53 ± 20	absent	absent	*M. lohena*, green algae on rocks, *Oligochaeta sp.*, no surrounding vegetation
	S-4	3/21/2019	18:30	21.6	11.8	Basalt rubble, pahoehoe surroundings	65 ± 36	absent	absent	*M. lohena*, no surrounding vegetation.
	S-5	2/24/2019	8:38	21.5	12	Basalt rubble and coral, mixed pahoehoe surroundings,	0.14	present (abundant)	absent	*Pantala flavescens, Pennisetum setaceum, Schizothrix clacicola, Poecilia* sp. and *Gambusia affinis present.* Minimal vegetation around pond. Signs of visitation - trash and traps in pool
	S-6	3/21/2019	18:18	21.6	11.2	Very narrow basalt crack, a'a surroundings.	63	absent	absent	*H. rubra* very small. Also observed: *M. lohena*, No surrounding vegetation. *Capparis sandwichiana* nearby, Abundant ants at pond edge.
	S-7	2/24/2019	8:09	21.3	11.6	Basalt rubble (some rounded), mixed pahoehoe surroundings	absent	present (abundant)	absent	Also observed: *Pennisetum setaceum, Schizothrix clacicola*, both *Poecilia sp.* (occasional) and *Gambusia affinis* (abundant). Opihi shells observed. Rounded stones along basin and trail.
	S-8	2/24/2019	8:01	21.3	11.9	Basalt rubble with a few white coral stones, shell fragments, pahoehoe surroundings	3.3 ± 2.1	present (abundant)	absent	H. rubra large and only on NE side of pool. Thiarid snails (2), *Pennisetum setaceum, Capparis sandwichiana, Schizothrix clacicola, Macrobrachium grandimanus* (7), *Poecilia* sp. and *Gambusia affinis*. Water-worn wall with rounded corals surrounding pond. Opihi shells observed. Trail to pond.
	S-9	3/21/2019	18:43	21.5	11.1	Basalt crack, a'a surroundings.	320	absent	absent	*H. rubra* very small. *M. lohena*, abundant ants at pond edge. No surrounding vegetation.
	S-10	2/24/2019	9:33	19.8	14.3	Pahoehoe with light organic material and some sand, small basalt pebbles	373 ± 47	absent	absent	*M. lohena* (common), *Schinus terebinthifolius, Pennisetum setaceum, Argiope appens, Talinum fruticosum*

MARINE BENTHIC BIOTA SURVEY

INTRODUCTION

The Natural Energy Lab 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-relation 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 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 47 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), and the results and findings for the 2019 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 (sites with steep slope only have coordinates for 50-fsw pin):

Site	GPS	Notes
Ho'ona Bay	50: 19.73255, - 156.0578	Mooring located at 30fsw. Pins align across depth gradient on 160-degree bearing and are adjacent to mooring. Surveys conducted along isobaths on west side of each pin.
NPPE	50: 19.73137, -156.0609	Pins align across depth gradient on 90-degree bearing. Surveys conducted along isobaths on west side of each pin.
12" Pipe North	50: 19.72825, -156.0625	Pins are just to south of pipe platform. Chain from pipe aligns with 30fsw pin, and bearing is consistent to 15fsw pin. Surveys conducted along isobaths on southwest side of each pin.
12" Pipe South	50: 19.72627, -156.06159	Pins are located to south of pipe. Follow 50-degree bearing from pipe at each isobaths to the pins. Surveys conducted along isobaths on south side of each pin.
18" Pipe	50: 19.72176, -156.05868	Pins are located to south side of pin at each isobaths. Surveys conducted along isobaths on south side of each pin.
Wawaloli	50: 19.71463, -156.05188 35: 19.7149, - 156.05136 15: 19.71535, - 156.05086	Pins are located at each bearing. Isobaths are much more separated than other sites. Surveys conducted along isobaths on south side of each pin.

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 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 benthic substrate characteristics (percent cover, species richness, and species diversity).

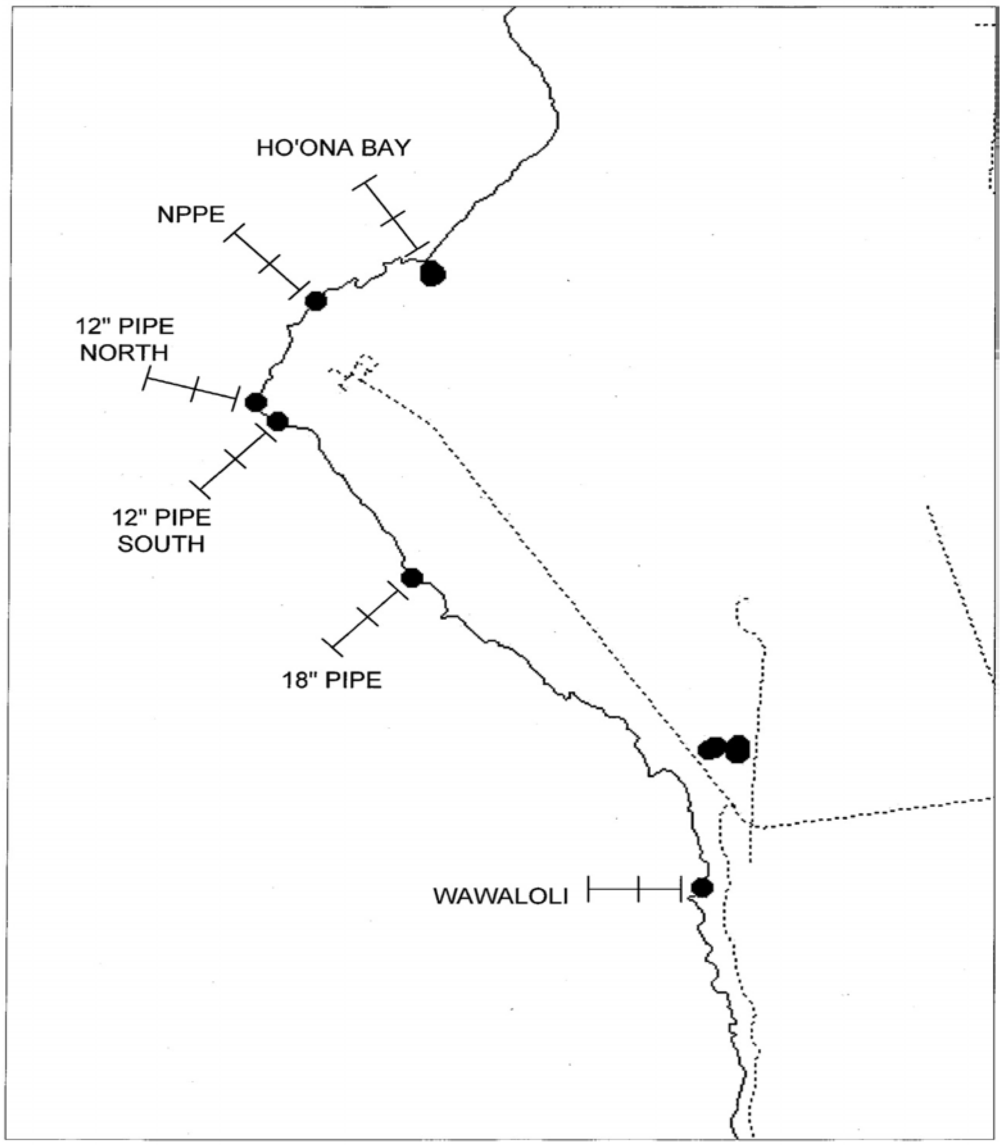

Figure 13. Six stations with three transects per station at deep (~50-fsw), moderate (~35-fsw), and shallow (~15-fsw) depths along the NELHA coastline. A total of 18 transects are completed for both the benthic monitoring and fish assemblage monitoring.

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 37.05%, the most dominant corals were *Porites lobata* (25.23%), *Porites compressa (6.07%), Porites evermanni* (1.53%), *Montipora capitata* (2.67%), *Montipora patula* (0.65%) and *Pocillopora meandrina* (0.83%). These coral species were present among all the stations. Other corals present were *Pocillopora grandis (*previously *eydouxi)*, *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. comressa and M. capitata* were the dominant corals in the shallow (~15-fsw) and moderate depths (~35-fsw) among the six stations. *P. lobata* and *P. compressa* were the most dominant corals at the deep depths (~50-fsw) among the six stations. *P. meandrina* was most abundant at the Wawaloli station, 18” Pipe, and 12” Pipe stations. *P. evermanni* was most abundant at the 12” Pipe South station. *P. compressa* was most abundant at Hoona Bay and NPPE stations. *P. lobata* had the highest levels of abundance at Hoona Bay and NPPE 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 2019 were similar to previous 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 Hoona Bay and NPPE sites exhibited the highest levels of coral cover (48.10% and 47.00% respectively). Coral cover at these two sites was dominated by *P. lobata and P. compressa.*

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Species richness and species diversity was highest at 12” Pipe North. The benthic substrate at this site was predominantly occupied by *P. lobata* (23.80%), with *P. evermanni* (2.00%), *P. compressa* (3.40%), and *M. capitate* (2.00%) coral species also exhibited mean levels of coral cover above 1%. Values of coral cover exhibited statistically significant differences among the sites. Overall coral cover was significantly higher (p<0.05, Kruskal-Wallis) at Hoona Bay and NPPE compared to the other sites. *P. lobata, P. compressa* also exhibited significantly higher values of cover (p<0.05, Kruskal-Wallis) at Hoona Bay and NPPE compared to the other sites. *P. meandrina* exhibited significantly higher values of cover (p<0.05, Kruskal-Wallis) at Wawaloli and 18” Pipe sites.

Values of overall coral cover were statistically similar among all depths. Moderate depths had the highest cover of 39.05%, with deep and shallow sites exhibiting 37.80% and 34.30% coral cover. *P. compressa* showed significantly higher values of cover (p<0.05, Kruskal-Wallis) at the deep sites compared to moderate and shallow. *P. meandrina* showed significantly higher values of cover (p<0.05, Kruskal-Wallis) at the shallow sites compared to moderate and deep sites. Among the deep stations, coral was most abundant at NPPE and Ho’ona Bay sites (56.70% and 58.30%), which was also seen in 2017 and 2018. The observed patterns in coral cover among the surveyed depths are similar to previous years and showed similar patterns in coral cover among sites in 2016-2018 (Burns and Kramer 2016, 2017, 2018).

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 May 2019.

Table 5: Summary of benthic substrate data and comparative analyses from surveys conducted in May 2019.

Station	Wawaloli				18" Pipe				12" Pipe South		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Overall coral cover	36.00	30.20	15.00		35.20	36.10	30.40		38.10	36.00	28.70
P. lobata	27.40	23.70	14.20		27.20	17.40	20.00		30.30	21.80	22.60
P. evermanni	3.50					4.00	2.00		3.00	4.60	0.50
P. compressa					1.40	5.40	6.40			1.00	2.60
P. meandrina	2.60	2.90			2.50	1.00			1.00	1.00	0.70
P. eydouxi											
M. capitata	1.50	3.10	0.80		3.80	8.30	1.60		1.80	5.90	1.50
M. patula	1.00	0.50	0.00		0.30		0.40		2.00	1.70	0.80
Species count	5.00	4.00	3.00		5.00	5.00	5.00		5.00	6.00	6.00
Species diversity (H)	1.46	1.44	1.15		1.46	1.48	1.38		1.43	1.56	1.39
Station	12" Pipe North				NPPE				Hoona Bay		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Overall coral cover	27.10	35.20	37.70		32.90	51.60	56.70		36.40	44.70	58.30
P. lobata	20.10	27.20	24.00		24.10	34.00	30.00		29.80	31.10	29.20
P. evermanni	0.30	3.20	2.60		0.70	1.50			0.70		0.40
P. compressa		3.50	6.70		2.10	14.10	26.50		2.40	10.50	26.20
P. meandrina	1.70		0.60		1.00						
P. eydouxi	2.00										
M. capitata	1.50	0.60	3.80		3.60	2.00	0.20		3.10	2.70	1.70
M. patula	1.50	0.70			1.40				0.40	0.40	0.80
Species count	6.00	5.00	5.00		6.00	4.00	3.00		5.00	4.00	5.00
Species diversity (H)	1.50	1.44	1.48		1.51	1.47	1.47		1.42	1.52	1.55
Mean value comparis	Wawa	18" Pipe	12" Pipe S	12" Pipe N	NPPE	H - Bay	p-value	Shallow	Moderate	Deep	p-value
Overall coral cover	27.10	33.90	34.30	33.40	47.00	48.10	**0.01**	34.30	39.05	37.80	0.39
P. lobata	21.80	21.50	24.90	23.80	29.40	30.10	**0.01**	26.50	25.90	23.30	0.10
P. evermanni	1.20	2.00	2.70	2.00	0.70	2.00	0.32	1.40	2.20	1.00	0.38
P. compressa		4.40	1.20	3.40	14.20	13.00	**0.01**	1.00	5.80	11.40	**0.01**
P. meandrina	1.80	1.20	0.90	0.80	0.30		**0.01**	1.50	0.80	0.20	**0.01**
P. eydouxi				0.70			0.07	0.30			0.13
M. capitata	1.80	4.60	3.10	2.00	1.90	2.50	0.66	2.60	3.80	1.60	0.23
M. patula	0.50	0.20	1.50	0.70	0.50	0.50	0.16	1.10	0.55	0.30	0.09
Species count	5.00	6.00	6.00	7.00	6.00	5.00	0.68	7.00	6.00	6.00	0.74
Species diversity (H)	1.35	1.44	1.46	1.47	1.48	1.50	0.81	1.46	1.49	1.40	0.63

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 2013-2018, and how they compare to the current data from 2019.

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%. While several of the changes in overall coral cover among these years were noted as significant (ANOVA, $p<0.01$), the last six years have provided a consistent range (~25-50%) 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 2019, 37.05%, is within this range and shows the benthic communities to exhibit consistent values of coral cover for the last 9 years.

Other studies conducted throughout the 18-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 Hoona Bay and NPPE exhibiting statistically higher values of coral cover than the 12" and 18" Pipe sites, and all sites exhibiting higher coral cover than Wawaloli. *P. meandrina* has also been shown to have significantly higher coral cover at shallow depths compared to deep depths, and *P. compressa* to have higher coral cover at deep depths compared to shallow depths. The 2019 data supported this trend in overall coral cover with significantly higher mean values of overall coral cover observed at the Hoona Bay and NPPE sites compared to the other four monitoring stations. The 2019 data also supported previous studies with *P. compressa* having significantly higher cover values at deeper sites. The 2019 data showed P. lobata to have significantly higher values of cover at all sites among all three depths. The 2019 data show no significant differences in species richness or species diversity among the six stations and three depth profiles. 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%, 29%, 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 2019 was 25.23%. This value is higher than observed in 2018 (22.49%) and more similar to previous years. While this value is lower than during the years 2013-2015, there was 1.53% cover attributed to *P. evermanni,* which was possibly not identified in previous years due to morphological similarity. The differences in coral cover from 2013 to 2018 are less than 5%, which indicates consistency in this coral being the dominant coral species. The overall percent cover of mounding *Porites* coral in 2019 is not statistically different to the previous four years. The 2019 values of coral cover for mounding *Porites* was also very similar among surveys conducted during the previous 5-years, thus indicating these are the dominant coral colonies among these stations and this species 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 2019 data also support this trend; with nearly all the *P. compressa* coral cover being observed at the deeper 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 (3.98% - 21.59%) and was found to have statistically higher values in shallow sites in 2014 (Bybee et al. 2014). The 2019 data are similar to the generally lower values recorded in 2017 and 2018, and no colonies were observed at a few stations. The overall cover of *P. meandrina* cover did not exhibit statistically significant differences among sites compared to the past three years. Values of *P. meandrina* cover in 2019 were highest at shallow depths. The variability in *P. meandrina* coral cover over the last several years may be associated with the loss of *P. meandrina* corals along leeward coastlines at shallow depths throughout Hawaii due to regional elevations 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 higher levels of *P. meandrina* cover in shallow depths, compared to 2017 and 2018, 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 2019 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 2009-2018. The data from 2019 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 2019 data did support the previous findings of significantly higher coral cover at the more northern sites, Hoona Bay and NPPE.

The mean values of *P. meandrina* cover have shown a significant decrease in abundance from shallow to deep and have been observed at all shallow and moderate depths (Bybee et al. 2014, WHALE Environmental 2015). As mentioned above, this coral has high growth rates and serves as a colonizer of disturbed habitat in areas with high water motion (Dollar 1982). The 2016 data showed a decrease in *P. meandrina cover* in shallow sites, which is likely due to the statewide episodic increase in seawater temperatures in 2014-2015. The values of coral cover of *P. meandrina* were highest at shallow sites in 2019, which suggests potential recruitment and recovery of this species at this depth zone. Future surveys at the same spatial locations will enable documentation of how effectively *P. meandrina* can re-colonize at the shallow survey stations and how the community structure of this species may change following the prior disturbances.

The results and findings of the surveys conducted over the last 21 years have shown 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 in 2017, 2018 and 2019, the three years using the permanent pins. While variability will always exist due to the randomly selected locations for quadrats along the transect, the high similarity in values among the previous two years suggest the permanent sites are helping in accurately detecting changes in the benthic communities at these survey sites.

Despite variability in the mean values of coral cover among the survey stations and depths over time, the data has shown these corals exhibit patterns in zonation and community structure that are typical of Hawaiian reefs on leeward coastlines. The consistent values of species richness and diversity indicate the assemblages have not experienced any dramatic changes over the last two decades. The 2019 data show no significant variation in benthic composition among the stations and depths, and no significant changes compared to the last several years of monitoring. These findings indicate the nearshore marine benthic communities are not exhibiting any signs of detrimental impacts associated with the NELHA facility.

MARINE FISH BIOTA SURVEY

INTRODUCTION

The Natural Energy Lab 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-relation 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 26 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.

PLANB CONSULTANCY

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 Hoona Bay and the lowest was at Wawaloli, which is similar to patterns seen from 2016-2018 where the northern sites have higher counts of individual fish. This range in individuals was 80 to 438. Shallow and moderate habitats had similarity in the total number of individuals (216 and 219 respectively), with deep sites having the highest number (399 individuals). While there were differences in the mean values, there were no statistically significant differences in the total number of individual fishes counted among all six stations (p=0.19) or among the three depth gradients (p=0.72). All values are reported in Table 6.

Number of Species

The mean number of species recorded was highest at the Hoona Bay and lowest at Wawaloli. This range in mean number of species was 15 to 32. The shallow, moderate, and deep habitats had 23-26 species of fish recorded for surveys among these depths. While there were differences in mean values of the number of species recorded, there was no statistically significant difference among the six stations (p=0.06) or among the three depth gradients (p=0.50). 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 previous years.

Species Diversity and Biomass

Species diversity ranged from 1.80 at Wawaloli to 3.17 at 12” Pipe North. The mean species diversity among the deep depths was 2.60, 2.74 among moderate depths, and 2.92 among the shallow depths. There were no significant differences in species diversity among the six stations surveyed (p=0.08). There were also no significant differences in species diversity among the three depth gradients (p=0.52)

Fish biomass was highest at the Hoona Bay (145.74 g/m2) and lowest at Wawaloli (108.15 g/m2). Biomass was lowest at moderate depths (114.15 g/m2), and highest at the deep depths (130.15 g/m2). No significant differences in mean biomass were detected among the sites (p=0.95) or depth gradients (p=0.64).

Table 6: Summary of fish survey data and comparative analyses from surveys conducted in May 2019.

Station	Wawaloli				18" Pipe				12" Pipe South		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Fish count	59.00	122.00	60.00		370.00	175.00	329.00		159.00	248.00	706.00
Number of species	19.00	17.00	8.00		30.00	15.00	25.00		29.00	26.00	24.00
Diversity	2.04	1.65	1.68		3.07	2.37	2.63		3.20	2.85	2.50
Biomass	150.48	118.56	55.40		123.21	45.78	201.96		69.65	141.80	129.22
Station	12" Pipe North				NPPE				Hoona Bay		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Fish count	212.00	258.00	195.00		329.00	302.00	164.00		184.00	192.00	939.00
Number of species	27.00	22.00	24.00		23.00	26.00	20.00		28.00	30.00	37.00
Diversity	3.32	3.21	2.98		2.70	3.00	3.28		3.14	3.35	2.48
Biomass	119.50	90.64	148.10		135.64	105.72	138.50		147.06	182.43	107.74
Mean value comparis	Wawa	18" Pipe	12" Pipe S	12" Pipe N	NPPE	H - Bay	p-value	Shallow	Moderate	Deep	p-value
Fish count	80.00	291.00	371.00	222.00	265.00	438.00	0.19	219.00	216.00	399.00	0.72
Number of species	15.00	23.00	26.00	24.00	23.00	32.00	0.06	26.00	23.00	23.00	0.50
Diversity	1.80	2.70	2.85	3.17	3.00	3.00	0.08	2.92	2.74	2.60	0.52
Biomass	108.15	123.65	113.56	119.41	126.62	145.74	0.95	124.25	114.15	130.15	0.64

COMPARATIVE ANALYSIS OF TEMPORAL TRENDS IN FISH DATA

The goal of this report is to provide a detailed characterization of the nearshore fish assemblages at the six stations and three depth gradients used for long-term monitoring of marine habitats adjacent to the NELHA facilities. Previous reports have performed extensive analyses to compare data from these sites from 1992-2016 (Ziemann 2010, Bybee and Barrett 2012, Bybee et al. 2013, 2014, Whale Environmental 2015, Burns and Kramer 2016). This report will discuss the key findings from these previous reports and how they compare to the current data from the 2019 surveys.

Previous studies have reported variation in fish assemblage structure over the past 25 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 2019 data exhibited similar patterns and values for all parameters to the 2016, 2017, and 2018 data (Burns and Kramer 2016, 2017, 2018). The data from the past three four 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.

PLANB CONSULTANCY

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 2018 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 were higher than some previous years, but in the same range as those observed in 2010, 2016, 2017 and 2018. 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 26-year time-span of the monitoring program is effective for noticing any substantial detrimental changes that may be associated with acute or long-term disturbances.

A general pattern that has been detected in previous years was that fish assemblages exhibited higher abundance, diversity, and biomass near the Pipe sites and lower values off Wawaloli Beach. This pattern is still evident, as values at Wawaloli were lowest in 2014, 2015-2018, and in the 2019 data (Bybee et al. 2014, WHALE Environmental 2015, Burns and Kramer 2016 & 2017, Table 6). The reason of this pattern is likely habitat differences. Both the northern sites and those adjacent to the pipes display steep topographic relief with highly complex basalt substrate. Complex habitat is a known driver of fish abundance and diversity. The Wawaloli Beach site is in an embayment, and the substrate not occupied by live coral is predominantly sand (Appendix 2 and 4). These differences in habitat composition may be driving the consistent differences in fish assemblages seen at Wawaloli, and they will likely remain evident in future surveys. The 2019 data continued to support this trend, with similar values of biomass, count, and diversity in comparison to previous years.

In summary, the reports conducted over the past 26 years show variability in fish assemblage data, but long-term trends indicate that the fish communities in the area are highly productive and diverse. There are no dramatic declines in abundance or changes in population structure that indicate any detrimental impacts are associated with proximity to the NELHA facility.

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APPENDICES

Appendix 1 – Pond Monitoring

Appendix 1.1. Physical characteristics of Northern and Southern complex anchialine ponds, summarized from faunal surveys conducted from May 1989 to October 2008 (Brock 2008, Ziemann and Conquest 2008), and water quality surveys in 2009. Pond 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 ponds located within and surrounding the NELHA facility, during surveys conducted from May 1989 to August 2008 (Brock 2008). Introduced fish species (Poeciliids) were recorded as present (x) or absent (0).

Survey Date	Pond: N-1 (Count/0.1m^2)								Pond: N-2 (Count/0.1m^2)			Pond: N-3 (Count/0.1m^2)							
	Thiarid Snails (Melania sp.)		*H. rubra*	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/0.1m^2)						Pond: N-5 (Count/0.1m^2)					
	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

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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	Photo Name	Sub-Categories	Algae	Asptax Asparagopsis taxiformis (Asptax)	Caurac Caulerpa racemosa (Caurac)	Caulser Caulerpa serrulata (Caulser)	Caulsert Caulerpa sertularioides (Caulsert)	Codara Codium arabicum (Codara)	CCA Crustose Coralline (CCA)	BG Cyanophyta (BG)	Dasyir Dasya iridescens (Dasyir)	Dichmar Dichotomaria marginata (Dichmar)	Dictcav Dictyospaeria cavernosa (Dictcav)	Dictver Dictyosphaeria versluysii (Dictver)	Dicty Dictyota species (Dicty)	Gibhaw Gibsmithia hawaiiensis (Gibhaw)	Halop Halimeda opuntia (Halop)	Lobvar Lobophora variegata (Lobvar)	Marflab Martensia flabelliformis (Marflab)	Marfrag Martensia fragilis (Marfrag)	Neoman Neomeris annulata (Neoman)	Padina Padina species (Padina)	Porhor Portieria hornemanii (Porhor)	Prewel Predaea weldii (Prewel)	Sarg Sargassum (Sarg)	Turbor Turbinaria ornata (Turbor)	Turf Turf (Turf)	venven Ventricaria ventricosa (venven)	red algae
12S	50	2									50	10																	30		
12S	50	3									60	5																	28		
12S	50	4									40	5																	47		
12S	50	6									45	7																	30		1
12S	50	11									35																		19		3
12S	50	17									15	10											1						67		1
12S	50	19									5	10											1						53		1
12S	50	21									20	20																	52		
12S	50	23										3							1										79		
12S	50	25									10	6							4										60		
12S	35	2									10	5											1						56		
12S	35	3									10	5																	31		
12S	35	4									15	5																	52		
12S	35	8									10	5																	63		2
12S	35	14									10	15																	48		
12S	35	16									10																		43		
12S	35	19									15	10							1										49		
12S	35	20									8	18																	32		
12S	35	27									10	5																	40		
12S	35	28									5	3																	71		
12S	15	1									15	5																	68		
12S	15	5									5	3																	68		
12S	15	6										7																	77		
12S	15	8									5	7																	65		1
12S	15	12									5	3																	84		
12S	15	17									10	3																	67		
12S	15	21									10	2																	72		1
12S	15	23									10	6																	73		
12S	15	26									20	5																	39		
12S	15	29									12																		72		1

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Site	Depth	Location	Photo Name	Sub-Categories	Algae	Asptax	Caurac	Caulser	Caulsert	Codara	CCA	BG	Dasyir	Dichmar	Dictcav	Dictver	Dicty	Gibhaw	Halop	Lobvar	Marflab	Marfrag	Neoman	Padina	Porhor	Prewel	Sarg	Turbor	Turf	venven	
						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																											53		
12N	50	2										2																	52		
12N	50	6										1																	66		1
12N	50	9									5	1							1										60		1
12N	50	13									10	6																	60		
12N	50	15									10																		59		
12N	50	19									5																		63		1
12N	50	21										2							5				1						47		3
12N	50	23									5	2																	50		
12N	50	24									10	2							3										60		
12N	35	1										2																	78		
12N	35	2									10	5																	62		
12N	35	7									8																		66		
12N	35	9									7	5																	47		
12N	35	11									8	5																	60		
12N	35	12									3																		57		
12N	35	13									5	5																	65		
12N	35	17									5																		85		
12N	35	18									10																		58		
12N	35	21									5	10											1						62		
12N	15	2									10																		75		
12N	15	4									30																		50		
12N	15	5									5																		58		
12N	15	9									3																		45		
12N	15	11										5																	65		
12N	15	13									15																		70		
12N	15	15									5																		63		
12N	15	16									30	5																	53		
12N	15	21									5																		66		
12N	15	23									7	5																	41		

Site	Depth	Location	Photo Name	Sub-Categories	Algae	Asptax	Caurac	Caulser	Caulsert	Codara	CCA	BG	Dasyir	Dichmar	Dictcav	Dictver	Dicty	Gibhaw	Halop	Lobvar	Marflab	Marfrag	Neoman	Padina	Porhor	Prewel	Sarg	Turbor	Turf	venven	
						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									3							1											11		5
NPPE	50	1									5	6																	48		
NPPE	50	5									5	3											1						54		
NPPE	50	7									10	2																	61		
NPPE	50	8									10	3																	47		
NPPE	50	19									15	2																	40		
NPPE	50	23									20	5																	29		2
NPPE	50	24									20							1											23		
NPPE	50	27									10																		32		1
NPPE	50	29									10												1						58		1
NPPE	35	0									7	2											1						58		
NPPE	35	1									5	5																	49		
NPPE	35	2									10																		75	1	
NPPE	35	5									6																		53		1
NPPE	35	12									20																		67		
NPPE	35	14									12																		56		
NPPE	35	17									10	5																	52		
NPPE	35	19									6	5																	53		
NPPE	35	21									5																		66		
NPPE	35	22									20																		45		
NPPE	15	0									10																		70		
NPPE	15	1									10																		52		
NPPE	15	6									8	2																	62		
NPPE	15	8									5																		60		
NPPE	15	12									15																		65		
NPPE	15	13									5	2																	47		
NPPE	15	15									15																		68		
NPPE	15	19									5	2																	64		
NPPE	15	22									15	2																	71		
NPPE	15	25									3	1																	30		

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						Asptax	Caurac	Caulser	Caulsert	Codara	CCA	BG	Dasyir	Dichmar	Dictcav	Dictver	Dicty	Gibhaw	Halop	Lobvar	Marflab	Marfrag	Neoman	Padina	Porhor	Prewel	Sarg	Turbor	Turf	venven	
Site	Depth	Location	Photo Name	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	2									25																		28		
H-bay	50	13									30							1											17		
H-bay	50	15									20																		25		
H-bay	50	18									30																		23		1
H-bay	50	22									5	15																	26		
H-bay	50	29									15																		15		
H-bay	50	31									25	1																	8		
H-bay	50	33									12	8																	15		
H-bay	50	37									10	3																	27		
H-bay	50	41										5																	36		
H-bay	35	1										5																	42		
H-bay	35	6									25												1						53		
H-bay	35	11									10	2																	36		
H-bay	35	13										5																	60		
H-bay	35	18									20	5																	29		
H-bay	35	21									15	5																	45		
H-bay	35	23									15	5																	57		
H-bay	35	27									10	5											1						34		2
H-bay	35	32									10												1						33		
H-bay	35	35																											46		
H-bay	15	0									15																		47		
H-bay	15	4										5																	52		
H-bay	15	6									30												1						45		
H-bay	15	10						3			10	3																	59		
H-bay	15	14									25																		40		
H-bay	15	16									30	5																	50		
H-bay	15	18									15	5																	33		
H-bay	15	20									20	3																	67		
H-bay	15	21									20																		58		
H-bay	15	25									15																		43		

Site	Depth	Location	Photo Name	Sub-Categories	Algae	Asptax	Caurac	Caulser	Caulsert	Codara	CCA	BG	Dasyir	Dichmar	Dictcav	Dictver	Dicty	Gibhaw	Halop	Lobvar	Marflab	Marfrag	Neoman	Padina	Porhor	Prewel	Sarg	Turbor	Turf	venven	
				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	1									7	5																	56		
18	50	2									25	15																	54		
18	50	3									50	5																	33		
18	50	4									60	5																	12		
18	50	5									20	15							3										22		
18	50	10									40	5							1										6		
18	50	20									5	15							2										43		
18	50	23										15											1						61		
18	50	25									5								2				1						71		1
18	50	27									3	5											1						67		
18	35	0									20	5											1						46		1
18	35	4									5	2																	55		
18	35	5									10	5																	33		
18	35	10									5	3							1										54		
18	35	13									20	10							1										66		
18	35	19									10	5																	32		
18	35	20									15																		33		
18	35	23									25	5							1										48		
18	35	27									15	10																	40		
18	35	30									10	5																	38		
18	15	2									25																		30		
18	15	5										5																	42		
18	15	6									5	3																	61		
18	15	8									20	5																	58		
18	15	10									10	5																	44		
18	15	12									15	10																	62		
18	15	19									10	5																	35		
18	15	25										2																	77		
18	15	26									30	5																	30		
18	15	27									15	5																	73		

PLANB CONSULTANCY

						Asptax	Caurac	Caulser	Caulsert	Codara	CCA	BG	Dasyir	Dichmar	Dictcav	Dictver	Dicty	Gibhaw	Halop	Lobvar	Marflab	Marfrag	Neoman	Padina	Porhor	Prewel	Sarg	Turbor	Turf	venven	
Site	Depth	Location	Photo Name	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									20	1																	33		
Wawa	50	2									20																		27		
Wawa	50	3									10	3																	33		2
Wawa	50	6									10	3																	45		
Wawa	50	7									10	2																	42		1
Wawa	50	10									15	5																	36		1
Wawa	50	15									10	5																	40		
Wawa	50	17									5																		15		1
Wawa	50	21									7																		63		2
Wawa	50	24									5	6																	67		
Wawa	35	0									20	5																	44		
Wawa	35	3									3	5																	61		
Wawa	35	5									7																		54		
Wawa	35	10									10	5																	55		
Wawa	35	12										5																	58		
Wawa	35	18										3																	59		
Wawa	35	20									20	10																	30		
Wawa	35	22									10	7																	44		
Wawa	35	26										5																	57		
Wawa	35	27									5																		49		
Wawa	15	0									6	1																	49		
Wawa	15	4									5	10																	58		
Wawa	15	6									20	4																	32		
Wawa	15	10									8	5																	71		
Wawa	15	11									3	5																	62		
Wawa	15	15									3	1																	73		
Wawa	15	17									10	4																	68		
Wawa	15	21									5	5																	55		
Wawa	15	22									3	5																	62		
Wawa	15	24									10																		70		1

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

Site	Depth	Location	hoto Nam	Coral	Cyphastrea agassizi (cypag)	Cyphastrea ocellina (cypoc)	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Pocillopora damicornis (Pocdam)	Pocillopora eydouxi (Poceyd)	Pocillopora ligulata (Poclig)	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
12S	50	1								5													22									
12S	50	2										4											22									
12S	50	3																					30									
12S	50	5																					26									
12S	50	11								6									7				16									
12S	50	12																		15			15									
12S	50	13								3					12								12									
12S	50	15																		5			22									
12S	50	20										4								2			31									
12S	50	23																		4		5	30									
12S	35	4								6										10			15									
12S	35	5								8													27									
12S	35	6								11												6	25									
12S	35	7								5		5							5				24									
12S	35	9								6									5				18									
12S	35	11								10		5											28									
12S	35	12								6												12	30									
12S	35	15										4										12	15									
12S	35	16																				16	18									
12S	35	21								7		3											18									
12S	15	1								8		8											35									
12S	15	2										5										10	15									
12S	15	3								10		7											18									
12S	15	4																				10	45									
12S	15	6																					40									
12S	15	14																					40									
12S	15	15																					30									
12S	15	20																	5				22									
12S	15	23																				10	30									
12S	15	28																	5				28									

Site	Depth	Location	Photo Nam	Coral	Cyphastrea agassizi (cypag)	Cyphastrea ocellina (cypoc)	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Pocillopora damicornis (Pocdam)	Pocillopora eydouxi (Poceyd)	Pocillopora ligulata (Poclig)	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
12N	50	1								6										14			25									
12N	50	2								2										15			20									
12N	50	5								6										5			36									
12N	50	7								6										5			20									
12N	50	13								6													28									
12N	50	15																		18			10									
12N	50	16																		10			24									
12N	50	17								6												8	26									
12N	50	20								6									6			8	25									
12N	50	23																				10	26									
12N	35	3								6		6											20									
12N	35	5																		8			30									
12N	35	6																		8			20									
12N	35	7																		8			25									
12N	35	11										1											20									
12N	35	19													4							16	45									
12N	35	20													2								20									
12N	35	21																		1			22									
12N	35	23																		8			45									
12N	35	28																		2		16	25									
12N	15	1										1											22									
12N	15	2										5											16									
12N	15	3								4							8						25									
12N	15	4										1					12						28									
12N	15	7								2		8							2				25									
12N	15	9								6													18									
12N	15	14																	6				18									
12N	15	15																	3				15									
12N	15	20								3												3	20									
12N	15	22																	6				14									

Site	Depth	Location ıoto Nam	Coral	Cyphastrea agassizi (cypag)	Cyphastrea ocellina (cypoc)	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Pocillopora damicornis (Pocdam)	Pocillopora eydouxi (Poceyd)	Pocillopora ligulata (Poclig)	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
NPPE	50	1																	25			25									
NPPE	50	3							1										15			30									10
NPPE	50	4																	20			35									
NPPE	50	7																	20			45									
NPPE	50	16																	25			40									
NPPE	50	17																	20			15									
NPPE	50	18							1										30			15									
NPPE	50	21																	25			45									
NPPE	50	23																	40			25									
NPPE	50	26																	45			25									
NPPE	35	2							10										15			50									
NPPE	35	3																				25									
NPPE	35	4																	10			40									
NPPE	35	6																	30			35									
NPPE	35	9																	20		10	20									
NPPE	35	10																	16		5	35									
NPPE	35	13							10										10			15									
NPPE	35	21																	10			50									
NPPE	35	23																	15			30									
NPPE	35	30																	15			40									
NPPE	15	3																	15			40									
NPPE	15	4							5					5					6			10									
NPPE	15	7							5					5								20									
NPPE	15	8							10		5											35									
NPPE	15	12							5									5			6	32									
NPPE	15	14																				20									
NPPE	15	20							6		6											20									
NPPE	15	21							1		3							5				22									
NPPE	15	2							4												1	22									
NPPE	15	26																				20									

PLANB CONSULTANCY

Site	Depth	Location ɿoto Nam	Coral	Cyphastrea agassizi (cypag)	Cyphastrea ocellina (cypoc)	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Pocillopora damicornis (Pocdam)	Pocillopora eydouxi (Poceyd)	Pocillopora ligulata (Poclig)	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
H-bay	50	2																	16			45									
H-bay	50	3							1										30			25									
H-bay	50	7							5		2								40			20									
H-bay	50	8																	2			16									
H-bay	50	10																	35			26									
H-bay	50	13							5										12		4	32									
H-bay	50	16																	35			36									
H-bay	50	17							5		6								32			36									
H-bay	50	18																	30			26									
H-bay	50	21							1					5					30			30									
H-bay	35	3							3										16			45									
H-bay	35	4																	18			35									
H-bay	35	6							2										15			15									
H-bay	35	9							6										10			40									
H-bay	35	7							2		4								10			25									
H-bay	35	13																	16			45									
H-bay	35	19							5										2			20									
H-bay	35	20																	10			45									
H-bay	35	22							1													25									
H-bay	35	26							8										8			16									
H-bay	15	1																	12			34									
H-bay	15	2							4										12			25									
H-bay	15	3																				34									
H-bay	15	5							5												5	15									
H-bay	15	8							5												2	35									
H-bay	15	9																				36									
H-bay	15	10																				36									
H-bay	15	12							6		4											36									
H-bay	15	14							5													22									
H-bay	15	16							6													25									

Site	Depth	Location ıoto Nam	Coral	Cyphastrea agassizi (cypag)	Cyphastrea ocellina (cypoc)	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Pocillopora damicornis (Pocdam)	Pocillopora eydouxi (Poceyd)	Pocillopora ligulata (Poclig)	Pocilliopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
18	50	2							4													16									
18	50	3							1													18									
18	50	4							1													22									
18	50	6							5										8			30									
18	50	8																	10			38									
18	50	9							5										15			15									
18	50	12									2										20	10									
18	50	13																	8			15									
18	50	16									2								8			20									
18	50	17																	15			16									
18	35	2																	8			30									
18	35	4							3												20	15									
18	35	6							50													15									
18	35	7																			20	10									
18	35	9																	18			25									
18	35	11							2									5	14			5									
18	35	12							4													20									
18	35	18							24										10			1									
18	35	21																				28									
18	35	23																5	4			25									
18	15	2																5	14			25									
18	15	3																5				24									
18	15	4							8													30									
18	15	6							8													33									
18	15	7							8													32									
18	15	9							5									5				35									
18	15	11							5									5				25									
18	15	17																				18									
18	15	20							4													24									
18	15	21									3							5				26									

PLANB CONSULTANCY

Site	Depth	Location 10to Nam	Coral	Cyphastrea agassizi (cypag)	Cyphastrea ocellina (cypoc)	Fungia scutaria (Funscu)	Leptastrea purpurea (Leppur)	Leptoseris bewickensis (Lepbew)	Montipora capitata (Moncap)	Montipora flabellata (Monfla)	Montipora patula (Monpat)	Montipora species (Monsp)	Pavona duerdeni (Pavdue)	Pavona varians (Pavvar)	Pocillopora damicornis (Pocdam)	Pocillopora eydouxi (Poceyd)	Pocillopora ligulata (Poclig)	Pocillopra meandrina (Pocmea)	Porites compressa (Porcom)	Porites brighami	Porites evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
Wawa	50	1																				15						5			80
Wawa	50	2																				15						2			83
Wawa	50	3																				15						5			80
Wawa	50	5																				15									85
Wawa	50	8							1													15									84
Wawa	50	9							6													10						5			79
Wawa	50	16							1													16									83
Wawa	50	17																				16									84
Wawa	50	20																				15						1			84
Wawa	50	23																				10						90			0
Wawa	35	1																15				45									
Wawa	35	2							6		5							5				15									
Wawa	35	3							5									5				16									
Wawa	35	6							2													35									
Wawa	35	8							5									1				15									
Wawa	35	10																				18									
Wawa	35	16																1				22									
Wawa	35	21							3													16									
Wawa	35	23							5													30									
Wawa	35	24							5									2				25									
Wawa	15	1							3												10	30									
Wawa	15	2							2													20									
Wawa	15	5																				25									
Wawa	15	7																5				26									
Wawa	15	8																			15	28									
Wawa	15	11																				25									
Wawa	15	14																5			10	35									
Wawa	15	23																6				25									
Wawa	15	24							5		5							5				30									
Wawa	15								5		5							5				30									

Table 2.3 Benthic habitat characterization data – Mobile Invertebrates

Row Labels	Sum of D. paucispinum	Sum of Echinometra mathaei	Sum of Echinothrix sp.	Count of Echinometra oblonga	Sum of H. mammillatus	Sum of Tripneustes gratilla
⊟ 18		**2**			**2**	
15					2	
35						
50		2				
⊟ 12N		**13**	**1**			
15		5				
35		5				
50		3	1			
⊟ 12S		**1**	**2**			
15						
35						
50		1	2			
⊟ H-bay	**1**	**3**				**2**
15	1					
35		2				1
50		1				1
⊟ NPPE		**20**	**2**			**1**
15		1	2			
35		7				
50		12				1
⊟ Wawa			**4**			
15						
35			4			
50						
Grand Total	**1**	**39**	**9**		**2**	**3**

Appendix 3: Nearshore fish assemblage data

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

Haona Bay	5/27/19							
50'			35'			15'		
Species	**Individuals**	**Size (cm)**	**Species**	**Individuals**	**Size (cm)**	Species	Individuals	Size (cm)
M. kuntee	40	15	A. nigrofuscus	4	6	A. nigrofuscus	7	9
M. kuntee	43	18	A. nigrofuscus	11	8	A. nigrofuscus	13	12
M. flavolineatus	1	18	A. nigrofuscus	6	10	A. nigrofuscus	8	10
M. vanicolensis	1	16	C. agilis	3	3	G. varius	1	8
N. literatus	1	14	C. agilis	1	5	C. strigosus	8	10
A. nigrofuscus	6	5	C. strigosus	3	6	C. strigosus	8	12
A. nigrofuscus	10	6	C. strigosus	9	8	C. jactator	1	4
A. nigrofuscus	10	8	C. strigosus	7	9	C. jactator	2	5
C. agilis	200	2	C. strigosus	8	10	C. vanderbiliti	20	2
C. agilis	300	4	C. strigosus	4	12	C. vanderbiliti	24	3
C. agilis	100	6	C. vanderbiliti	12	2	C. vanderbiliti	20	4
D. albisella	1	14	C. vanderbiliti	28	3	T. duperrey	1	10
C. strigosus	10	6	C. vanderbiliti	21	4	T. duperrey	2	11
C. strigosus	10	8	N. literatus	1	18	T. duperrey	1	12
C. strigosus	10	10	T. duperrey	4	6	T. duperrey	1	16
C. potteri	2	8	T. duperrey	1	9	Z. flavescens	1	12
N. literatus	2	14	Z. flavescens	6	14	Z. flavescens	9	13
N. literatus	1	18	Z. flavescens	2	12	Z. flavescens	6	14
N. literatus	1	19	C. sordidus	1	12	M. vidua	1	22
N. literatus	1	22	C. sordidus	1	15	M. niger	5	22
N. literatus	1	24	C. sordidus	2	22	C. multicinctus	2	9
C. jactator	1	5	C. sordidus	1	16	C. multicinctus	2	10
C. jactator	1	4	C. sordidus	2	24	Z. cornutus	2	13
Z. flavescens	16	9	C. sordidus	1	20	S. marginatus	2	9
Z. flavescens	3	13	C. multicinctus	1	8	S. marginatus	1	11
Z. flavescens	5	11	C. multicinctus	1	10	S. marginatus	1	12
Z. flavescens	5	14	M. niger	7	23	N. literatus	1	26
C. sordidus	2	14	G. varius	1	6	N. literatus	1	19
C. sordidus	2	12	G. varius	1	8	S. balteata	1	14
C. sordidus	1	18	C. jactator	2	6	C. ornatissimus	1	15
T. duperrey	2	8	S. bursa	1	13	F. commersonii	1	70
T. duperrey	3	10	P. arcatus	1	9	F. commersonii	1	55
T. duperrey	4	12	M. niger	1	17	C. imparipennis	1	4
C. thompsoni	6	13	Z. cornutus	1	14	D. hystrix	1	30
P. multifasciatus	1	18	C. hanui	1	5	D. hystrix	1	34
P. evanidus	1	8	A. chinensis	1	30	F. flavissimus	1	13
C. argus	1	20	C. ornatissimus	1	13	C. quadrimaculatu	1	12
C. argus	1	30	N. literatus	1	18	C. sordidus	1	20
C. argus	1	38	A. abdominalis	11	13	C. sordidus	2	12
A. furca	1	25	S. rubroviolaceus	1	17	C. sordidus	1	17
C. ornatissimus	1	11	C. dumerilii	1	18	P. multifasciatus	1	14
C. ornatissimus	2	16	C. dumerilii	1	20	H. ornatissimus	1	13
P. johnstonianus	3	6	P. aspricaudus	1	7	M. grandoculis	1	36
P. johnstonianus	1	7	P. aspricaudus	1	9	A. abdominalis	15	12
S. rubroviolaceus	2	20	C. verater	5	14	P. insularis	1	16
S. rubroviolaceus	1	43	M. flavolineatus	1	21			
C. auriga	1	17	Z. cornutus	1	14			
A. chinensis	1	50	A. thompsoni	3	14			
C. ovalis	1	12	F. flavissimus	1	12			
A. abdominalis	36	13	F. flavissimus	2	15			
A. vaigiensis	36	13	C. argus	1	52			
L. kasmira	1	21	C. argus	1	50			
G. meleagris	1	58						
M. grandoculis	1	40						
M. grandoculis	2	35						
M. grandoculis	1	30						
M. vidua	1	17						
C. multicinctus	2	8						
C. strigosus	10	6						
C. strigosus	10	8						
C. strigosus	10	10						
P. insularis	1	22						
P. pleurostigma	1	17						
F. commersonii	1	100						
F. commersonii	1	90						
D. hystrix	1	30						

NPPE	5/26/19							
50'			35'			15'		
Species	**Individuals**	**Size (cm)**	**Species**	**Individuals**	**Size (cm)**	***Species***	**Individuals**	**Size (cm)**
Z. flavescens	3	8	*C. strigosus*	10	10	*A. guttatus*	12	15
Z. flavescens	3	11	*C. strigosus*	15	12	*A. guttatus*	12	18
Z. flavescens	4	7	*C. strigosus*	10	14	*A. nigrofuscus*	8	9
Z. flavescens	8	9	*C. strigosus*	9	8	*A. nigrofuscus*	4	14
Z. flavescens	1	13	*T. duperrey*	1	8	*A. nigrofuscus*	9	10
Z. flavescens	1	14	*T. duperrey*	1	9	*C. strigosus*	10	10
Z. flavescens	1	15	*T. duperrey*	2	5	*C. strigosus*	10	14
A. nigrofuscus	6	6	*T. duperrey*	1	12	*C. strigosus*	9	12
A. nigrofuscus	5	8	*T. duperrey*	1	14	*C. strigosus*	6	14
A. nigrofuscus	4	10	*A. nigrofuscus*	9	8	*Z. flavescens*	10	13
C. strigosus	2	8	*A. nigrofuscus*	1	4	*Z. flavescens*	10	15
C. strigosus	4	10	*A. nigrofuscus*	10	10	*T. duperrey*	2	11
C. strigosus	5	12	*P. johnstonianus*	1	6	*T. duperrey*	1	12
C. strigosus	1	13	*C. sordidus*	1	26	*T. duperrey*	1	6
C. sordidus	1	26	*C. sordidus*	2	18	*T. duperrey*	1	8
C. sordidus	1	11	*C. sordidus*	1	20	*T. duperrey*	4	4
C. sordidus	3	16	*C. sordidus*	4	13	*T. duperrey*	1	14
C. sordidus	2	18	*C. sordidus*	1	22	*C. vanderbilti*	7	2
C. argus	1	26	C. lunula	1	13	*C. vanderbilti*	12	3
C. ornatissimus	2	14	*Z. flavescens*	6	13	*C. vanderbilti*	27	4
G. varius	1	5	*Z. flavescens*	5	14	*N. literatus*	2	18
G. varius	1	7	*Z. flavescens*	1	10	*Z. cornutus*	2	18
T. duperrey	1	11	*P. arcatus*	1	9	*M. niger*	1	18
T. duperrey	1	7	*S. bursa*	1	15	*M. niger*	2	20
T. duperrey	1	13	*S. bursa*	1	16	*C. ornatissimus*	2	16
T. duperrey	1	8	*C. jactator*	1	4	*H. ornatissimus*	1	6
C. multicinctus	4	10	*G. varius*	2	10	M. vidua	1	21
C. multicinctus	4	8	*G. varius*	2	6	*H. ornatissimus*	1	5
C. multicinctus	2	9	*N. literatus*	1	25	*M. favolineatus*	124	24
P. multifasciatus	1	12	*P. multifasciatus*	1	20	*C. multicinctus*	1	11
N. literatus	1	16	*P. multifasciatus*	1	16	*P. insularis*	1	16
N. literatus	1	18	*C. multicinctus*	2	10	*P. insularis*	1	14
N. literatus	2	10	*C. multicinctus*	1	9	*M. grandoculis*	1	36
N. literatus	3	12	*M. favolineatus*	27	24	*C. hawaiiensis*	1	19
P. arcatus	2	9	*M. niger*	1	19	*C. hawaiiensis*	7	20
P. arcatus	1	10	*C. vanderbilti*	25	2	*C. hawaiiensis*	5	16
C. hanui	1	5	*C. vanderbilti*	30	3	*A. leucopareius*	9	14
H. ornatissimus	1	11	*C. vanderbilti*	30	4	*A. chinensis*	1	38
P. johnstonianus	2	6	*H. ornatissimus*	1	11	*F. flavissimus*	1	13
C. agilis	16	6	*H. ornatissimus*	1	10	*C. sordidus*	1	16
C. agilis	28	4	*H. ornatissimus*	2	12	*C. sordidus*	1	20
C. agilis	15	5	*A. abdominalis*	50	15	*C. sordidus*	1	27
L. phthirophagus	1	8	*A. vaigiensis*	20	15	*M. burdti*	6	16
L. phthirophagus	1	5	*A. olivaceus*	1	22			
P. forestri	1	10	*C. ornatissimus*	1	14			
C. vanderbilti	8	3	*C. auriga*	5	15			
C. vanderbilti	5	4	*M. grandoculis*	1	28			

12 Pipe North	5/26/19									
50'				35'				15'		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**
T. duperrey	1	8		*N. literatus*	2	22		*Z. flavescens*	8	10
T. duperrey	1	7		*N. literatus*	1	17		*Z. flavescens*	14	14
A. nigrofuscus	4	8		*N. literatus*	1	23		*Z. flavescens*	11	13
A. nigrofuscus	10	10		*N. literatus*	7	21		*C. hawaiiensis*	2	18
A. nigrofuscus	8	12		*Z. flavescens*	10	12		*C. hawaiiensis*	1	16
C. strigosus	2	10		*Z. flavescens*	5	16		*C. hawaiiensis*	5	15
Z. flavescens	8	14		*Z. flavescens*	28	13		*C. hawaiiensis*	4	20
Z. flavescens	4	12		*Z. flavescens*	8	15		*A. nigrofuscus*	3	14
Z. flavescens	6	10		*Z. flavescens*	1	12		*A. nigrofuscus*	1	11
C. sordidus	1	40		*C. strigosus*	7	10		*Z. cornutus*	4	15
C. sordidus	1	28		*C. strigosus*	5	11		*P. insularis*	1	14
C. sordidus	10	14		*C. strigosus*	6	8		*A. achilles*	1	11
C. sordidus	15	18		*C. strigosus*	1	14		*C. vanderbilti*	10	4
C. sordidus	16	20		*A. nigroris*	6	11		*C. vanderbilti*	12	3
C. sordidus	5	28		*S. bursa*	1	18		*N. literatus*	1	21
C. multicinctus	2	11		*S. rubroviolaceus*	1	22		*C. sordidus*	1	28
C. vanderbilti	30	2		*C. multicinctus*	2	10		*C. sordidus*	2	13
C. vanderbilti	11	4		*C. jactator*	1	6		*C. sordidus*	3	12
C. vanderbilti	27	3		*C. sordidus*	20	25		*C. sordidus*	3	15
N. literatus	1	29		*C. sordidus*	30	16		*C. sordidus*	1	24
N. literatus	1	24		*C. sordidus*	1	30		*T. duperrey*	3	12
N. literatus	1	21		*C. sordidus*	20	15		*T. duperrey*	1	9
Z. corntus	1	16		*C. sordidus*	16	20		*T. duperrey*	1	8
C. agilis	12	5		*C. sordidus*	17	18		*T. duperrey*	1	6
C. multicinctus	2	11		*T. duperrey*	3	8		*H. ornatissimus*	1	12
H. ornatissimus	1	7		*T. duperrey*	1	11		*S. bursa*	2	13
H. ornatissimus	1	5		*T. duperrey*	2	4		*S. bursa*	1	12
A. olivaceus	1	19		*T. duperrey*	2	6		*H. polylepis*	30	16
M. vidua	1	22		*T. duperrey*	1	9		*F. flavissimus*	1	12
P. insularis	1	18		*G. varius*	2	11		*C. quadrimaculatus*	1	13
S. bursa	1	15		*G. varius*	1	14		*A. guttatus*	2	15
H. polylepis	1	16		*A. triostegus*	8	13		*M. vanicolensis*	19	18
C. hanui	1	5		*A. nigrofuscus*	4	13		*P. insularis*	1	14
S. spiniferum	1	21		*A. nigrofuscus*	12	10		*M. niger*	5	21
C. jactator	1	4		*A. nigrofuscus*	11	8		*Kyphosus spp.*	4	17
C. jactator	1	6		*C. ornatissimus*	1	12		*Kyphosus spp.*	6	30
N. unicornis	1	28		*C. multicinctus*	2	10		*Kyphosus spp.*	5	28
P. arcatus	2	12		*C. agilis*	1	16		*Kyphosus spp.*	6	24
G. varius	1	8		*A. olivaceus*	1	20		*A. nigrofuscus*	4	12
				H. polylepis	1	13		*A. nigrofuscus*	4	10
				H. polylepis	1	10		*C. strigosus*	14	12
				H. polylepis	2	12		*C. ornatissimus*	1	13
				A. guttatus	1	14		*A. olivaceus*	1	18
				P. multifasciatus	1	17		*M. kuntee*	4	17
				Z. corntus	2	14		*Z. veliferum*	1	21
				S. marginatus	1	8		*Z. veliferum*	1	27
								A. abdominalis	4	14

12 Pipe South 5/26/19

50'

Species	Individuals	Size (cm)
A. nigrofuscus	14	6
A. nigrofuscus	7	8
A. nigrofuscus	6	10
C. agilis	140	3
C. agilis	150	4
C. agilis	120	5
C. agilis	80	6
C. strigosus	8	10
C. strigosus	12	8
C. strigosus	15	7
C. strigosus	8	5
C. vanderbiliti	18	2
C. vanderbiliti	20	3
N. literatus	2	26
N. literatus	1	18
N. literatus	1	20
T. duperrey	1	10
T. duperrey	1	13
T. duperrey	2	11
S. bursa	1	14
S. bursa	1	6
C. sordidus	1	22
C. sordidus	2	24
C. sordidus	1	18
G. varius	1	11
G. varius	1	12
P. arcatus	2	9
P. arcatus	1	7
Z. cornutus	1	13
C. quadrimaculatus	2	12
C. argus	1	20
C. argus	1	32
Z. flavescens	7	13
Z. flavescens	1	15
Z. flavescens	13	14
A. olivaceus	1	17
F. flavissimus	3	11
P. insularis	1	16
C. jactator	2	5
C. multicinctus	1	7
C. multicinctus	1	11
C. multicinctus	3	10
C. multicinctus	2	8
C. lunula	1	14
L. phthirophagus	1	6
S. rubroviolaceus	2	28
S. rubroviolaceus	2	32
S. rubroviolaceus	1	40
C. carolinus	1	25
H. polylepis	41	15

35'

Species	Individuals	Size (cm)
A. nigrofuscus	12	9
A. nigrofuscus	10	10
A. nigrofuscus	7	7
A. scriptus	1	29
T. duperrey	1	12
T. duperrey	1	10
T. duperrey	2	9
Z. flavescens	9	12
Z. flavescens	6	14
Z. flavescens	4	16
C. vanderbiliti	13	2
C. vanderbiliti	48	3
C. vanderbiliti	20	4
S. balteata	1	12
C. sordidus	1	21
C. sordidus	1	18
C. sordidus	2	10
C. sordidus	1	28
H. ornatissimus	1	12
H. ornatissimus	2	7
S. bursa	1	13
P. multifasciatus	1	13
Z. cornutus	1	14
C. argus	1	23
G. varius	1	6
P. tetrataenia	2	5
A. olivaceus	1	21
M. vidua	1	20
C. strigosus	6	9
C. strigosus	6	10
A. nigroris	1	16
P. insularis	1	21
P. insularis	1	17
N. unicornis	1	33
N. unicornis	3	28
N. unicornis	1	30
N. unicornis	1	24
A. abdominalis	30	14
L. phthirophagus	1	5
C. agilis	40	4
C. ornatissimus	1	13
C. ornatissimus	1	16
F. flavissimus	1	13
P. cyclostomus	1	30

15'

Species	Individuals	Size (cm)
C. quadrimaculatus	1	9
C. jactator	1	5
G. varius	1	8
G. varius	1	9
A. nigrofuscus	8	9
A. nigrofuscus	5	14
T. duperrey	1	11
T. duperrey	1	12
T. duperrey	1	13
N. literatus	1	16
Z. flavescens	9	12
Z. flavescens	9	15
P. insularis	1	14
C. strigosus	7	11
C. strigosus	10	14
C. vanderbiliti	15	3
C. vanderbiliti	20	4
A. olivaceus	1	17
M. niger	8	16
P. imparipennis	1	3
H. ornatissimus	2	10
H. ornatissimus	1	12
H. ornatissimus	1	13
S. bursa	1	10
S. bursa	2	16
F. flavissimus	1	12
S. balteata	1	9
C. hawaiiensis	5	17
N. literatus	1	16
N. literatus	2	17
Kyphosus spp.	1	20
A. nigricans	1	12
A. blochii	1	33
A. achilles	1	7
P. multifasciatus	1	16
Z. flavescens	4	7
Z. flavescens	4	12
Z. flavescens	4	10
S. psittacus	1	21
C. amboinensis	1	7
M. kuntee	3	14
M. kuntee	17	14
P. ewaensis	1	5

PLANB CONSULTANCY

18	5/27/19									
50'				35'				15'		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**
T. duperrey	17	10		*N. literatus*	1	19		*A. nigrofuscus*	9	10
T. duperrey	3	8		*C. agilis*	2	4		*A. nigrofuscus*	4	7
C. potteri	1	6		*C. agilis*	1	6		*A. nigrofuscus*	6	12
C. potteri	1	8		*C. vanderbiliti*	46	2		*A. nigrofuscus*	2	9
C. gaimard	4	6		*C. vanderbiliti*	54	3		*C. strigosus*	6	9
C. gaimard	4	9		*C. vanderbiliti*	10	4		*C. strigosus*	9	10
C. gaimard	1	12		*T. duperrey*	2	4		*C. strigosus*	4	16
C. gaimard	1	8		*T. duperrey*	1	11		*N. literatus*	1	17
C. agilis	35	4		*T. duperrey*	1	12		*N. literatus*	1	22
A. nigrofuscus	12	6		*T. duperrey*	2	7		*C. hawaiiensis*	2	18
A. nigrofuscus	12	8		*G. varius*	1	6		*C. hawaiiensis*	1	20
A. nigrofuscus	15	10		*H. ornatissimus*	2	6		*C. hawaiiensis*	1	26
C. vanderbiliti	60	2		*H. ornatissimus*	2	8		*C. hawaiiensis*	1	28
C. vanderbiliti	60	3		*H. ornatissimus*	6	5		*T. duperrey*	1	5
C. vanderbiliti	60	4		*A. nigrofuscus*	6	5		*T. duperrey*	5	6
Z. flavescens	1	5		*A. nigrofuscus*	8	6		*T. duperrey*	14	8
Z. flavescens	2	13		*A. nigrofuscus*	6	8		*T. duperrey*	2	15
Z. flavescens	1	14		*A. nigrofuscus*	5	10		*C. multicinctus*	1	8
L. phthirophagus	1	7		*Z. flavescens*	2	11		*G. varius*	1	8
C. jactator	2	4		*Z. flavescens*	3	12		*H. ornatissimus*	1	6
C. jactator	2	7		*Z. flavescens*	1	14		*H. ornatissimus*	3	8
C. jactator	1	5		*P. multifasciatus*	1	14		*H. ornatissimus*	1	10
C. hanui	1	5		*C. argus*	1	30		*C. sordidus*	1	12
P. octotaenia	1	8		*C. sordidus*	1	17		*C. sordidus*	2	14
P. octotaenia	1	10		*C. jactator*	1	4		*C. sordidus*	10	15
C. multicinctus	1	4		*C. jactator*	1	3		*C. sordidus*	9	17
S. bursa	1	17		*C. jactator*	3	6		*C. lunula*	7	14
S. bursa	1	14		*S. bursa*	1	16		*C. vanderbiliti*	50	2
A. olivaceus	2	22		*F. flavissimus*	2	10		*C. vanderbiliti*	65	3
C. strigosus	1	9		*F. flavissimus*	1	13		*C. vanderbiliti*	50	4
C. strigosus	4	6		*P. evanidus*	1	7		*M. kuntee*	6	13
C. strigosus	3	4						*M. kuntee*	3	15
H. ornatissimus	2	8						*S. rubroviolaceus*	1	42
H. ornatissimus	1	12						*S. rubroviolaceus*	1	36
G. varius	1	10						*L. phthirophagus*	1	6
G. varius	1	7						*Z. flavescens*	8	10
P. multifasciatus	1	8						*Z. flavescens*	12	12
P. multifasciatus	1	16						*Z. flavescens*	12	14
P. arcatus	1	9						*Z. flavescens*	10	9
N. literatus	1	21						*Kyphosus spp.*	1	18
N. literatus	1	27						*Kyphosus spp.*	1	24
C. sordidus	1	15						*Kyphosus spp.*	2	25
S. balteata	1	8						*M. niger*	7	20
S. balteata	2	9						*M. niger*	11	21
P. ewaensis	1	6						*M. niger*	12	24
M. geoffroy	1	6						*M. vidua*	8	17
S. diabolus	1	23						*A. nigroris*	4	14
								P. arcatus	1	12
								P. arcatus	1	11
								C. jactator	1	6
								P. octotaenia	1	8
								F. commersonii	1	115
								F. flavissimus	3	14
								N. hexacanthus	1	36
								S. psittacus	1	23
								A. leucopareius	1	17
								A. leucopareius	2	16
								C. amboinensis	1	11
								S. balteata	1	6
								S. balteata	2	8

Wawa	5/26/19									
50'				35'				15'		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**
P. tetrataenia	1	6		*C. vanderbiliti*	32	2		*A. nigrofuscus*	7	12
T. duperrey	1	11		*C. vanderbiliti*	30	3		*A. nigrofuscus*	10	13
T. duperrey	2	8		*C. vanderbiliti*	39	4		*A. nigrofuscus*	12	10
I. pavo	1	17		*Z. flavescens*	6	13		*T. duperrey*	3	14
I. pavo	2	14		*Z. flavescens*	6	15		*T. duperrey*	1	13
C. vanderbiliti	15	2		*T. duperrey*	2	5		*T. duperrey*	1	16
C. vanderbiliti	17	3		*T. duperrey*	1	7		*T. duperrey*	1	10
C. vanderbiliti	15	4		*T. duperrey*	1	12		*T. duperrey*	4	7
S. bursa	1	21		*T. duperrey*	2	10		*T. duperrey*	1	5
C. gaimard	1	5		*A. nigrofuscus*	1	14		*Z. flavescens*	6	13
P. octotaenia	1	4		*C. melampygus*	1	26		*Z. flavescens*	12	14
	2	7		*S. bursa*	1	16		*N. literatus*	1	22
				S. bursa	1	12		*S. bursa*	1	16
				A. olivaceus	1	24		*C. vanderbiliti*	20	3
				A. olivaceus	2	18		*A. chinensis*	1	42
				N. literatus	1	22		*P. multifasciatus*	1	17
				H. ornatissimus	1	18		*C. quadrimaculatus*	3	13
				H. ornatissimus	3	11		*Z. cornutus*	1	15
				P. octotaenia	1	10		*Z. cornutus*	1	14
				A. olivaceus	2	16		*C. hawaiiensis*	6	18
				G. varius	1	6		*C. hawaiiensis*	1	14
				A. nigroris	2	15		*C. hawaiiensis*	1	16
				A. nigroris	1	18		C. melampygus	1	24
				C.	2	13		*A. triostegus*	2	14
				M. niger	1	21		*N. literatus*	2	22
				M. vidua	1	21		A. leucopareius	3	14
								M. niger	3	21
								M. niger	4	24
								C. ephippium	2	16

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

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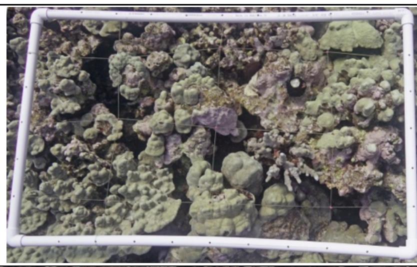
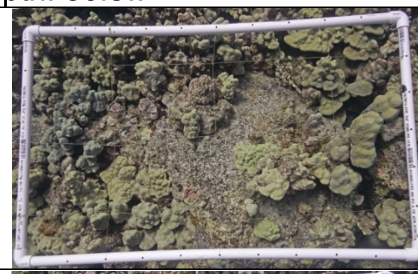
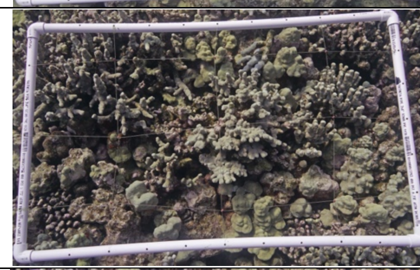
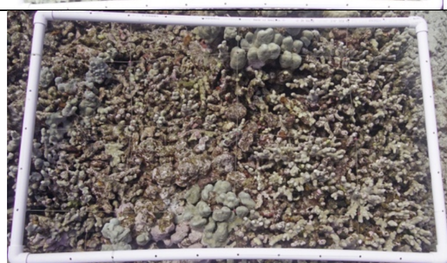
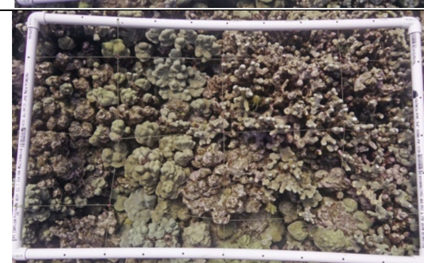
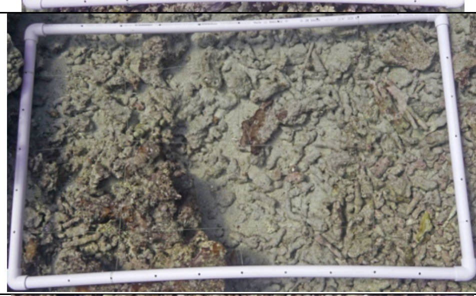
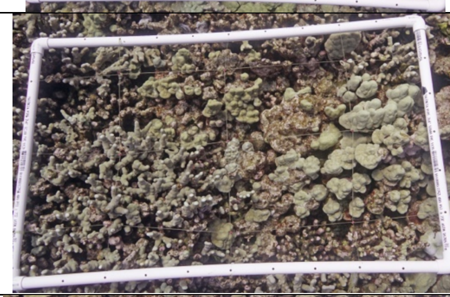
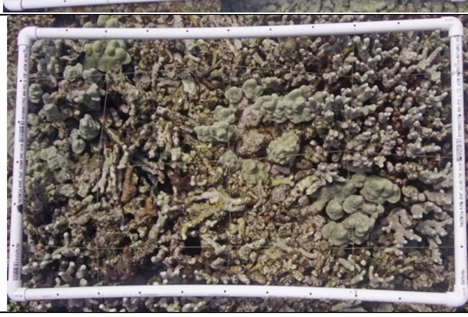
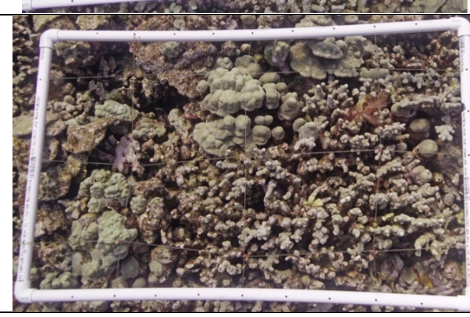
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
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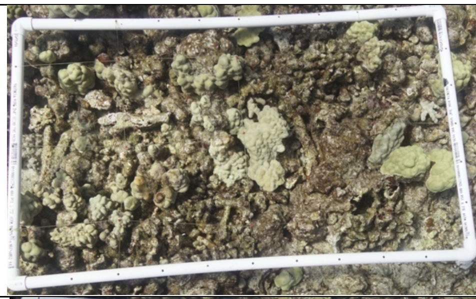	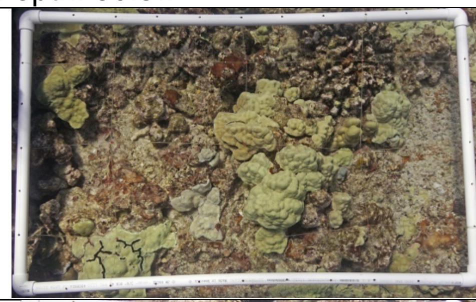
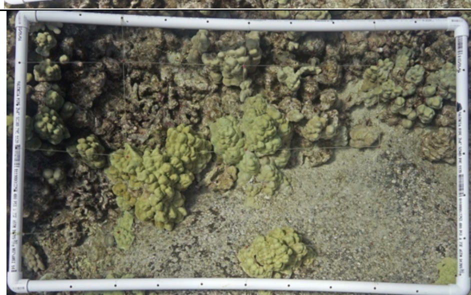	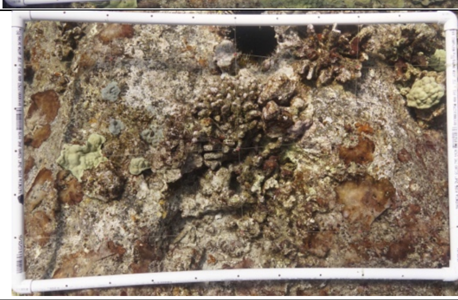
	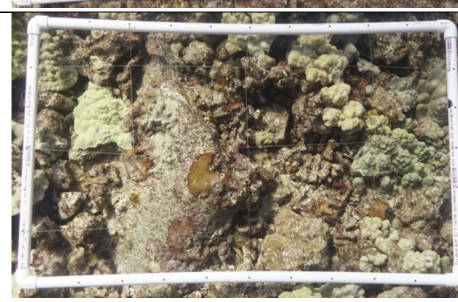
	
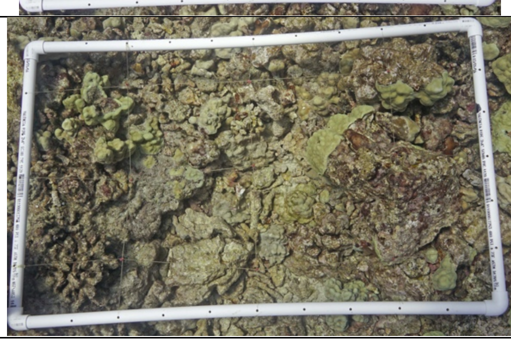	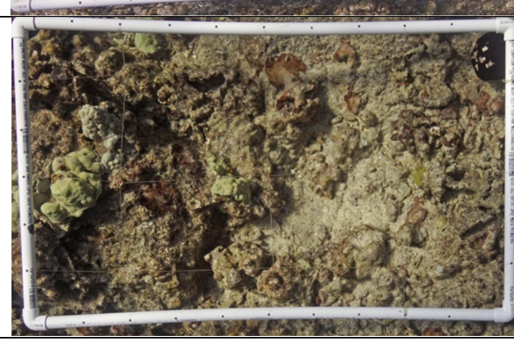

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	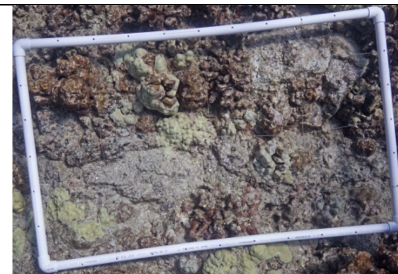
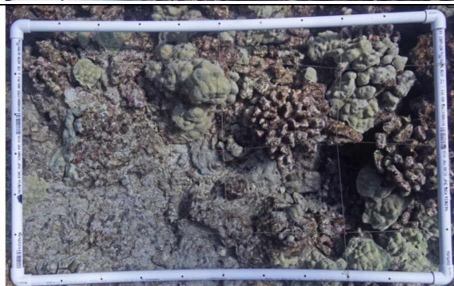	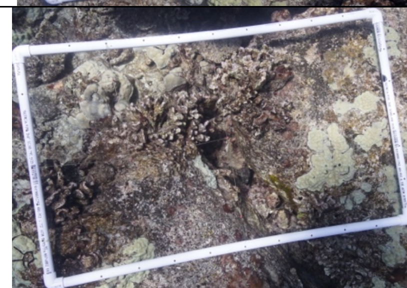
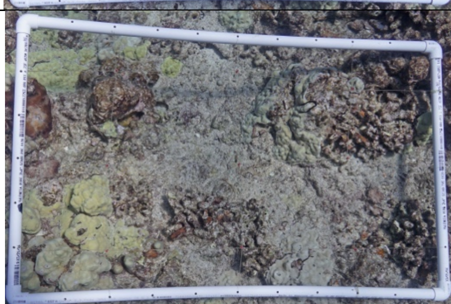	
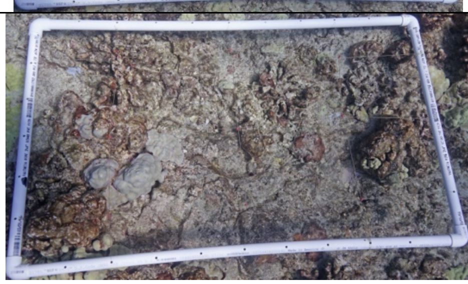	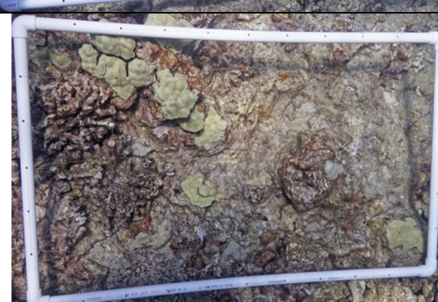
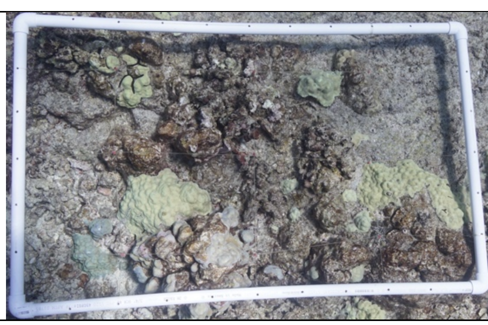	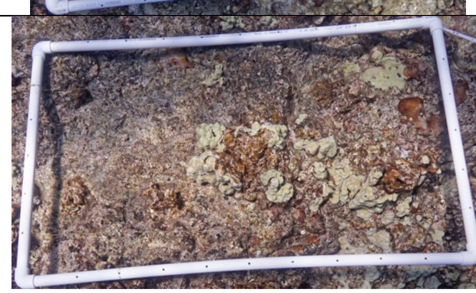

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	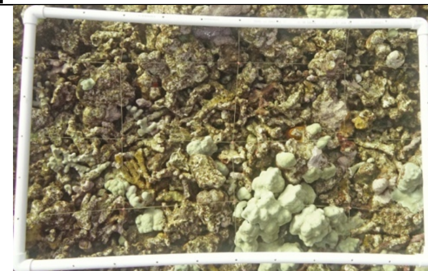
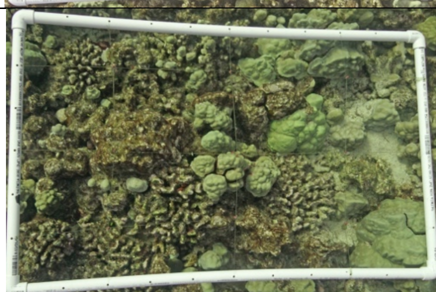	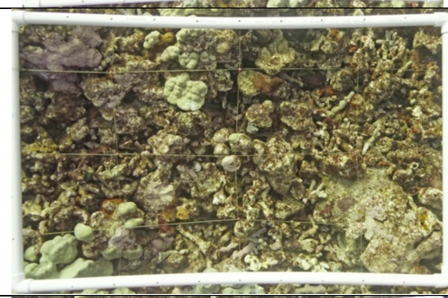
	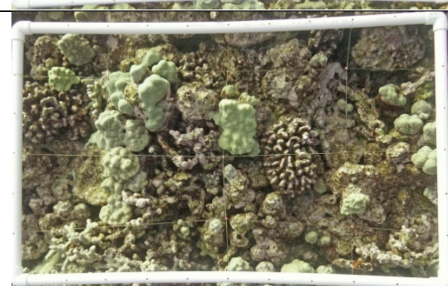
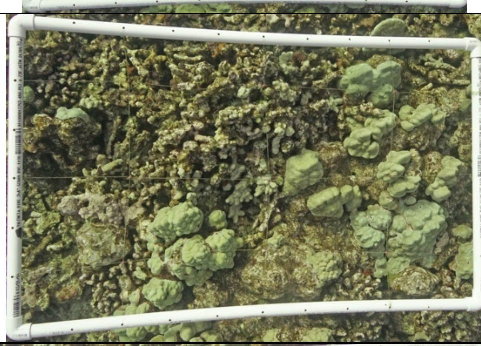	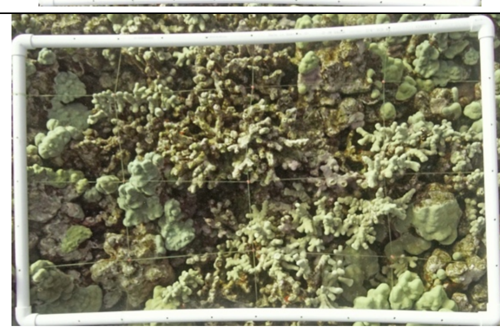
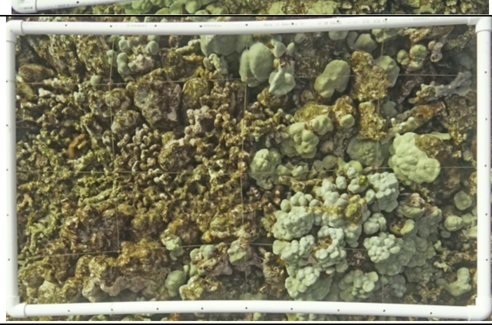	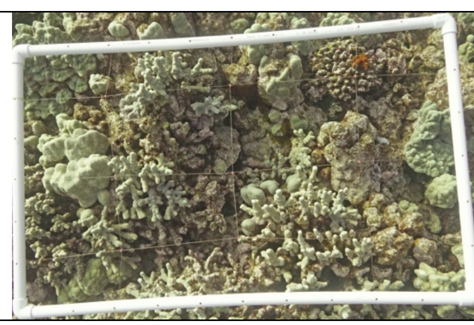

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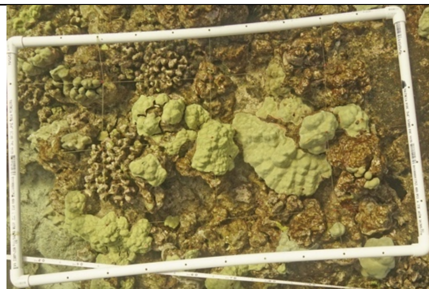	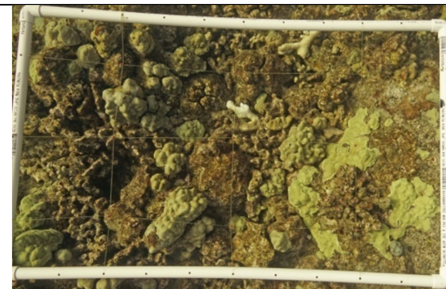
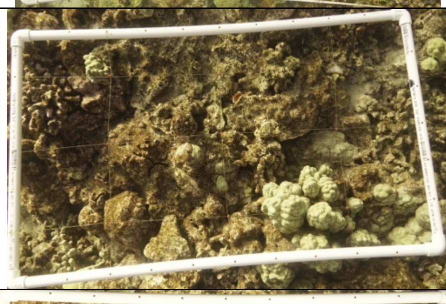	
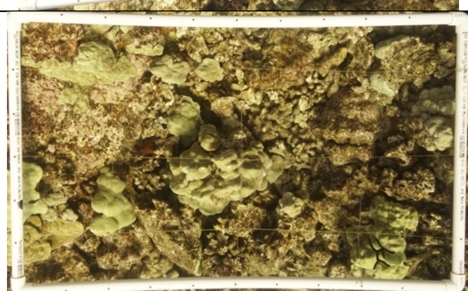	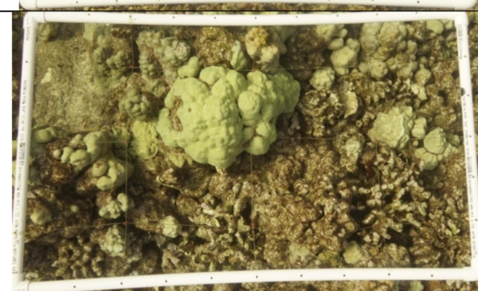
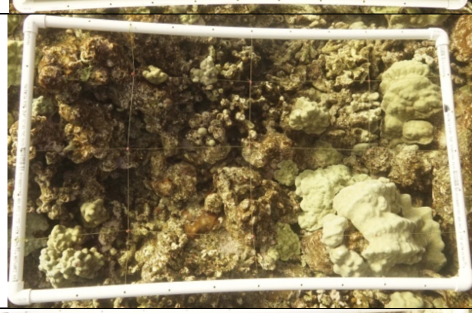	
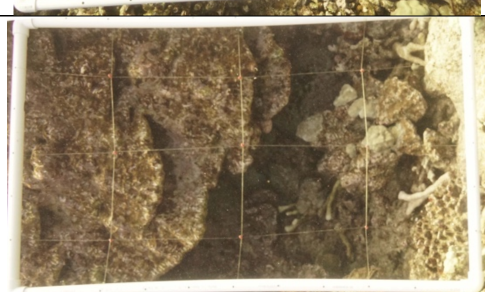	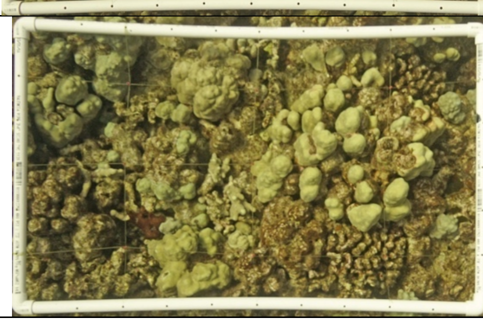

PLANB CONSULTANCY

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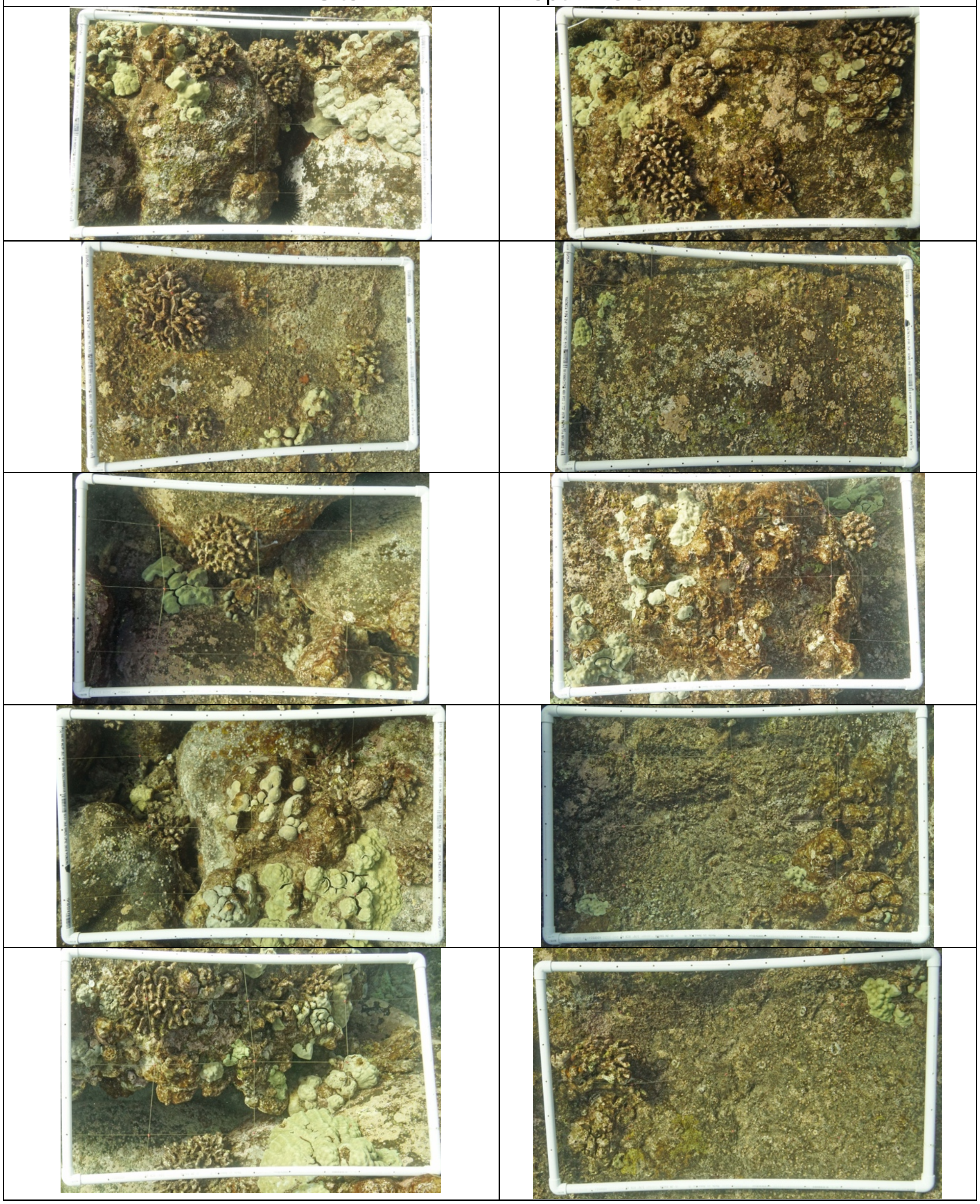

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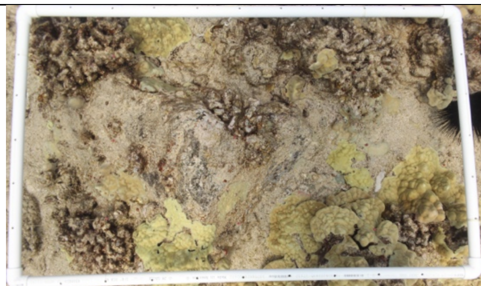	
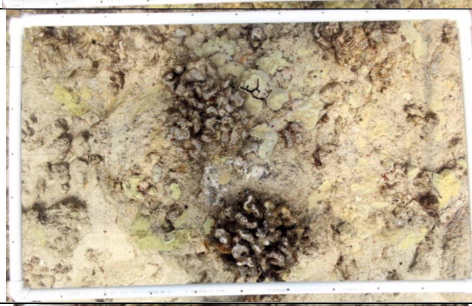	
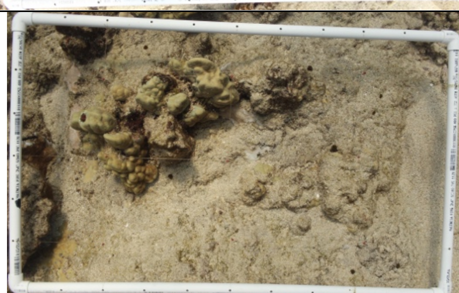	
	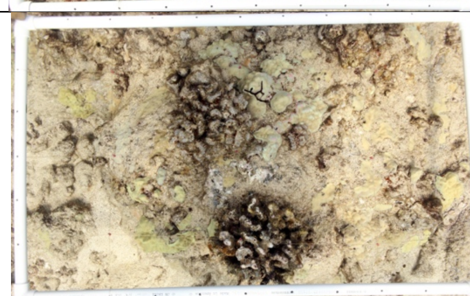
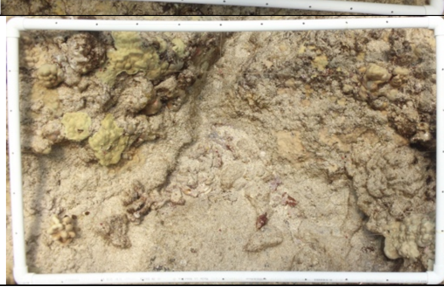	

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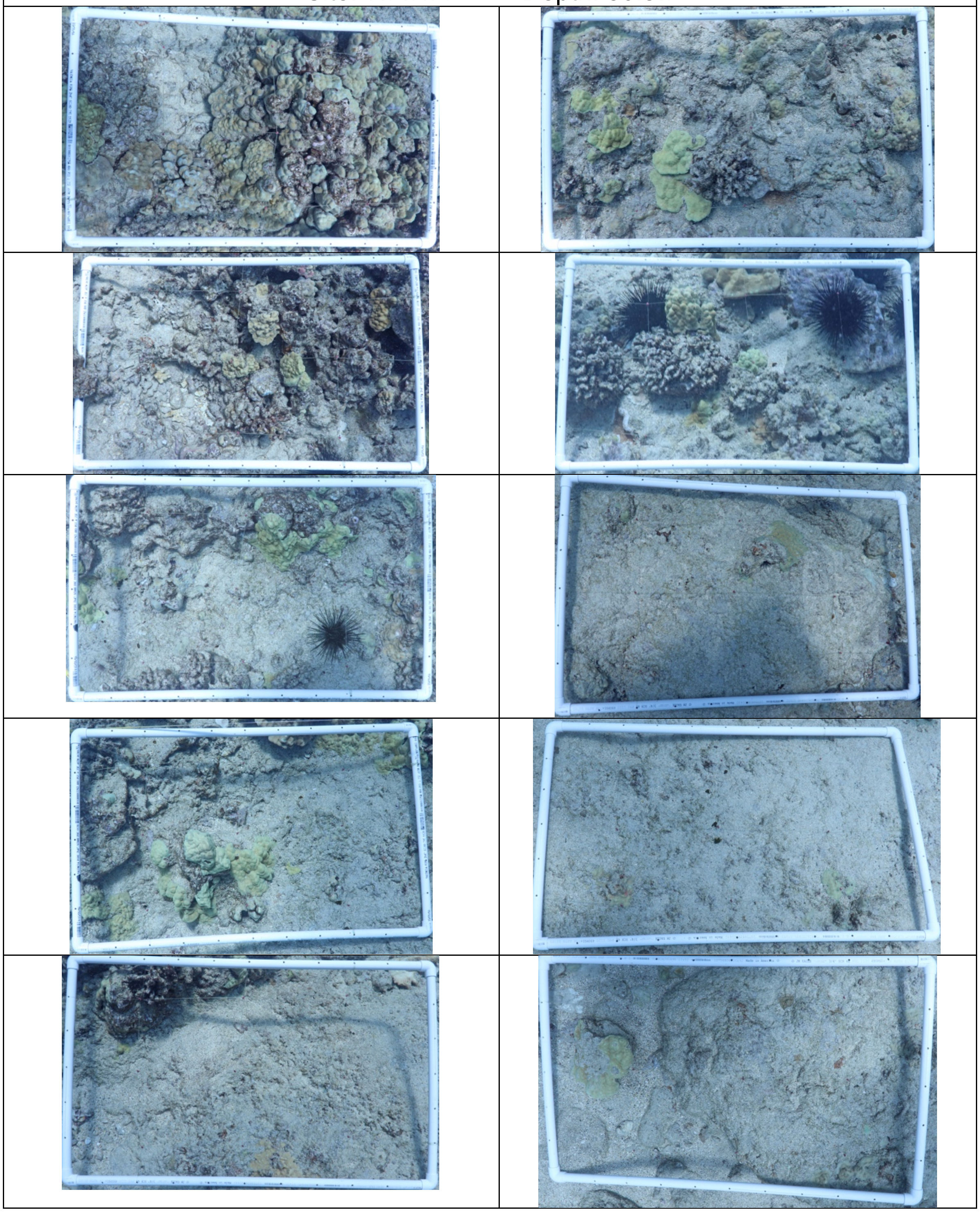

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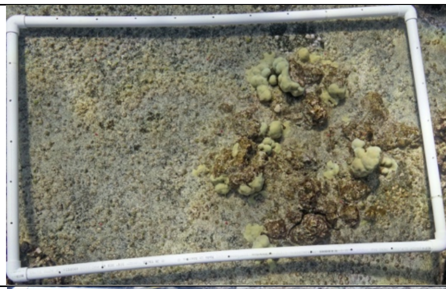	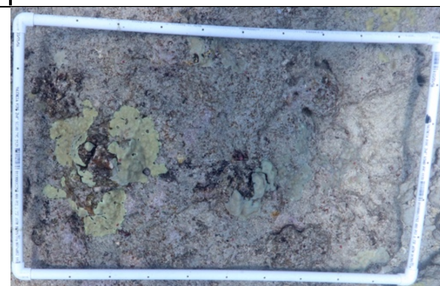
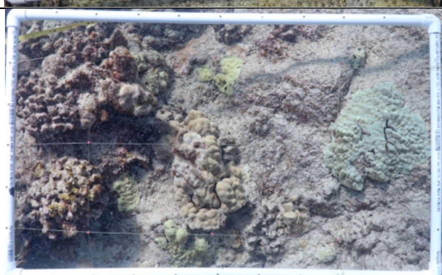	
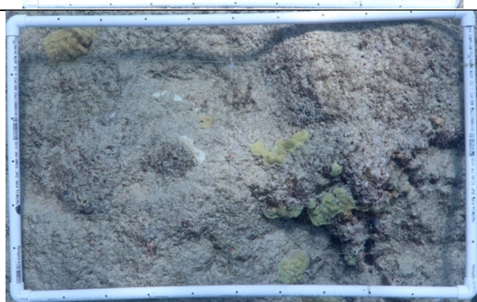	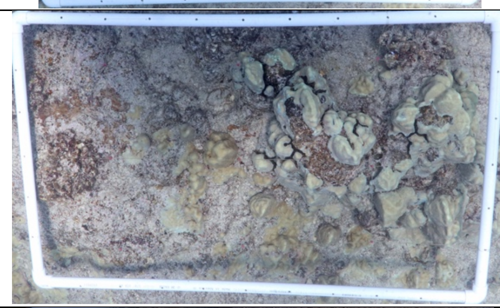
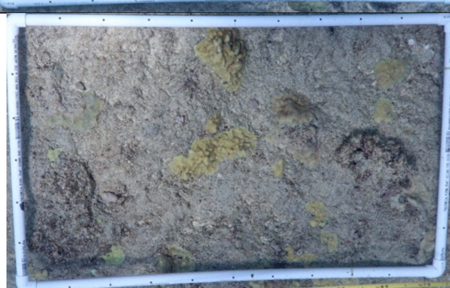	
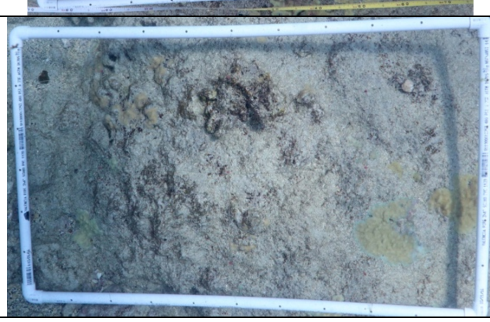	

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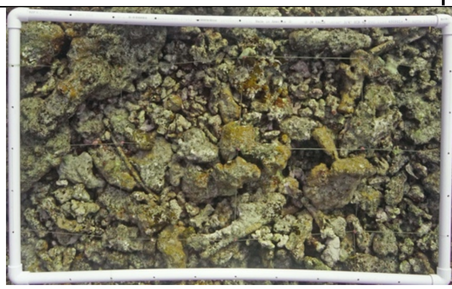
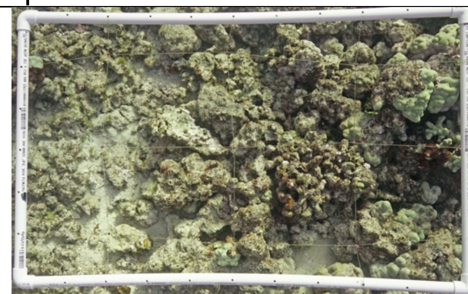
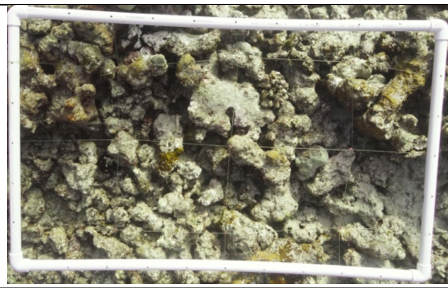
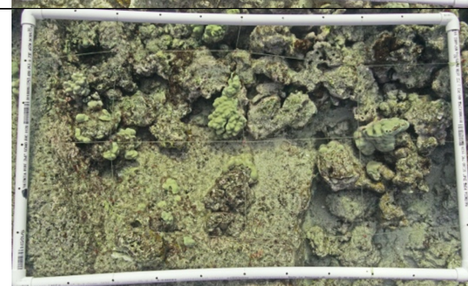
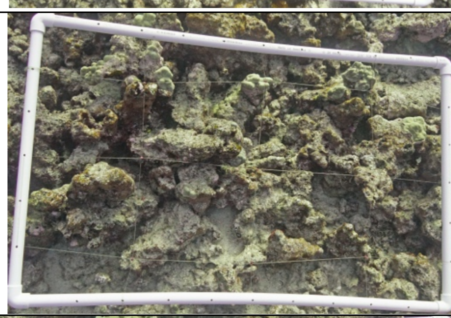
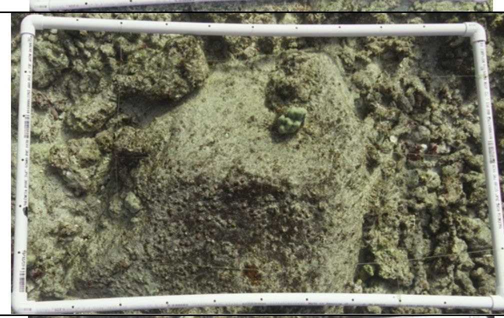
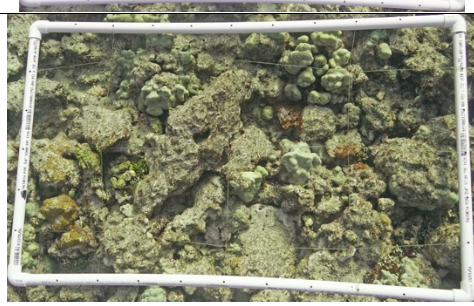
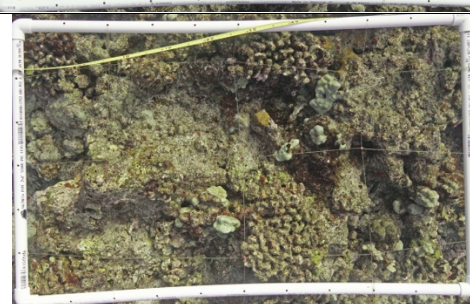
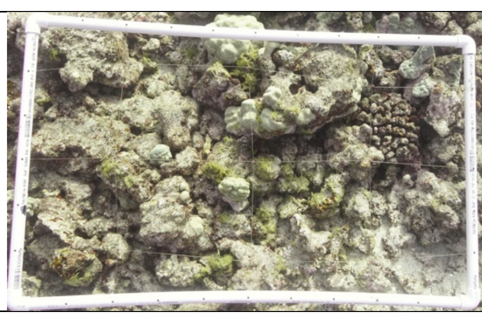
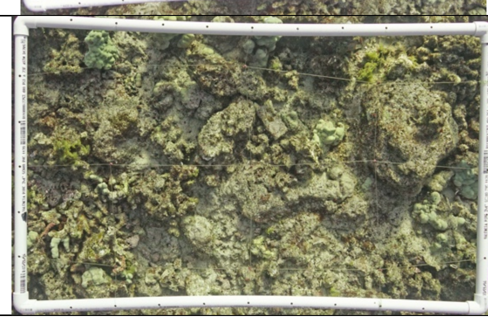
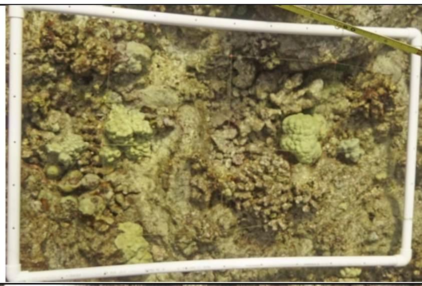
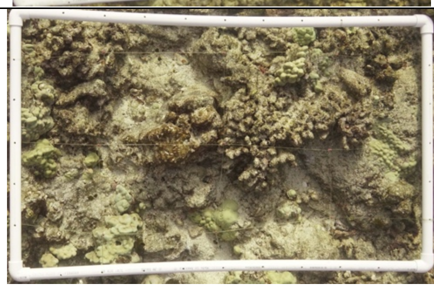
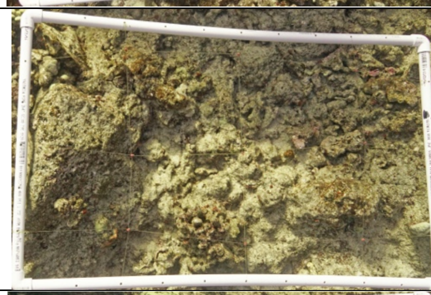
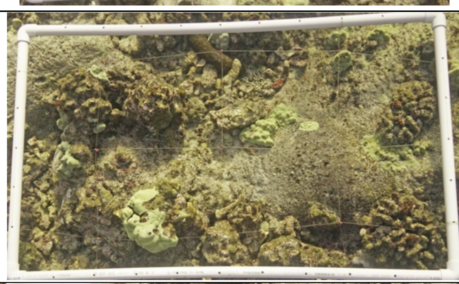
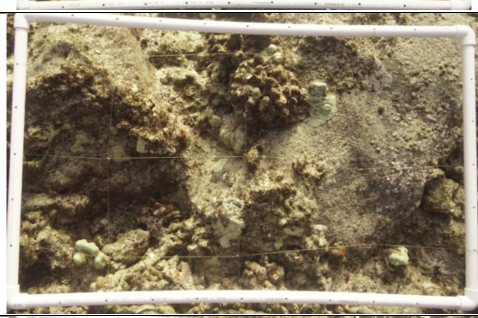
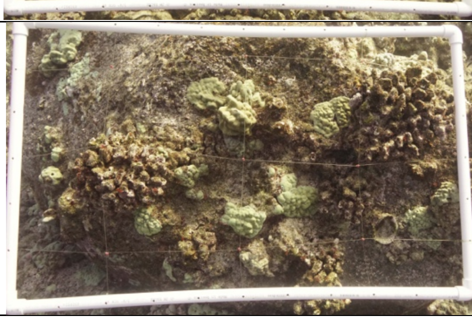
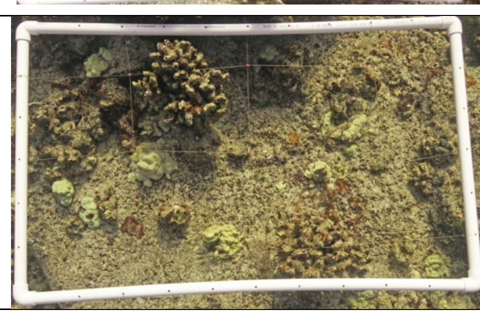
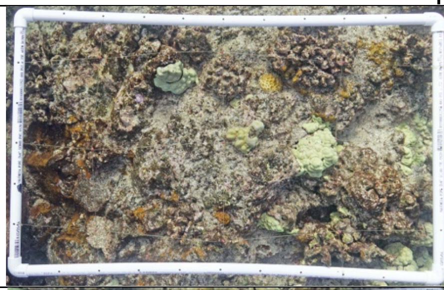
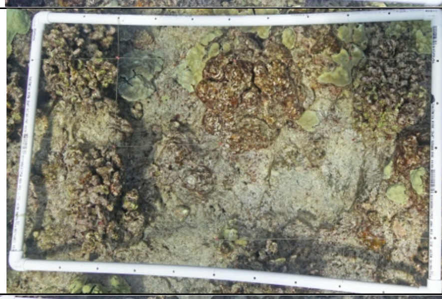
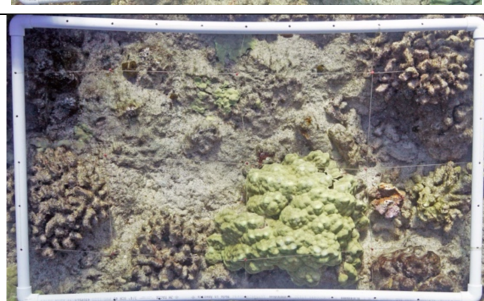
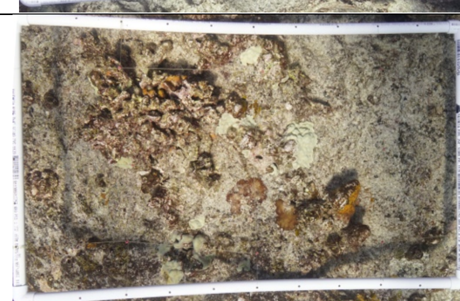
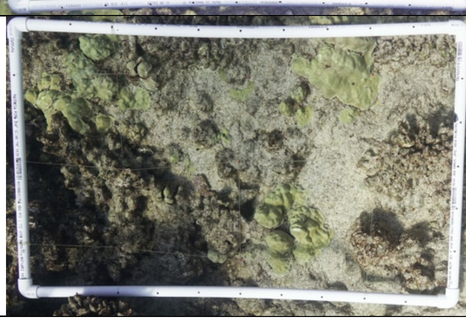
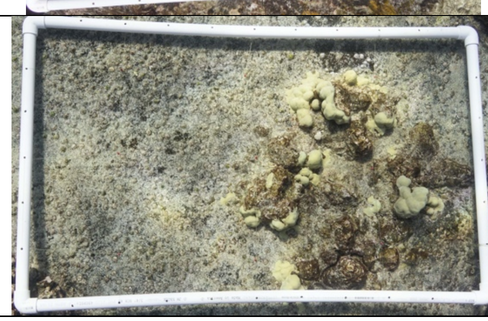
	
	
	
	
	

Site: 18 Pipe	Depth: 30fsw
	
	
	
	
	

Site: 18 Pipe	Depth: 15fsw
	
	
	
	
	

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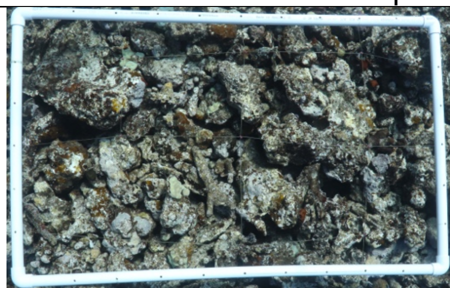
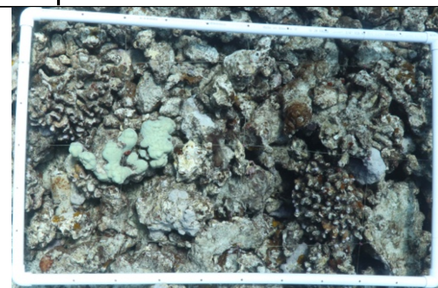
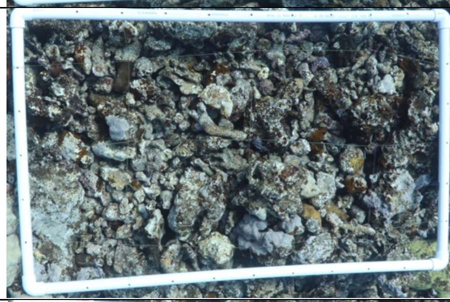
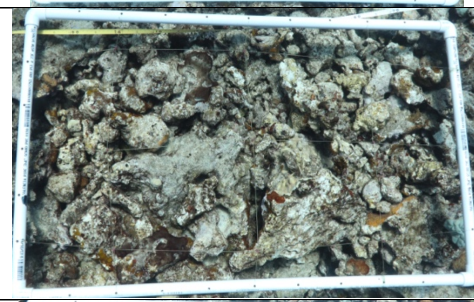
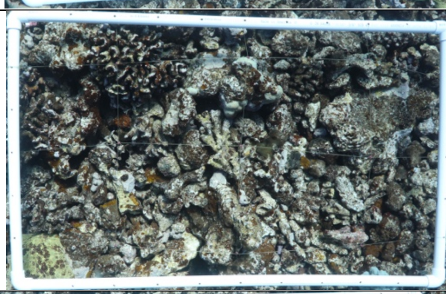
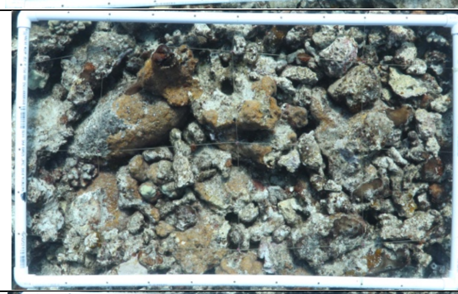
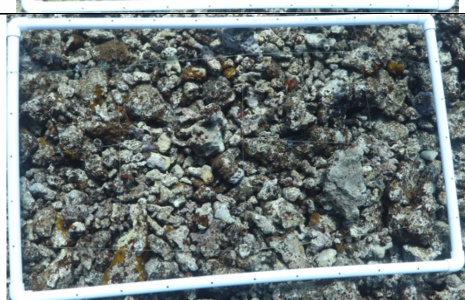
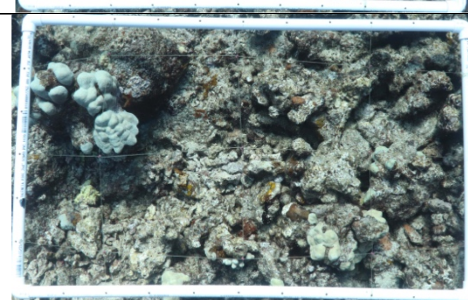
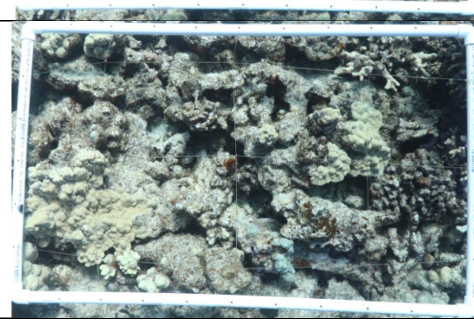
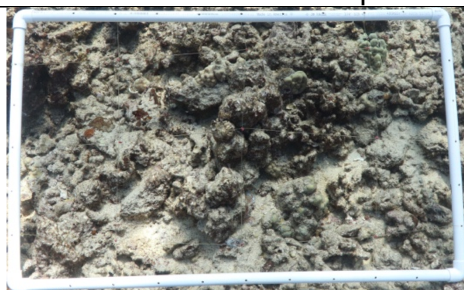
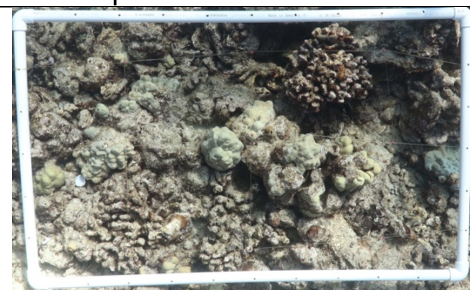
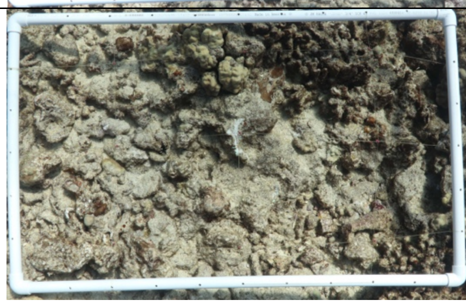
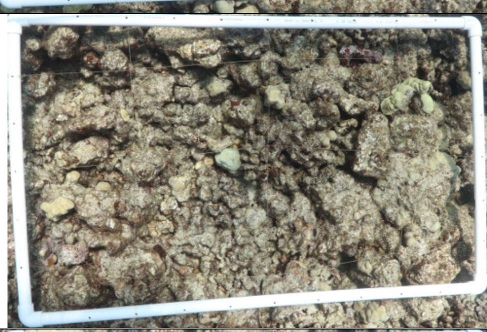
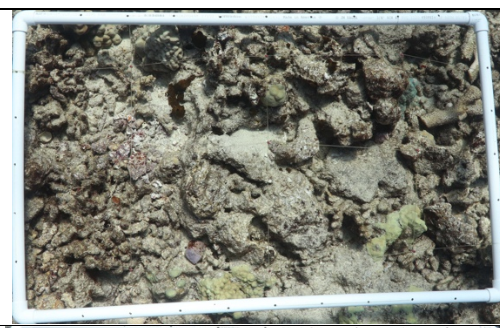
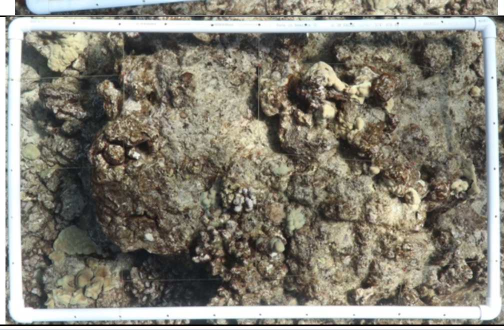
	
	
	
	
	

Site: 12 Pipe South	Depth: 30fsw
	
	
	
	
	

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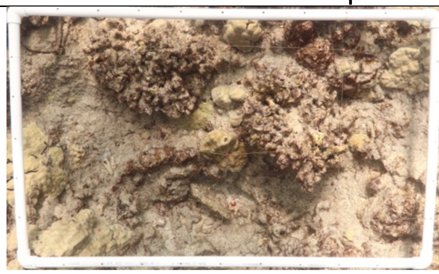
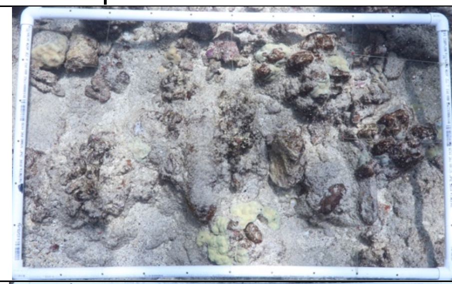
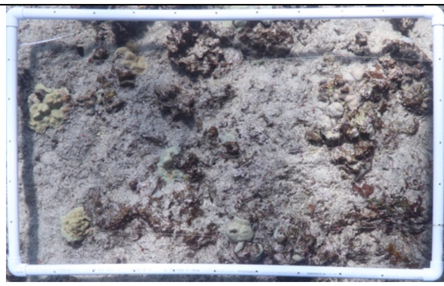
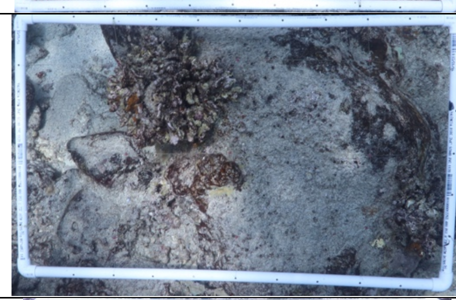
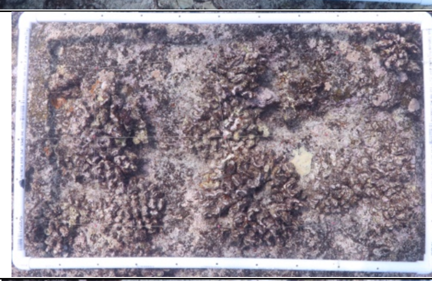
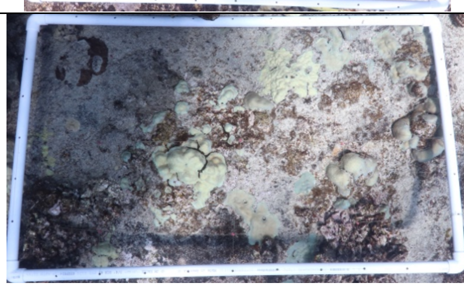
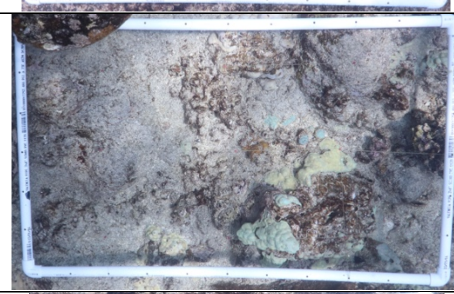
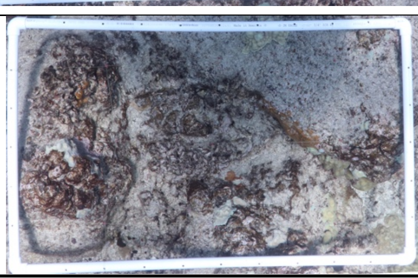
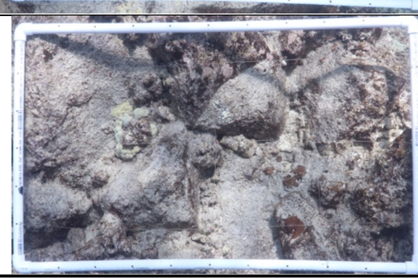
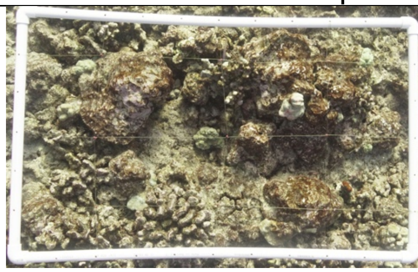
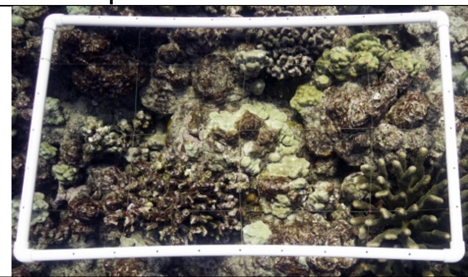
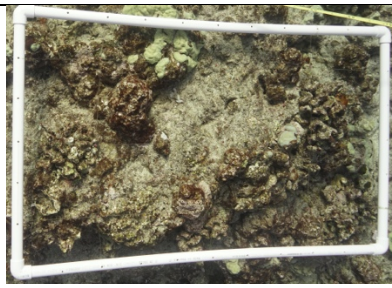
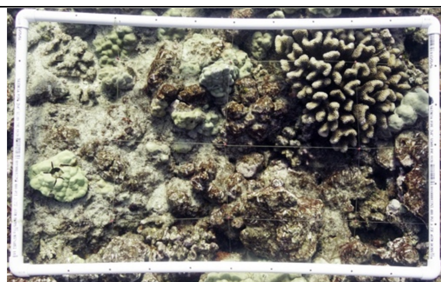
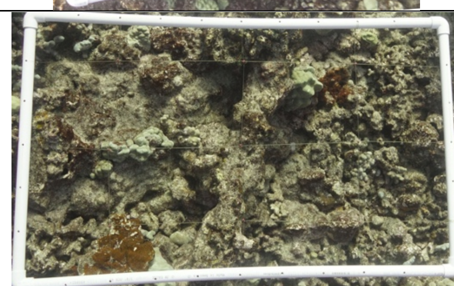
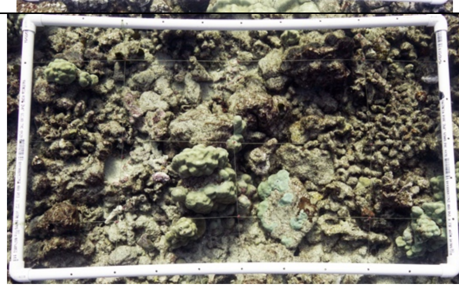
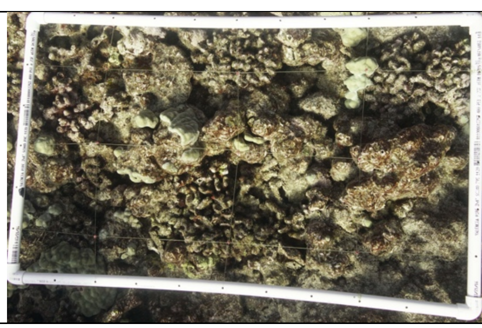
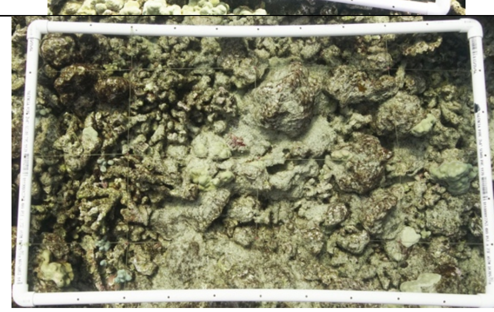
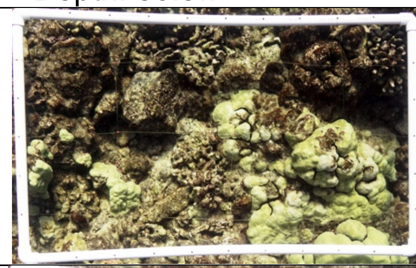
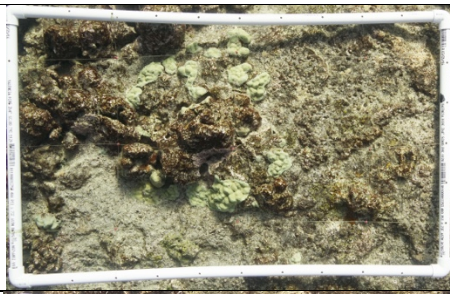
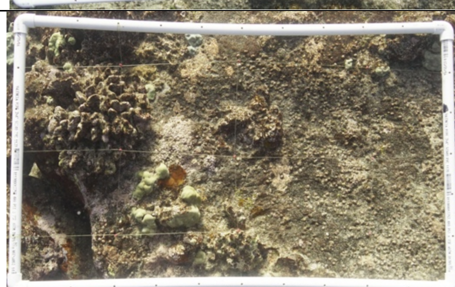
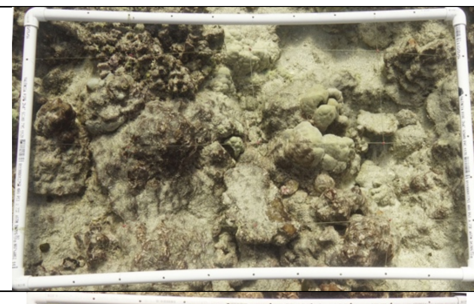
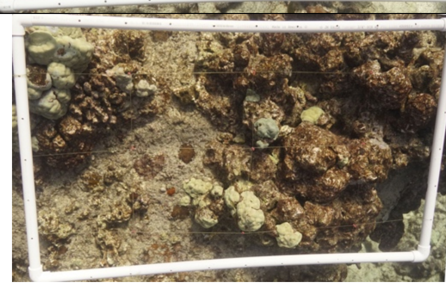
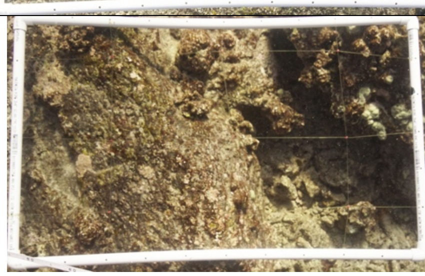
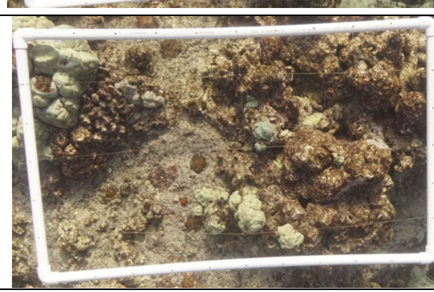
	
	
	
	
	

Site: 12 Pipe North	Depth: 50fsw
	
	
	
	
	

Site: 12 Pipe North	Depth: 30fsw
	
	
	
	
	

Site: 12 Pipe North	Depth: 15fsw