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Benthic and Biota Monitoring Program

Natural Energy Laboratory of Hawaii Authority

Survey Report – 2017

Prepared for:

Natural Energy Laboratory of Hawaii Authority (NELHA)
P. O. Box 1749 Kailua-Kona, HI 96745

Prepared by:

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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 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 45 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 2017 survey.

There are several anchialine pond systems in the vicinity of the NELHA facility. The ponds exist in spatially distinct Northern and Southern systems. The North system supports five unique ponds, and the South system supports ten unique ponds. This report details the faunal census conducted in each pond in April and May 2017. Physical parameters were measured (e.g., temperature, salinity, conductivity, pH) in conjunction with surveys of flora and fauna in each pond. The surveys were supplemented with digital images to provide a visual record of the pond systems.

The results of the 2017 anchialine pond survey were generally consistent with previous annual surveys, with variances detailed in the following report. Faunal surveys indicated that almost all anchialine ponds without introduced fish present supported communities of native organisms, including ‘ōpae ‘ula (*Halocaridina rubra*). Similar to previous surveys, anchialine ponds with introduced fish present had minimal turbidity (visually assessed) and minimal overgrowth by invasive algae. This suggests that current water quality conditions are consistent with previous conditions (nutrient pollution has not occurred), and/or that normal grazing activities have continued within the ponds, perhaps nocturnally.

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 gradients (~15-fsw, ~30fsw, and ~50fsw) 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 seven years have found the coral cover to stabilize in the range of ~30-50%. The overall coral cover for 2017 was 32.97%, which is within this range and shows the benthic communities to have exhibited relatively consistent values of coral cover for the last eight years. Permanent pins were established this year, which should help to improve our ability to temporally track shifts in benthic composition and structure over time.

Of the overall percent coral cover among the six stations (32.97%), the most dominant corals were *Porites lobata* (17.56%), *Porites compressa* (9.58%), and *Porites evermanni* (6.51%), and *Montipora patula* (3.91%) These corals were present among all the stations. Other corals present were *Pocillopora meandrina, Pocillopora grandis*, *Leptastrea purpurea, Leptastrea bewickensis, Montipora capitata, Montipora flabellata, Pavona varians, Pocillopora eydouxi, Porites rus and Fungia scutaria.* These corals accounted for approximately 5-10% 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 2017 show similar values of abundance, diversity, and biomass to 2016. 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.

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ANCHIALINE POND SURVEY

INTRODUCTION

Anchialine ponds are a unique ecosystem 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 these ponds, with numerous examples at Keāhole Point where the NELHA facility is located. Interest in these ecosystems, previously described by numerous researchers (Holthuis 1973, Maciolek and Brock 1974), stemmed from observations of abundant assemblages of tiny, red shrimp (ʻōpae ʻula) that appeared to be restricted to this particular habitat. Anchialine systems occur globally, and can be found on 30 islands within in 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 ponds 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 influencing anchialine ponds 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 ponds in Hawaiʻi are uniquely suited to the varying salinity conditions. Specialized species include crustaceans, mollusks, plants, and other taxa. Table 1 summarizes the species previously reported from the ponds located within and adjacent to the NELHA facility at Keāhole Point, Hawaiʻi (Brock 2008, Ziemann and Conquest 2008).

Two specialized decapod shrimp species, the endemic *Halocaridina rubra* (ʻōpae ʻula) and indigenous *Metabataeus lohena*, are common inhabitants in many of the anchialine ponds at Keāhole Point. *H. rubra* are omnivorous, and preferentially inhabit anchialine ponds throughout the day to feed on microalgae, macroalgae, and detritus (Bailey-Brock and Brock 1993). Anchialine ponds are typically connected to one another via lava tubes, rock fissures, and micro-cracks in the surrounding basalt substrate, and reproduction and larval dispersal of *H. rubra* generally occur within the subterranean (hypogeal) sections of anchialine systems. *H. rubra* have a relatively long lifespan of approximately 10 - 20 years, and are key grazers within anchialine ponds, maintaining a standing crop of plants, bacteria, diatoms, and protozoans in the ponds through active grazing. This ʻgardeningʼ role contributes to the overall health of anchialine pond ecosystems, allowing for other species to reside within the sunlit (epigeal) portion of the ponds. Because of this critical ecosystem function, *H. rubra* (ʻōpae ʻula) are thought to be a keystone species within these systems (Bailey-Brock and Brock 1993). The relatively larger indigenous shrimp species, *M. lohena*, is also omnivorous, but can also sometimes consume *H. rubra* (Yamamoto *et al.* 2015).

Introduced fish species (e.g. mosquitofish, guppies) are a substantial threat to native species within anchialine ponds, and can cause sharp declines in *H. rubra* abundance due to increased 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 ponds with established populations of introduced fish are not able to support *H. rubra* assemblages during the day in open, epigeal areas.

Anthropogenic alterations associated with coastal development and other shoreline activities can result in negative impacts to anchialine pond ecosystems. Examples include invasive species introductions, physical/structural alterations, and groundwater reduction/ contamination. Additionally, recent sea-level forecast models suggest that anchialine ponds on Hawaiʻi Island and throughout the state may form larger pool complexes and/or have a more frequent surface connection to the ocean in the coming decades (Marrack and O'Grady 2014). Additionally, new anchialine ponds may be created further inshore, depending on substrate elevation. These anticipated changes associated with sea-level rise forecast dramatic impacts on anchialine pond ecology. Fortunately, submarine connections between ponds will likely allow *H. rubra* to populate new higher elevation ponds.

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 ponds in Hawaiʻi (Santos 2006). A study to understand the population structure of *H. rubra* on Hawaiʻi Island showed that two distinct lineages exist on the east and west coasts of the 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 ponds in Hawaiʻi (e.g. at the level of ponds and pond complexes), is appropriate for determining *H. rubra* population status, and is utilized in this survey.

The two groups of ponds 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). 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 introductions (Brock 2008, Ziemann and Conquest 2008). More recently, signs of visitation and usage have been noted for certain easily accessible ponds (Burns and Kramer 2016).

Results of the May 2017 survey as part of NELHA's Comprehensive Environmental Monitoring Program (CEMP) are subsequently reported.

METHODS

Anchialine ponds located within the NELHA facility form northern and southern complexes, including five ponds in the Northern complex and ten ponds in the Southern complex (Figures 1 - 3). The Northern pond complex, including ponds N-1 through N-5, is located approximately 100 m inland of the cobble beach at Hoʻona Bay (Figure 2), and the Southern pond complex, including ponds 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, except for pond S-10, which is located approximately 600 m south of the main pond complex (Figure 3).

Table 2 describes the location and size of each pond at the NELHA site. A Garmin 76Cx hand-held GPS unit was used to locate and re-record the latitude and longitude for each pond during the May 2017 survey. This year, coordinates were updated to a five-decimal system for improved ease of pond relocation (Table 2). Pond size was confirmed from measurements first reported by Brock 2008 (Table 2), except for pond S-10, which was first surveyed in 2015 (Whale Environmental Services 2015). Pond dimensions and basin characteristics for historically surveyed ponds are included in Appendix 1.1 (Brock 2008).

Because anchialine pond ecosystems are significantly influenced by tide, the water level, chemistry, and appearance of the surveyed ponds were expected to vary with tidal level. The effect of tidal level was particularly apparent for the Northern pond complex, including ponds N-2, N-3, N-4 and N-5. At low tide, these ponds were separated by basalt substrate outcrops, while at high tide, these pools formed a single body of water. This interconnectivity was particularly apparent during annual peak tides (or "King's tides") during which tidal levels exceeded + 2.3 ft. in 2017 (Figure 7). While the water level in the Southern group ponds was also strongly tidally affected, ponds were not observed to be interconnected.

Faunal observations for the May 2017 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 pond interconnection. Sampling of the ponds was conducted at tidal levels ranging from + 0.5 to + 2.0 ft. For pond "complexes," ponds were surveyed only when physically separated from other adjacent ponds (below the daily maximum tide).

Faunal surveys were conducted from May 25th to May 30th, 2017. Temperature and salinity measurements were collected concurrently using a hand-held YSI Pro-Series Quatro water quality meter and data logger. Visual observations of organisms within each pond were supplemented by photographs and high-definition video taken with a Nikon Coolpix AW120 1080p digital waterproof camera. Images and videos were reviewed within the two weeks following the visual surveys. Randomly selected photo-quadrats ranged in size from 0.02 m^2 to 0.07 m^2 (based on feasibility according to pond size and depth). Individual photo-quadrats were isolated from video footage for *H. rubra* quantification. The number of replicate photo-quadrats analyzed depended on pond area, and ranged from 3 to 7 replicates. *H. rubra* density was determined for each photo-quadrat, then averaged for each pond. Three ponds with low water levels (S-4, S-6, S-9) were surveyed visually *in-situ* for *H. rubra* density. *H. rubra* density for each photo-quadrat 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).

Two to five-minute videos were recorded at each pond to document the environmental surroundings and fauna present, and were later examined to qualitatively assess the biological community. Video surveys were designed to include less common, cryptic, or highly mobile species, as well as surrounding vegetation. Only the presence or absence of non-native organisms was recorded for this survey.

RESULTS

Water quality measurements and faunal census results from the May 2017 survey are summarized in Tables 3 and 4, and include temperature and salinity observations, *H. rubra* density, Poecilid presence, *Ruppia* spp. presence, and other notes on pond condition. Pond characteristics were partially explained by location, with higher species diversity and higher density vegetation surrounding the Northern ponds compared to the Southern ponds (Figures 4 - 9). The Southern ponds tended to be surrounded by non-vegetated or sparsely vegetated basalt, and were more likely to host introduced fish, likely because of their relative conspicuousness and accessibility (Figures 8 and 9). During this survey, certain Southern ponds experienced higher visitation rates, likely due to their proximity to Wawaloli Beach Park and Makako Bay Drive.

Similar to recent surveys where water quality was analyzed, the Southern ponds were less saline and slightly cooler during the May 2017 survey compared to the Northern ponds, suggesting that relatively higher groundwater influence occurs within the Southern complex. For the Southern ponds, temperature ranged from 21.9 – 24.2 C°, and salinity ranged from 10.2 to 12.2 ppt, with distal pond S-10 driving the upper end of this range for both parameters (Table 4). For the Northern ponds, temperature and salinity were somewhat higher, ranging from 22.9 - 26.8 C° and from 13.6 - 17.4 ppt., respectively (Table 3). This pattern corroborates previous surveys (Bybee *et al.* 2014, Burns and Kramer 2016, Appendix 1.1), and reflects varying degrees of groundwater and marine influence within the ponds.

In previous surveys, the majority of the Northern anchialine ponds hosted higher densities of *H. rubra* compared to the Southern ponds. However, during the May 2017 survey, several Southern ponds had similarly high densities (> 100 individuals/ 0.1 m^2), including ponds S-3, S-4, S-9 and S-10. All Northern ponds had *H. rubra* present, including pond N-5, in which *H. rubra* were not observed in April 2016, possibly due to frequent physical disturbance to the pond substrate. A moderate density of *H. rubra* (77 ± 22 count/ 0.1 m^2) was also observed in pond N-3, where they were absent during the 2014 survey (Bybee *et al*. 2014), and observed at a very low density in 2016 (Burns and Kramer 2016). The somewhat uncommon indigenous shrimp species, *M. lohena*, was observed within the same Northern ponds as in the 2016 survey (N-1 and N-2), and was observed in two additional Southern ponds during the 2017 survey compared to recent surveys (new: S-3 and S-4; observed in recent previous surveys: S-9 and S-10). Similar to the 2016 survey, the uncommon indigenous species, *Macrobrachium grandimanus*, was only observed in Pond S-7 (Table 4). However surprisingly, five (5) individuals were recorded during the survey. Historically and in more recent surveys (excluding this one), *M. grandimanus* had also been observed in ponds S-1, S-5, and S-8 (Bybee *et al.* 2014, Appendix 1.2).

Several Northern ponds hosted assemblages of the aquatic grass, *Ruppia* spp., including ponds N-1, N-3, and N-5. In previous surveys, *H. rubra* was typically not found within these grass beds, however during the May 2017 survey, *H. rubra* were frequently observed within and along the substrate below dense beds of *Ruppia* spp. A non-native damselfly, *Ischnura posita*, was observed within emergent *Ruppia* spp. beds at two Northern ponds, N-1 and N-3, suggesting that these ponds might also provide habitat for rare native damselfly species (e.g. *Megalagrion* spp.).

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

Introduced Poeciliid fish, including *Gambusia affinis* and *Poecilia* spp. were observed in five of the Southern area ponds, including S-1, S-3, S-5, S-7, and S-8 (Figures 8 and 9, Tables 3 and 4). For pond S-3, Poecilids were not noted in recent surveys (Bybee *et al.* 2014, Burns and Kramer 2016), but were recorded previously in 1994, 2007 and 2008 surveys (Appendix 1.2). During the May 2017 survey, only one small individual was observed in pond S-3. Where introduced fish were present, shrimp populations, including *H. rubra* and *M. lohena*, were dramatically reduced in density or were absent. As of the survey date in May 2017, introduced fish were not observed in any of the Northern area ponds (Table 3). However, one individual of tide-pool/ nearshore fish species, *Kuhlia* spp. (āholehole), was observed in pond N-3.

Significant archeological features were noted at several ponds in both the Northern and Southern complexes, including ponds N-5, S-5, S-7, S-8, and S-10. Features included water-worn basalt and/or coral stones, walls or structures surrounding the ponds, and waterworn stones embedded within trails leading to the ponds. Conversely, signs of recent visitor impacts were observed at four of the surveyed ponds in the Southern complex, including ponds S-1, S-3, S-4, and S-5 in the Southern area. Modifications from visitors included visible trash along pond edges, the addition of rocks to pond basins (leading to increased shading and pond depth reduction), and refuse addition to ponds and surroundings.

DISCUSSION

The West Hawai'i coastline hosts more than 500 anchialine ponds, which are unique, tidally influenced brackish ecosystems that host a specialized array of species (Yamamoto et al. 2015). Two complexes of ponds 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 ponds locally and throughout Hawai'i Island by tracking ecosystem changes overtime and evaluating causative factors.

The anchialine ponds at NELHA were resurveyed in May 2017, and compared to previous censuses, spanning back to May 1989. The census results from May 2017 were relatively similar to previous recent surveys (Bybee *et al.* 2013, Bybee *et al.* 2014, Whale Environmental Services 2015, Burns and Kramer 2016), yet highlighted specific changes in the ponds when compared to historical data. The major drivers of pond ecology were: 1) pond location, either Northern or Southern areas (Figures 1 - 3), 2) groundwater influence reflected in temperature and salinity readings (Tables 3 and 4), 3) the presence or absence of introduced fish (Figures 8 and 9), and 4) the intensity of human visitor impacts to the ponds.

Water quality is a key indicator in assessing anchialine pond ecosystem health, and measurements collected in May 2017 were consistent with surveys in previous years (Bybee *et al.* 2014, Whale Environmental Services 2015, Burns and Kramer 2016, Appendix 1.1), suggesting that groundwater influence within the ponds has remained relatively consistent. Although nitrogen and phosphorus level were not specifically measured within in the ponds during this survey, benthic communities had not changed substantially, even when compared to historical surveys, suggesting that water quality has likely remained relatively consistent within the ponds to date. The Southern ponds were cooler and less saline during the May 2017 survey compared to the Northern ponds, suggesting that relatively higher groundwater influence occurs within the Southern ponds. This finding complemented previous surveys (Appendix 1.1).

All five of the Northern ponds hosted *Halocaridina rubra* (ʻōpae ʻula), including pond N-5, in which *H. rubra* were absent in 2016 (Figure 6). In 2014, *H. rubra* were not observed in pond N-3, however in May 2017, *H. rubra* were detected at a low density (1.5 $\pm$ 2.7 (count/ 0.1 m^2)) (Table 3). At high tide, ponds N-2, N-3, N-4 and N-5 were inter-connected (Figure 7), which provides a simple mechanism for organismal exchange following depletion events (in addition to submarine/ hypogeal pond connections). This observed pond interconnectivity likely allowed for the replenishment of *H. rubra* within pond N-5 since the 2016 survey. As documented in previous years, Poeciliid fish were not observed in any Northern ponds (Bybee *et al.* 2014, Burns and Kramer 2016, Appendix 1.2), which allows for the continued presence of relatively high-density *H. rubra* assemblages.

The historical introduction of Poeciliid fish within anchialine ponds at NELHA has significantly affected pond ecology, and continues to alter pond ecology in four Southern area ponds including, S-1, S-5, S-7, and S-8 (Figure 8). Additionally, during the May 2017 survey, one small individual Poeciliid was observed in pond S-3, and removal is recommended, if feasible. Poecilids were not noted in pond S-3 in recent previous surveys, but were recorded in 1994, 2007 and 2008 (Appendix 1.2). Within ponds S-5, S-7, and S-8, *H. rubra* and *M. lohena* were not observed in the May 2017 survey, despite the presence of these shrimp in nearby uninvaded ponds. For pond S-1, a few individual *H. rubra* were observed within deep cracks and crevices in the pond, which likely provided a spatial refuge from predation. Capps *et al*. (2009) and Carey et al. 2011 suggest that *H. rubra* within fish-invaded ponds may alter their behavior by only residing within protected areas (inaccessible by fish) of the pond, or by only entering the epigeal regions of the pond at night to feed. During this survey, ponds were surveyed during daylight hours, and the nocturnal behavior *of H. rubra* was not assessed. While *H. rubra* was the dominant community member within ponds uninvaded by Poecilids, *Metabataeus lohena* was also frequently observed in uninvaded ponds (Tables 3 and 4).

Despite the presence of introduced fish in certain ponds, water clarity was high and invasive macroalgae was absent within the invaded ponds, according to the visual, qualitative surveys (Tables 3 and 4). This suggests that water quality characteristics have remained consistent, and/or that grazing activities within the invaded ponds have continued post-invasion. Because of the subterranean (hypogeal) connections between the Southern area ponds, recolonization by *H. rubra* and other crustacean species would likely be rapid if Poecilids were removed.

Video observations of the ponds allowed for qualitative documentation of less common, more motile species, and also provided a record of the vegetation surrounding each pond. Species present at each pond are listed in Tables 3 and 4, and generally, Northern area ponds tended to host a more diverse assemblage of pond inhabitants and surrounding vegetation (Figures 4-7, Table 3). The less common anchialine pond shrimp species, *Metabataeus lohena,* was observed in May 2017 at ponds N-1, N-2, S-3, S-4, S-9, and S-10. Five individuals of *Macrobrachium grandimanus* were observed in pond S-7, and were approximately 10 - 12 cm in length. Despite the presence of Poecilids in Southern Pond S-7, *M. grandimanus* has been able to co-exist, perhaps by reaching a size that precludes consumption.

Signs of visitor impacts were observed at several of the surveyed Southern ponds. Affected ponds were generally near access points, including Wawaloli Beach Park and Makako Bay Drive, and were also relatively visible due to minimal surrounding vegetation. Modifications in and around the ponds included the addition of rocks to pond basins (leading to increased shading and pond depth reduction), toilet paper and rubbish additions, and the removal/addition of Poeciliid fish and *H. rubra* for fishing bait and other uses. Structural changes and associated lighting changes likely influence overall pond ecology, and may alter algal assemblages, a key food source for *H. rubra*. Rubbish and other refuse disposal may affect the water quality of the ponds, while faunal removal and additions can affect the overall ecology of the ponds. For pond N-5, obvious signs of visitation and physical disturbance were documented in the April 2016

faunal survey (Burns and Kramer 2016), and included pond substrate disturbance (algal cover facing down), trampled *Ruppia* spp., increased turbidity, and *H. rubra* absence. During the May 2017 faunal survey, the condition of pond N-5 had improved substantially, including improved water clarity, the presence of *Ruppia* spp., and the presence of low density *H. rubra* in the pond, suggesting that visitation and physical disturbance has declined within the past year.
Predicted sea-level rise is a significant future threat to Hawaiian anchialine pond ecosystems, and will likely drive substantial changes in pond interconnectedness, depth, location, and water chemistry (Marrack and O'Grady 2014). These physical changes will have a critical influence on faunal composition within the ponds. Notably, the highest tides of the year (referred to as the "King's tides") occurred throughout the Hawaiian Islands in May 2017, just prior to the faunal surveys (Figure 7). These seasonal high tides offer a preliminary view of potential anchialine pond ecosystem changes associated with rising sea-level (SOEST website, Accessed May 2017, <www.soest.hawaii.edu/coasts/sealevel/>).

Anchialine ponds located near the public beach park facility, including ponds S-1 through S-5, showed signs of frequent visitation and human usage. However, the results of the May 2017 anchialine pond survey at NELHA did not indicate that anthropogenic inputs from local aquaculture and other facilities are degrading the ponds.

FIGURES

Figure 1. The study area included Northern and Southern anchialine pond complexes in the vicinity of the NELHA facility. (Map generated using Google Earth 7.1.7).

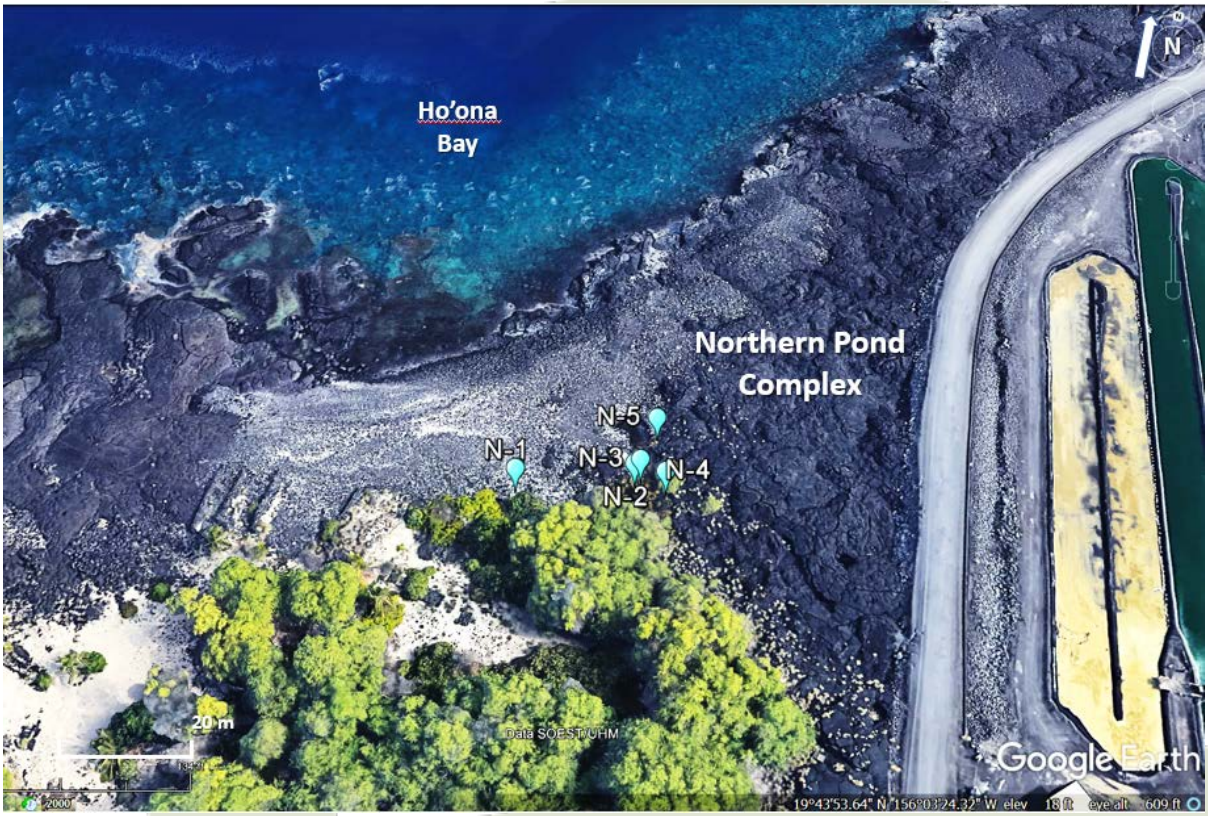

Figure 2. Locations of the Northern complex of anchialine ponds (N – 1 through N –5), located inland of the cobble beach at Ho'ona Bay. (Map generated using Google Earth 7.1.7).

Figure 3. The Southern complex of anchialine ponds (S-1 through S-10), located adjacent and south of the Wawaloli Beach Park facility at NELHA. (Map generated using Google Earth 7.1.7).


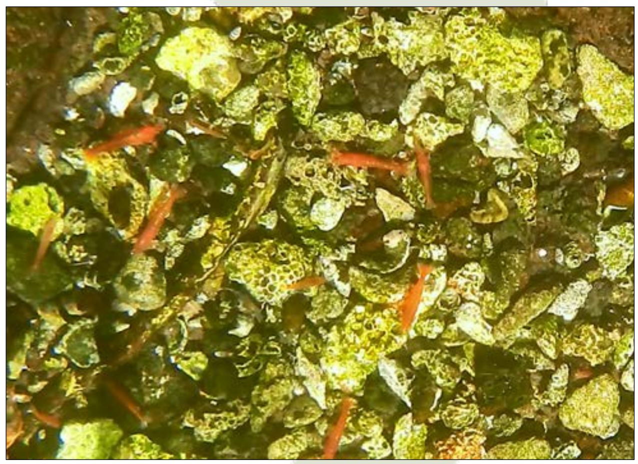

Figure 4. (left) Northern group pond, N - 1 at a tide level of + 1.83’ (white slate in the image facing North), and (right) a typical section of the pond basin, hosting a high density of *Halocaridina rubra* (‘ōpae ‘ula). Ponds in the Northern group were typically characterized by relatively diverse and dense surrounding vegetation and a high density of H. rubra within the ponds. Compared to previous census years, surrounding vegetation has continued to encroach substantially into the pond basin of N - 1.


Figure 5. (left) A Northern group pond, N-2, at a tide level of + 2.01‘, and (right) a typical photo-quadrat within pond N-2, hosting a high density of *Halocaridina rubra* (‘ōpae ‘ula). Introduced fish (Poeciliids) are absent within the Northern ponds.

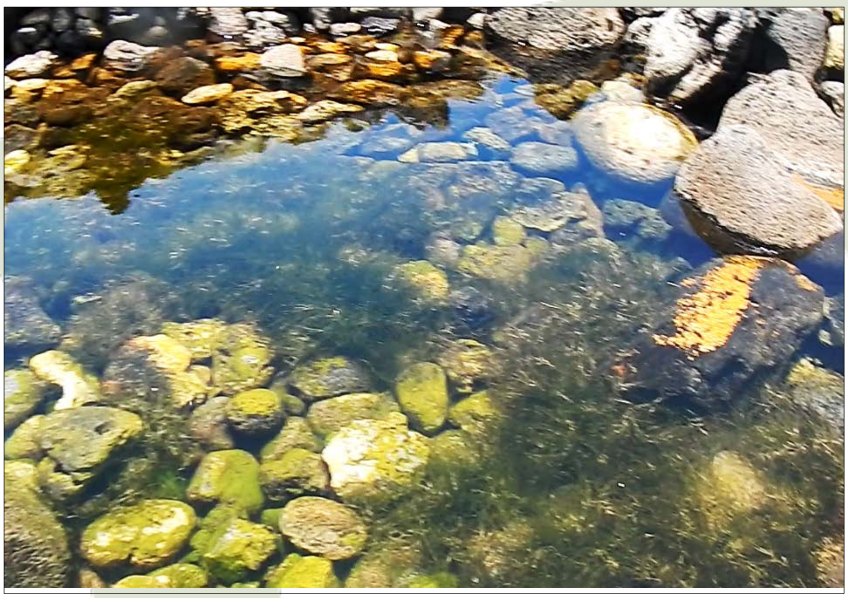

Figure 6. A typical pond basin area for Northern group pond, N-5, including the aquatic grass, *Ruppia* spp. and a low density of *H. rubra*. During the May 2017 survey, a low density of *H. rubra* and substantial recovery of *Ruppia* spp. was observed relative to the April 2016 survey, suggesting a reduction in physical disturbance to the pond occurred during the year.

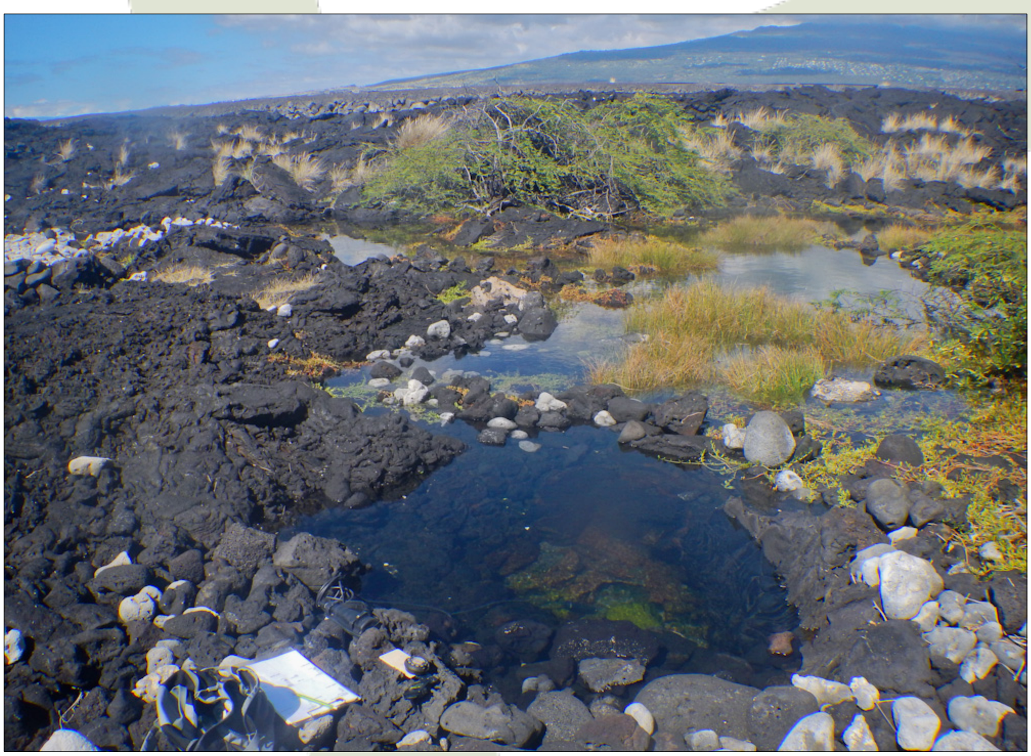

Figure 7. During high tide, the Northern ponds become a complex interconnected by surface waters, as exemplified on May 25th, 2017 at a tide level of +2.37'. Pond N-2 is in the foreground, with ponds N-3 and N-4 in the upper right, and pond N-5 in the upper left. The white slate in the image is facing North.

Figure 8. Southern group pond, S-5 (left), at a tide level of + 0.50‘ (the white slate in the image is facing North), and (right) introduced and abundant Poeciliids within the pond. Numerous ponds in the Southern group had populations of introduced fish, which was generally associated with highly reduced or absent *H. rubra* assemblages.

Figure 9. Southern group pond, S-7 (left), at a tide level of 2.10’ on May 25, 2017 (the white slate in the image is facing North). During the survey, five (5) individuals of the relatively uncommon native prawn species, *Macrobrachium grandimanus* (ōpae ‘oeha‘a), were observed within the pond (lower right). Introduced Poeciliids were also observed in pond S-7 (upper right), driving an absence of the shrimp species, *H. rubra*.

TABLES

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)
	Metabataeus 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)
	Rantala 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 25 May 2017 to 30 May 2017, at a tidal level ranging from + 0.6 to + 2.0 ft. Poeciliid fish and *Ruppia* spp. 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 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 spp.*	Comments/ Other Species
Northern Ponds	**N-1**	5/26/2017	14:50	23.0	17.4	Water-worn (rounded) basalt cobble, some silt, shell hash and sand, *Ruppia* present	122 ± 16	absent	present	Also observed: *M. lohena,* Thiarid snails, *Scaevola taccada, Prosopis pallida, Tournefortia argentea, Thespesia populnea, Sesuvium portulacastrum, Ischnura posita, Argiope appensa*
	N-2	5/26/2017	15:25	24.4	15.2	Basalt rubble, pahoehoe surroundings	78 ± 22	absent	absent	Also observed: *M. lohena,* Thiarid snails, *Pantala flavescens, Tramea lacerata, Sesuvium portulacastrum, Prosopis pallida, Metopograpsus messor,* orange cyanobacterial mat, *Lyngbya sp.*
	N-3	5/28/2017	12:38	22.9	13.8	*Ruppia* dominant, underlying cobble, pahoehoe surroundings	77 ± 27	absent	present	Also observed: Thiarid snails (low density), *Lyngbya sp., Sesuvium portulacastrum, Scaevola taccada, Prosopis pallida, Cladium sp., Ischnura posita, Kuhlia sp.* (1), intensive thermocline noted.
	N-4	5/30/2017	18:05	26.8	13.6	Silt bottom with cobble and shells, pahoehoe surroundings	33 ± 18	absent	absent	Also observed: Thiarid snails (high density), *Sesuvium portulacastrum, Cladium sp.,* ~ 5% cover of orange cyanobacterial mat and *Lyngbya* sp.
	N-5	5/28/2017	12:21	23.5	15.0	Water-worn (rounded) basalt cobble and coral rock	23 ± 9	absent	present	Also observed: *Sesuvium portulacastrum, Pantala flavescens*, *Tramea lacerata*, orange cyanobacterial mat, *Lyngbya* sp.

Table 4. Faunal census data collected for the Southern pond complex of anchialine ponds at the NELHA facility. The pond surveys were conducted in May 2017, at a tidal level ranging from + 0.5' to + 2.0'. Poeciliid fish and *Ruppia* spp. were recorded as present or absent, and other organisms 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: Temp (C°)	Water Quality: Salinity (ppt)	Faunal Surveys: Substrate	Faunal Surveys: *H. rubra* (Count/0.1m^2) (Mean ± SE)	Faunal Surveys: Poeciliids	Faunal Surveys: *Ruppia spp.*	Comments/ Other Species
Southern Ponds	**S-1**	5/28/2017	9:33	22.6	10.5	Basalt rubble/ pebbles, pahoehoe surroundings	1.3 ± 1.3	present	absent	Also observed: *Pennisetum setaceum, Schinus terebinthifolius*, ~ 5% cover orange cyanobacterial mat, trash in area noted (visitation), Both *Poecilia* sp. and *Gambusia affinis* observed.
	S-2	5/28/2017	9:40	-	-	-	-	-	-	Pond filled in with rocks
	S-3	5/30/3017	17:18	22.2	10.7	Basalt rubble/ pebbles, pahoehoe surroundings	183 ± 64	present (1 individual)	absent	Too shallow for photoquadrats. In-situ visual surveys used. Also observed: *M. lohena*, Too shallow for photoquadrats, no surrounding vegetation, toilet paper observed adjacent to pond (visitation), a few new rocks added to pond (?).
	S-4	5/30/3017	17:32	22.2	10.6	Basalt rubble, pahoehoe surroundings	present (*In-situ*= 176 ± 55)	absent	absent	Too shallow for photoquadrats. *In-situ* visual surveys used. Also observed: *M. lohena*, no surrounding vegetation. Trash in area noted (visitation), additional rocks added to pond (?)
	S-5	5/28/2017	9:49	21.9	10.6	Basalt rubble, pahoehoe surroundings	absent (0 ± 0)	present (abundant)	absent	Also observed: *Pennisetum setaceum,* orange cyanobacterial mat (~2 % cover), light algal turf cover, both *Poecilia* sp. and *Gambusia affinis*. Signs of visitation.
	S-6	5/25/2017	17:45	22.3	10.4	Very narrow basalt crack, a'a surroundings.	present (*In-situ*= 43 ± 14)	absent	absent	Also observed: No surrounding vegetation.
	S-7	5/25/2017	17:20	23.4	10.6	Basalt rubble (some rounded), pahoehoe surroundings	absent (0 ± 0)	present (abundant)	absent	Also observed: *Macrobrachium grandimanus (5!)*, Thiarid snails, *Capparis sandwichiana, Pennisetum setaceum*, orange cyanobacterial mat (low cover), *Pantala flavescens*, both *Poecilia sp.* (occasional) and *Gambusia affinis* (abundant), rounded stones along basin and trail. Intensive thermocline observed.
	S-8	5/25/2017	17:10	23.8	10.7	Basalt rubble with a few white coral stones, pahoehoe surroundings	absent (0 ± 0)	present (abundant)	absent	Also observed: *Pennisetum setaceum*, orange cyanobacterial mat (low cover), both *Poecilia* sp. and *Gambusia affinis*. Water-worn wall with rounded corals surrounding pond. Opihi shells observed. Trail to pond. Intensive thermocline observed.

S-9	5/25/2017	18:00	22.0	10.2	Basalt crack, a'a surroundings.	present (*In-situ*= 109 ± 43)	absent	absent	Too shallow for photoquadrats. *In-situ* visual survey used. Also observed: *M. lohena, Argiope appensa.* No surrounding vegetation.
S-10	5/25/2017	16:29	24.2	12.2	Pahoehoe with light organic material, small basalt pebbles	125 ± 32	absent	absent	Also observed: *M. lohena, Schinus terebinthifolius, Sesuvium portulacastrum, Pennisetum setaceum,* mongoose feces, large opihi shell in pond, intensive thermocline observed

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 (~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 45 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 surveys are summarized by Burns and Kramer (Burns and Kramer 2016), and the results and findings for the 2017 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 10). 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.

Photographs were taken of each quadrat using an underwater camera with a wide-angle lens adaptor. 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 so the photos can 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).

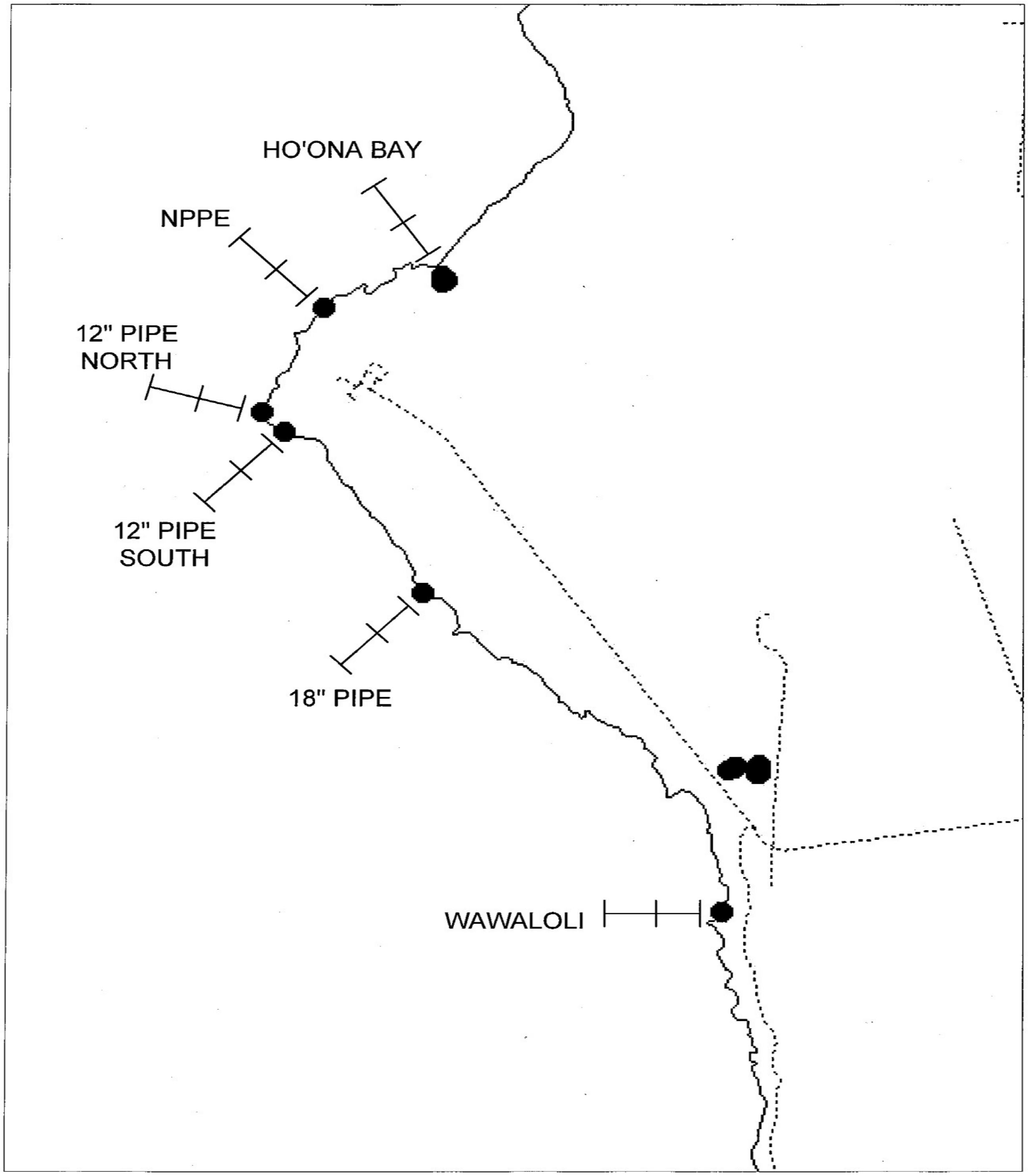

Figure 10. Six stations with three transects per station at deep (~50-fsw), moderate (~35-fsw), and shallow (~15-fsw) depths along the NELHA coastline. A total of 18 transects are completed for both the benthic monitoring and fish assemblage monitoring.

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 4**.**

The overall percent coral cover among the six stations was 32.97%, the most dominant corals were *Porites lobata* (17.56%), *Porites compressa (9.58%), Porites evermanni* (6.51%), and *Montipora patula* (3.91%). These coral species were present among all the stations. Other corals present were *Pocillopora meandrina, Pocillopora grandis*, *Leptastrea purpurea, Leptastrea bewickensis, Montipora capitata, Montipora flabellata, Pavona varians, Pocillopora eydouxi, Porites rus and Fungia scutaria.* These corals accounted for approximately 5-10% of the overall relative benthic cover.Values of percent cover for the dominant coral species at each station and depth are provided in Table 4.

P. lobata was the most dominant coral in the shallow depths (~15-fsw) among all six stations. *P. lobata, P. evermanni, P. grandis,* and *P.compressa* were the dominant corals in the moderate depths (~35-fsw) among the six stations. *P. lobate, P. evermanni, and P. compressa* were the most dominant corals at the deep depths (~50-fsw) among the six stations. Similar to previous years, *P. meandrina* was most abundant at the 12" Pipe South station, and *P. evermanni* was most abundant at the Wawaloli station. *P. compressa* had the highest levels of coral cover at 12" Pipe South and Hoona Bay, while *P. lobata* had the highest levels of coral cover at the other stations. The distribution, abundance, and percent cover of the corals among all stations in 2017 were similar to previous years. Photographs of each photographed quadrat are included in Appendix 4.

Table 4 provides a detailed comparison of the percent cover, species richness, and species diversity of corals among all stations and survey depths. The H-Bay and NPPE sites exhibited the highest levels of coral cover (39.63% and 37.00% respectively). Coral cover at these two sites was dominated by *P. lobata, P. compressa,* and *P. evermanni.* Species richness and species diversity was highest at 12" Pipe North, similar to 2016. The benthic substrate at this site was also predominantly occupied by *P. lobata* (12.2%), and also had high values of coral cover for *P. compressa*.

Values of coral cover were statistically similar among all depths. Shallow had highest cover of 34.34%, with moderate and deep sites exhibiting 32.20% and 32.37% coral cover. Among the deep stations, coral was most abundant at NPPE and Ho'ona Bay sites (38.38% and 41.30%) followed by 12" Pipe South (34.29%). These patterns in coral cover among the surveyed depths are similar to previous years, and showed the same pattern in coral cover among sites in 2016.

The differences among the data discussed above were measurable, however, no statistically significant differences were found when comparing all metrics pertaining to the benthic substrate among the six stations and different survey depths (Table 4).

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 the 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 4: Summary of benthic substrate data and comparative analyses from surveys conducted in April 2017

Station	Wawaloli			18" Pipe			12" Pipe South		
Depth	Shallow	Moderate	Deep	Shallow	Moderate	Deep	Shallow	Moderate	Deep
Overall coral cover	29.13	28.84	30.66	33.69	28.13	24.53	30.53	40.45	34.29
P. lobata	15.80	13.50	14.66	16.11	16.30	14.11	16.20	15.70	15.56
P. evermanni		7.60	10.00				1.00		
P. compressa						7.00		2.00	15.00
P. meandrina	1.00						8.00	0.00	1.00
P. eydouxi								20.00	
M. capitata	3.33	4.14	6.00	10.33	7.00	3.43	3.00	1.75	3.67
M. patula	7.00	3.60		7.25	4.86		2.33	2.00	3.50
Species count	5.00	4.00	2.00	4.00	3.00	3.00	5.00	5.00	6.00
Species diversity (H)	1.27	1.34	0.56	1.15	1.07	0.96	1.20	1.15	1.58

Station	12" Pipe North			NPPE			Hoona Bay		
Depth	Shallow	Moderate	Deep	Shallow	Moderate	Deep	Shallow	Moderate	Deep
Overall coral cover	29.77	28.50	25.10	41.66	30.95	38.38	41.25	36.67	41.30
P. lobata	27.78	25.00	14.60	19.50	18.40	17.44	18.50	18.50	18.30
P. evermanni				12.00		3.00	0.00	7.50	10.00
P. compressa			9.00		7.50	8.70	15.00	7.12	12.00
P. meandrina									
P. eydouxi									
M. capitata	1.00		1.50	5.50	2.80	3.44	5.00	3.20	1.00
M. patula		3.50		3.66	2.25	3.80	2.75		
Species count	3.00	2.00	3.00	5.00	4.00	6.00	4.00	4.00	5.00
Species diversity (H)	0.60	0.31	1.07	1.20	1.30	1.54	0.99	1.26	1.31

Mean value comparisons	Wawa	18" Pipe	12" Pipe S	12" Pipe N	NPPE	H - Bay	p-value	Shallow	Moderate	Deep	p-value
Overall coral cover	29.54	28.78	35.09	27.79	37.00	39.63	0.06	34.34	32.20	32.37	0.67
P. lobata	14.65	15.51	15.85	22.45	18.45	18.43	0.09	18.98	17.90	15.78	0.14
P. evermanni	8.80		1.00		7.50	8.75	0.50	6.50	7.55	7.66	0.91
P. compressa	7.00	7.00	15.00	9.00	8.10	11.38	0.33	15.00	7.33	9.78	0.32
P. meandrina	1.00		4.50				0.47	4.50		1.00	0.47
P. eydouxi			3.33				1.00		20.00		1.00
M. capitata	4.49	6.91	2.80	1.25	3.91	3.06	0.14	4.69	3.77	3.17	0.84
M. patula	5.30	6.05	2.61	3.50	3.23	2.75	0.20	4.60	3.24	3.65	0.51
Species count	6.00	6.00	7.00	9.00	7.00	7.00	0.06	7.00	7.00	7.00	0.60
Species diversity (H)	1.15	1.27	1.18	1.39	1.38	1.29	0.14	1.05	1.27	1.17	0.82

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 2013-2016, and how they compare to the current data from 2017.

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 (~40-50%) 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 are 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 2017, 32.97%, is within this range and shows the benthic communities to exhibit consistent values of coral cover for the last 8 years.

Other studies conducted throughout the 18-year period of monitoring have found significant differences in overall coral cover among the six stations, and the depth gradient (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. While the 2017 data did show the highest mean values of overall coral cover at the Hoona Bay and NPPE sites, there were no statistically significant differences among the six stations. There were also no statistically significant differences among the depth gradients. Furthermore, the 2017 data also 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 coral cover.

Previous reports have also 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 2017 was 17.55%. While this value is lower, there was

7.24% cover attributed to *P. evermanni,* which was possibly not identified in previous years due to morphological similarity. The overall percent cover of mounding *Porites* coral in 2017 is not statistically different to the previous three years. The values of coral cover for mounding *Porites* was also very similar in 2016, thus indicating these are the dominant coral colonies among these stations, and this species is exhibiting minimal changes in community structure.

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 2017 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 2017 data exhibit a decrease in *P. meandrina* cover at some sites, and no colonies were observed at a few stations. The range in percent cover of this species was larger than previous years (0-25%), and overall *P. meandrina* cover did not decrease significantly among all sites compared to previous years. Values of *P. meandrina* cover 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 realtively higher levels of *P. meandrina* cover in shallow depths, compared to 2016, 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 2017 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 2009-2017. The data from 2017 exhibited a relatively lower value of coral cover to 2016, but patterns in community structure were similar, thus suggesting coral composition has remained similar at these sites.

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 2017, 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 20 years have shown variability in the characterization of coral communities among the six stations. Considering that no permanent markers are 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 would 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. Future surveys will now be able to track temporal dynamic of the benthic communities with greater precision. Pins were placed at the following locations:

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: 19.73299, -156.0576	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.

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 dramatics changes over the last two decades. The 2017 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 (~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 25 years to ensure that any impacts to water quality, associated with activities conducted on the NELHA facility, are not causing detrimental changes to the nearshore fish assemblages in this area.

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

METHODS

Surveys of the nearshore fish assemblages were conducted at the same six stations and depth gradients (18 total transect surveys) used for assessment of the benthic substrate (Figure 10). 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 was 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 5, and the complete dataset is provided in Appendix 3.

Total Number of Individuals

The total number of individual fish was highest at 12" Pipe South and the lowest was at Wawaloli, which was the same pattern detected in 2016. This range in individuals was 120 to 336. Shallow and deep habitats had a similar number of individuals (252 and 244 respectively), with moderate sites having the lowest number (200 individuals). While there were differences in the mean values, there were no statistically significant differences in the total number of individual fish counted among all six stations (p=0.26) or among the three depth gradients (p=0.73). All values are reported in Table 5.

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 31 to 52. The shallow, moderate, and deep habitats had 41-42 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=0.12) or among the three depth gradients (p=0.91). All values are reported in Table 5.

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.

Species Diversity and Biomass

Species diversity ranged from 2.43 at Wawaloli to 3.36 at NPPE. The species diversity at the deep depths was 2.91, moderate depths was 3.01, and the deep depths was 3.02. There were no significant differences in species diversity among the six stations surveyed (p=0.27). There were also no significant differences in species diversity among the three depth gradients (p=0.89)

Fish biomass was highest at Hoona Bay (262.53 g/m2) and lowest at Wawaloli (80.92 g/m2). Biomass was lowest at shallow depths (136.64 g/m2), and highest at the moderate depths (177.79 g/m2). No significant differences in mean biomass were detected among the sites (p=0.17) or depth gradients (p=0.86).

Table 5: Summary of fish survey data and comparative analyses from surveys conducted in May 2017

Station	Wawaloli				18" Pipe				12" Pipe South		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Fish count	57.00	202.00	102.00		496.00	261.00	228.00		278.00	253.00	476.00
Number of species	35.00	38.00	21.00		41.00	34.00	37.00		30.00	43.00	42.00
Diversity	2.97	2.18	2.13		3.04	3.05	2.94		2.92	2.90	3.11
Biomass	58.20	75.68	108.88		323.41	100.02	99.80		111.03	158.73	283.95
Station	12" Pipe North				NPPE				Hoona Bay		
Depth	Shallow	Moderate	Deep		Shallow	Moderate	Deep		Shallow	Moderate	Deep
Fish count	217.00	167.00	235.00		191.00	112.00	109.00		270.00	207.00	314.00
Number of species	46.00	43.00	54.00		40.00	46.00	43.00		59.00	49.00	49.00
Diversity	3.00	3.19	3.32		3.20	3.60	3.29		3.03	3.13	2.69
Biomass	53.17	158.78	146.97		115.83	98.88	85.59		158.23	474.70	154.61
Mean value comparisons	Wawa	18" Pipe	12" Pipe S	12" Pipe N	NPPE	H - Bay	p-value	Shallow	Moderate	Deep	p-value
Fish count	120.33	328.33	335.66	206.33	137.33	263.67	0.26	251.50	200.33	244.00	0.73
Number of species	31.33	37.33	38.33	47.66	43.00	52.33	0.12	41.83	42.16	41.00	0.91
Diversity	2.43	3.01	2.97	3.17	3.36	2.95	0.27	3.02	3.01	2.91	0.89
Biomass	80.92	174.41	184.57	119.64	100.10	262.53	0.17	136.64	177.79	146.63	0.86

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 2017 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 2017 exhibited similar patterns and values for all parameters to the 2016 data. This shows the sites have again shown to support very abundant and diverse fish assemblages.

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 2017 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, and in the same range as those observed in 2010 and 2016. 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 25 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, 2016and in the 2017 data (Bybee et al. 2014, WHALE Environmental 2015, Burns and Kramer 2016, Table 5). 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.

In summary, the reports conducted over the past 25 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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B

APPENDICES

Appendix 1: Environmental and biological data reported from anchialine pond surveys between May 1989 and October 2008.

Appendix 1.1. Physical characteristics of northern and southern anchialine ponds, summarized from 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 surveyed 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. Census data reported for northern and southern anchialine ponds from surveys conducted from May 1989 to August 2008 (Brock 2008) with introduced fish species (Poeciliids) recorded as present (x) or absent (0).

Survey Date	Pond: N-1 (Count/0.1m²)								Pond: N-2 (Count/0.1m²)			Pond: N-3 (Count/0.1m²)							
	Thiarid Snails (Melania sp.)		*H. rubra*	Poecilia sp.	*M. grandi-manus*	*P. debilis*	*M. messor*	*T. cariosa*	Thiarid Snails (Melania sp.)	*H. rubra*	*Poecilia sp.*	Thiarid Snails (Melania sp.)			*H. rubra*		Poecilia sp.	*M. lar*	*P. debilis*
	a	b	a						a	a		a	b	c	a	b			
May 1989	78	71		x					36	22	0	62	21		1	15	0		0
Oct 1991	35	52		x					42	15	0	12	9	0	0	28	0		0
Mar 1992	49	31		x					72	3	0	67	23	0	0	0	x		0
May 1992	56	29		x					85	0	x	29	41	0	0	0	x		1
Oct 1992	24	62		x					41	72	0	24	15	6	15	38			1
May 1993	31	54		x					22	0	x	19	26	0	0	0	0		2
Dec 1993	42	59		x					27	0	x	31	17	8	0	0	x		1
May 1994	31	72		x					31	0	x	42	24	5	2	0	x		2
Jun 1994	43	68		x	2				28	4	x	51	33	6	0	0	x	1	1
Oct 1994	19	72		x	0				19	0	x	72	41	9	0	0	x	0	1
Mar 1995	40	52		x	0				31	42	0	40	23	9	0	0	x	1	2
Jun 1995	63	50		x	1	2			28	0	x	53	19	14	0	0	x	0	3
Dec 1997	39	67		x	0		4		33	0	x	49	31	18	0	0	x	0	0
Jun 1998	41	53		x	0		7	6	44	0	x	57	22	34	0	0	x	0	0
Nov 1998	38	52		x	0		9	5	56	0	x	28	26	14	0	0	x	0	0
May 1999	27	49		x	0		6	6	47	0	x	39	24	22	0	0	x	0	0
Dec 1999	36	68		x	0	0	8	3	47	0	x	37	31	12	0	0	x	0	0
June 2000	42	37		x	0	0	9	2	39	0	x	44	51	6	0	0	x	0	0
Nov 2000	34	55		x	0	0	5	4	51	0	x	34	29	9	0	0	x	0	0
May 2001	39	27		x	0	0	4	3	79	0	x	41	22	3	0	0	x	0	0
Nov 2001	37	23		x	0	0	6	2	66	0	x	39	33	3	0	0	x	0	0
May 2002	29	47		x	0	0	5	9	72	0	x	27	19	5	0	0	x	0	0
Dec 2002	21	17		x	0	0	7	5	37	0	x	41	38	5	0	0	x	0	0
Dec 2007	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug 2008	4	0		0	0	0	0	0	3	10	0	2	0	0	25	21	0	0	0

Appendix 1.2. (continued)

Survey Date	Pond: N-4 (Count/0.1m²)						Pond: N-5 (Count/0.1m²)					
	Thiarid Snails (Melania sp.)		***H. rubra***		**Poecilia sp.**	***M. grandi-manus***	**Thiarid Snails (Melania sp.)**		***H. rubra***	**Poecilia sp.**	***M. grandi-manus***	***M. messor***
	a	b	a	b			a	b	a			
May 1989	39	115	3	21	0		2	4	0	0		
Oct 1991	0	4	0	23	0		2	4	0	0		
Mar 1992	0	9	0	0	x		31	2	0	x		
May 1992	14	3	0	0	x		9	1	0	x		
Oct 1992	10	85	12	31	0		8	1	41	0		
May 1993	9	42	0	0	x		12	1	0	x		
Dec 1993	14	61	0	0	x		23	17	0	x		
May 1994	12	53	0	0	x		19	27	0	x		
Jun 1994	26	49	0	0	x		27	6	0	x		
Oct 1994	25	19	0	0	x		51	29	0	x		
Mar 1995	26	19	0	0	x	5	21	19	0	x	3	
Jun 1995	25	23	0	0	x	0	29	16	0	x	0	
Dec 1997	27	17	0	0	x	0	33	13	0	x	0	3
Jun 1998	33	21	0	0	x	0	42	27	0	x	0	5
Nov 1998	29	26	0	0	x	0	23	19	0	x	0	5
May 1999	27	19	0	0	x	0	24	12	0	x	0	4
Dec 1999	36	29	0	0	x	0	16	19	0	x	0	5
June 2000	29	17	0	0	x	0	12	26	0	x	0	5
Nov 2000	27	21	0	0	x	0	21	17	0	x	0	5
May 2001	dry						19	14	0	x	1	7
Nov 2001	29	17	0	0	x	0	17	12	8	x	0	5
May 2002	31	20	0	0	x	0	23	16	0	x	0	6
Dec 2002	27	18	0	0	x	0	17	21	0	x	0	3
Dec 2007	dry						0	0	0	0	0	0
Aug 2008	2	1	23	17	0	0	4	5	80	0	0	0

Appendix 1.2. (continued)

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

Appendix 1.2. (continued)

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

Appendix 1.3. The anchialine ponds census data for the survey conducted October 2008. In addition to quantitative counts, qualitative abundances were noted as follows: + few animals; scattered plants, ++ animals common; plants abundant in patches, +++ animals too numerous to count; plants covering substrate, and – none observed (Ziemann and Conquest 2008).

Area	Pond number	*Ruppia maritima*	Thiarid Snails	*Assiminea sp.*	*Theodoxus cariosa*	*Graspsus tenuicrustatus*	*Halocaridina rubra*	*Metabataeus lohena*	Poecilia sp.	Other Species, Comments
Northern Ponds	N-1				+		++	-	-	Ruppia absent
	N-2						+	-	-	Ruppia absent
	N-3	+	+				+++	-	-	Ruppia absent
	N-4						+++	-	-	Ruppia absent
	N-5	+	+				++	-	-	Ruppia absent
Southern Ponds	S-1						-	2	+	
	S-2						100	-	-	
	S-3						200	1	-	
	S-4						5	-	-	
	S-5						-	-	+	
	S-6						20	1	-	
	S-7						-	-	++	
	S-8						75	15	-	
	S-9						-	-	-	

Appendix 2: Nearshore marine habitat characterization data

Table 2.1 Benthic habitat characterization data - Algae

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
12S	50	0									25								1										71		
12S	50	5									10	5																	67		1
12S	50	6									15	1																	62		1
12S	50	16									10	2																	66		
12S	50	18									15								2										70		
12S	50	23									25	5																	64		2
12S	50	24									15	1																	75		2
12S	50	25									5	2																	76		
12S	50	30									5																		76		3
12S	50	36									10	10																	73		
12S	35	2									3	3																	43		1
12S	35	3									3	3																	82		1
12S	35	4									5	2																	73		
12S	35	7									3	3																	77		1
12S	35	12									5																		58		
12S	35	16									5	3																	87		
12S	35	17									5	4																	80		
12S	35	21									5	2							3										75		
12S	35	23									7																		78		
12S	35	26									15	4																	73		1
12S	15	1										10																	65		
12S	15	2										3																	91		
12S	15	9										2																	90		
12S	15	11									5	2																	67		
12S	15	13									20	5																	73		
12S	15	19									20	2																	53		
12S	15	21									5																		71		
12S	15	22									5																		84		
12S	15	32									25																		60		
12S	15	36									10	2																	83		

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
12N	50	0									30	5							1										28		
12N	50	2									8																		65		
12N	50	6									5	2							2										68		
12N	50	7										5																	73		
12N	50	12									8	5																	67		
12N	50	14									5	3																	82		
12N	50	19									8																		62		
12N	50	20									8	5																	67		
12N	50	27									5							1											69		
12N	50	29									5	8																	74		
12N	35	0									10	10																	40		
12N	35	5									30	10																	30		
12N	35	6									5	5																	72		
12N	35	8									30	5																	40		
12N	35	10									15	3																	57		
12N	35	12									10																		57		
12N	35	13									25																		55		
12N	35	14									5																		74		
12N	35	15									10	5																	79		
12N	35	19									5																		85		
12N	15	1									5	5																	63		
12N	15	4									5	2																	68		
12N	15	11									10	3																	47		
12N	15	12									60																		40		
12N	15	15									5																		69		
12N	15	18									25	5																	50		
12N	15	25									10																		60		
12N	15	28									15	5																	49		
12N	15	29									7	2																	60		
12N	15	35									10																		55		

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
NPPE	50	1									8																		55		1
NPPE	50	3									3	2							1				1						52		1
NPPE	50	5																					1						61		1
NPPE	50	7									5						1												71		
NPPE	50	8																	2				1						62		2
NPPE	50	10									5	2																	62		
NPPE	50	12										3																	74		2
NPPE	50	16									5	5																	56		
NPPE	50	21									5	3											1						68		
NPPE	50	26									6						1												67		
NPPE	35	5									15	2																	74		
NPPE	35	7									10																		78		
NPPE	35	12									25	3																	43		
NPPE	35	14										3																	55		
NPPE	35	15																										1	80		
NPPE	35	17									10	1																	64		
NPPE	35	20									5	3																	62		
NPPE	35	22									10																		53		
NPPE	35	24										5						1											73		
NPPE	35	32									5																		80		
NPPE	15	1									5																		74		
NPPE	15	11									10	3																	59		
NPPE	15	13									5	4																	66		
NPPE	15	15									10	5																	70		
NPPE	15	16																										1	76		
NPPE	15	17									10	5																	60		
NPPE	15	18									10	2																	78		
NPPE	15	21										3																	65		
NPPE	15	27									10																		60		
NPPE	15	29									25																		49		

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	1									10	2																	43		
H-bay	50	2									10	10																	30		
H-bay	50	3									10	10																	57		
H-bay	50	5									10																		44		
H-bay	50	6									5	5																	40		
H-bay	50	12									10	5																	14		
H-bay	50	18									10																		35		
H-bay	50	21									5	15																	40		
H-bay	50	22									5	10																	33		
H-bay	50	32									10	5																	24		
H-bay	35	1									25	20											1						34		
H-bay	35	2									20	10																	25		
H-bay	35	7									5							2											54		2
H-bay	35	9									5	5																	58		
H-bay	35	11									5	10																	67		
H-bay	35	12										10																	55		
H-bay	35	13									5	5																	64		
H-bay	35	20									5	10																	68		1
H-bay	35	27									2	10																	53		
H-bay	35	33										10																	55		
H-bay	15	0									2	10																	63		
H-bay	15	13									2																		70		
H-bay	15	16									3	5																2	69		1
H-bay	15	18									10	3																	63		
H-bay	15	20									5	10																	50		
H-bay	15	24									10	10																	70		
H-bay	15	27									2	5																	66		
H-bay	15	28									5	5																	50		
H-bay	15	29									20	5																	48		
H-bay	15	31										2																	93		

B

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
18	50	0									5																		76		
18	50	3									8								2										78		
18	50	7									10												1						68		
18	50	9									5	5							1										67		
18	50	14									6								5										59		
18	50	16									5	5																	75		1
18	50	19										3																	73		
18	50	20									5								5				1						69		
18	50	27									5																		75		
18	50	33									5												1						66		
18	35	0									5	12																	64		
18	35	2									7																		60		1
18	35	7									10																		62		
18	35	12										5																	86		
18	35	14									10																		74		
18	35	16									10	6																	71		
18	35	20									25																		66		
18	35	27										3																	74		
18	35	30									7	2																	56		
18	35	35									10																		66		
18	15	0									20								1										59		
18	15	1									5																		67		
18	15	3										2																	81		
18	15	4									17																		79		
18	15	5									15																		79		
18	15	11									5	5																	67		
18	15	18									15																		77		
18	15	23									5	5																	69		
18	15	28									15																		57		
18	15	37									17																		78		

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	1									5	1																	34		
Wawa	50	5									3	3																	30		
Wawa	50	7									8	1																	30		
Wawa	50	12									4	2																	40		
Wawa	50	16									4																		15		
Wawa	50	18									3	2																	40		1
Wawa	50	21									4																		60		
Wawa	50	22									5																		60		1
Wawa	50	27									8																		45		
Wawa	50	33									3																		48		1
Wawa	35	1										3																	57		
Wawa	35	4									5																		64		
Wawa	35	5									2																		72		
Wawa	35	7									10																		62		
Wawa	35	8									10																		60		
Wawa	35	16																											78		
Wawa	35	20																											59		
Wawa	35	23										2																	50		
Wawa	35	26									8																		44		
Wawa	35	36									2																		45		
Wawa	15	0									15	1																	68		
Wawa	15	1									5																		77		
Wawa	15	2									5	3																	85		
Wawa	15	10									6	3																	72		
Wawa	15	11									10																		76		
Wawa	15	18									5																		35		
Wawa	15	21									10																		53		
Wawa	15	24									20	3																	62		
Wawa	15	32									3																		87		
Wawa	15	36									6																		66		

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

Site	Depth	Location	Photo Name	Sponge (Sponge)	Spirastrealla vagabunda	Palythoa tuberculosa	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 evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
12S	50	0										1										1			1									
12S	50	5		1									1												10									5
12S	50	6		1											5										10									5
12S	50	16											5		5										6									6
12S	50	18										5						3							5									
12S	50	23										4																						
12S	50	24										1										1			5									
12S	50	25										1			2										4									10
12S	50	30										1	5		2										8									
12S	50	36		1								5													1									
12S	35	2																		20					25									5
12S	35	3											1												10									
12S	35	4																							10						5			5
12S	35	7											1												15									
12S	35	12																							7						10			20
12S	35	16																							5									
12S	35	17										1													10									
12S	35	21		1									2		2										10									
12S	35	23		1									3												8									3
12S	35	26																							7									
12S	15	1																							25									
12S	15	2											1												5									
12S	15	9																							5									3
12S	15	11											5		3							8			10									
12S	15	13																							2									
12S	15	19																							25									
12S	15	21													3									1	20									
12S	15	22													1										10									
12S	15	32																							15									
12S	15	36																							5									
12N	50	0											1										10		25									
12N	50	2											2										10		15									
12N	50	6																					8		15									
12N	50	7											2										8		12									
12N	50	12											1										7		12									
12N	50	14																							10									
12N	50	19																					10		20									
12N	50	20																							15									5
12N	50	27											1										10		12									2
12N	50	29		1									2												10									
12N	35	0																							30									10
12N	35	5																							10									20
12N	35	6																							10									8
12N	35	8																							25									
12N	35	10																							25									
12N	35	12													1										30									2
12N	35	13																							15						5			
12N	35	14				1																			15									5
12N	35	15		1																					5									
12N	35	19																							10									
12N	15	1				1						1													25									
12N	15	4																							25									
12N	15	11																							40									
12N	15	12																																
12N	15	15											1												25									
12N	15	18																							20									
12N	15	25																							30									
12N	15	28		1																					25									5
12N	15	29		1																					30									
12N	15	35																							30									5

B

Site	Depth	Location	Photo Name	Sponge (Sponge)	Spirastrealla vagabunda	Palythoa tuberculosa	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 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										2	1		2								6		20									5
NPPE	50	3											5										5		30									
NPPE	50	5											7										15		15									
NPPE	50	7											1										7		15									
NPPE	50	8													3								15		15									
NPPE	50	10											1										10		20									
NPPE	50	12											6		8								7											
NPPE	50	16											8		4								7		15									
NPPE	50	21											1		2								5	3	12									
NPPE	50	26											1										10		15									
NPPE	35	5											1		1										7									
NPPE	35	7											2												10									
NPPE	35	12													3								1		25									
NPPE	35	14											5										20		15									2
NPPE	35	15																					7		12									
NPPE	35	17											5												20									
NPPE	35	20																							30									
NPPE	35	22													2										35									
NPPE	35	24											1		3								2		15									
NPPE	35	32																							15									
NPPE	15	1											1		5										15									
NPPE	15	11													1									12	15									
NPPE	15	13																							25									
NPPE	15	15																							15									
NPPE	15	16		1											5										15									2
NPPE	15	17																							25									
NPPE	15	18																							10									
NPPE	15	21											10												20									2
NPPE	15	27																							30									
NPPE	15	29										1													25									

Site	Depth	Location	Photo Name	Sponge (Sponge)	Spirastrealla vagabunda	Palythoa tuberculosa	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 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	1																					20		25									
H-bay	50	2												5									25		20									
H-bay	50	3											3										8		12									
H-bay	50	5																							6						20			20
H-bay	50	6																					40		10									
H-bay	50	12											1										50		20									
H-bay	50	18											15										10		30									
H-bay	50	21											15										5		20									
H-bay	50	22											7										15		30									
H-bay	50	32											1										25	25	10									
H-bay	35	1																							5						10			5
H-bay	35	2																					10		10						10			15
H-bay	35	7											2										20		15									
H-bay	35	9											5										7	10	10									
H-bay	35	11											1										2		15									
H-bay	35	12																							35									
H-bay	35	13											3										3	5	15									
H-bay	35	20																					1		15									
H-bay	35	27											5												30									
H-bay	35	33																							35									
H-bay	15	0																							25									
H-bay	15	13											5		3										20									
H-bay	15	16																							20									
H-bay	15	18													4										15									5
H-bay	15	20																					25		10									
H-bay	15	24																							10									
H-bay	15	27													2										20									5
H-bay	15	28																							35									5
H-bay	15	29													2										25									
H-bay	15	31																							5									

Site	Depth	Location	Photo Name	Sponge (Sponge)	Spirastrealla vagabunda	Palythoa tuberculosa	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 evermanni (Porev)	Porites lobata (Porlob)	Porites rus	Tubastrea coccinea (Tubcoc)	Sarcothelia edmondsoni	Inorganics	Basalt (Basalt)	Rubble	Limestone (Limest)	Quad (Quad)	Sand (Sand)
18	50	0											3												6						5			5
18	50	3																					2								5			5
18	50	7		1									5												10									5
18	50	9																							7									15
18	50	14											5												15									10
18	50	16											1												5						3			5
18	50	19											2												7						5			10
18	50	20																							10									10
18	50	27											3												12									5
18	50	33				1							5										2		10						5			5
18	35	0											1		3										15									
18	35	2		2									5												20									5
18	35	7		1									7		3										10						2			5
18	35	12													1										8									
18	35	14				2									2										12									
18	35	16											6												7									
18	35	20													1										8									
18	35	27											5												8									10
18	35	30											10												15						5			5
18	35	35											1		1										10						2			10
18	15	0																							20									
18	15	1													12										10									6
18	15	3											12		1																			4
18	15	4																							4									
18	15	5																							6									
18	15	11								2					3										15									3
18	15	18																							8									
18	15	23											5												6									10
18	15	28											5		5										8									10
18	15	37																							5									

Site	Depth	Location	Photo Name	Sponge (Sponge)	Spirastrealla vagabunda	Palythoa tuberculosa	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 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																																60
Wawa	50	5																																64
Wawa	50	7																																61
Wawa	50	12																													3			51
Wawa	50	16																																81
Wawa	50	18																																54
Wawa	50	21											1												3						2			30
Wawa	50	22																							3									31
Wawa	50	27		1																											2			44
Wawa	50	33																							8									40
Wawa	35	1		1									6		3										15									15
Wawa	35	4											1											20	10									
Wawa	35	5		2									4												15									5
Wawa	35	7		1																				2	20									5
Wawa	35	8											3		2										25									
Wawa	35	16		1									1											5	10									5
Wawa	35	20											4		2									5	20									10
Wawa	35	23		1		1																		6	10									30
Wawa	35	26											10		10										8									20
Wawa	35	36													1										2						3			47
Wawa	15	0				1									5										10									
Wawa	15	1																							15						3			
Wawa	15	2																				1			6									
Wawa	15	10											2												10						3			4
Wawa	15	11				1							3												5						5			
Wawa	15	18																							60									
Wawa	15	21													15										17						5			
Wawa	15	24																							15									
Wawa	15	32													5										5									
Wawa	15	36											5		3			2							15									3

Table 2.3 Benthic habitat characterization data – Mobile Invertebrates

Row Labels	Count of Conus sp.	Count of sponges	Count of flatworms	Count of D. paucispinum	Count of Echinometra mathaei	Count of Echinothrix sp.	Count of Tripneustes gratilla	Count of Echinostrephus aciculatus	Count of Acanthaster planci	Count of Ophiocoma erinaceus
15	1	3		4	13			1	1	
18				1	1					
12N		2		1					1	
12S	1									
H-bay				1	4					
NPPE		1			6			1		
Wawa				1	2					
35		5		7	15	1	2			
18		2		2	1					
12N		1		1						
12S		2			2					
H-bay				2	3		1			
NPPE				1	6		1			
Wawa				1	3	1				
50		5	2	4	15	2			1	1
18		1			2					
12N		1			2	1				
12S		3	2	1	1					
H-bay				2	4				1	1
NPPE				1	6					
Wawa						1				
Grand Total	**1**	**13**	**2**	**15**	**43**	**3**	**2**	**1**	**2**	**1**

Appendix 3: Nearshore fish assemblage data

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

Hoona Bay	4/20/17							
50'			35'			15'		
Species	**Individuals**	**Size (cm)**	**Species**	**Individuals**	**Size (cm)**	**Species**	Individuals	Size (cm)
M. kuntee	44	18	*A. nigrofuscus*	12	10	*A. nigrofuscus*	1	14
M. kuntee	24	19	*A. nigrofuscus*	11	12	*A. nigrofuscus*	4	12
M. kuntee	50	20	*C. agilis*	22	4	*A. nigrofuscus*	10	8
A. nigrofuscus	5	10	*C. agilis*	22	5	*A. nigrofuscus*	10	10
A. nigrofuscus	4	14	*C. strigosus*	7	12	*C. strigosus*	1	15
A. nigrofuscus	1	12	*C. strigosus*	3	14	*C. strigosus*	2	12
C. agilis	21	3	*C. strigosus*	2	10	*C. strigosus*	3	13
C. agilis	40	4	*C. jactator*	1	4	*C. strigosus*	4	10
C. agilis	59	5	*C. vanderbiliti*	22	2	*C. strigosus*	4	14
C. strigosus	3	12	*C. vanderbiliti*	30	3	*C. strigosus*	5	11
C. strigosus	1	9	*C. vanderbiliti*	12	4	*C. jactator*	1	5
C. strigosus	1	10	*N. literatus*	1	21	*C. vanderbiliti*	59	2
C. potteri	1	6	*N. literatus*	1	34	*C. vanderbiliti*	60	3
C. ephippium	1	23	*N. literatus*	1	23	*C. vanderbiliti*	14	4
D. albisella	2	7	*T. duperrey*	1	17	*T. duperrey*	2	4
N. literatus	1	7	*T. duperrey*	1	7	*T. duperrey*	2	8
N. literatus	1	9	*Z. flavescens*	5	12	*T. duperrey*	1	12
N. literatus	1	10	*Z. flavescens*	3	8	*T. duperrey*	2	3
N. literatus	1	20	*Z. flavescens*	1	10	*T. duperrey*	1	5
M. grandoculis	1	28	*Z. flavescens*	5	14	*Z. flavescens*	1	17
M. grandoculis	1	30	*S. bursa*	1	20	*Z. flavescens*	5	12
S. bursa	1	11	*C. sordidus*	2	17	*Z. flavescens*	4	13
S. bursa	1	17	*C. sordidus*	2	21	*Z. flavescens*	1	15
Z. flavescens	3	8	*C. sordidus*	1	22	*S. bursa*	1	16
Z. flavescens	3	10	*C. sordidus*	1	28	*C. multicinctus*	1	10
Z. flavescens	1	6	*C. sordidus*	1	23	*P. arcatus*	1	10
Z. flavescens	2	7	*C. sordidus*	1	28	*P. arcatus*	2	9
C. sordidus	1	22	*C. multicinctus*	2	10	*P. arcatus*	1	7
C. sordidus	1	18	*M. grandoculis*	1	33	*G. varius*	1	8
C. sordidus	1	11	*M. grandoculis*	1	40	*G. varius*	1	7
M. vidua	1	20	*C. gaimard*	1	15	*Z. cornutus*	1	17
M. vidua	1	22	*P. multifasciatus*	1	17	*Z. cornutus*	1	10
A. thompsoni	1	14	*G. varius*	1	14	*M. niger*	2	20
L. kasmira	1	24	*G. varius*	1	10	*M. niger*	1	24
O. unifasciatus	1	12	*G. varius*	1	5	*S. fasciolatus*	2	8
T. duperrey	1	14	*G. varius*	1	8	*H. ornatissimus*	1	12
T. duperrey	2	12	*M. vidua*	8	22	*C. carolinus*	1	13
T. duperrey	1	10	*M. vidua*	3	20	*C. carolinus*	1	16
T. duperrey	1	11	*P. johnstonianus*	1	5	*C. carolinus*	1	9
C. multicinctus	1	8	*P. insularis*	1	22	*P. insularis*	2	18
C. argus	1	30	*P. insularis*	1	20	*P. insularis*	1	15
S. rubroviolaceus	1	44	*Z. cornutus*	1	15	*N. literatus*	2	22
P. johnstonianus	2	5	*C. ornatissimus*	1	14	*N. literatus*	1	18
Z. cornutus	1	18	*C. hanui*	1	3	*N. literatus*	1	19
S. spiniferum	1	20	*P. octotania*	1	8	*A. leucopareius*	11	16
A. olivaceus	1	24	*C. quadrimaculatus*	2	12	*A. leucopareius*	6	14
F. flavissimus	1	12	*X. auromarginatus*	1	18	*A. leucopareius*	7	18
F. flavissimus	2	14	*H. ornatissimus*	2	12	*A. chinensis*	1	48
M. flavolineatus	15	22	*Kyphosus spp.*	1	20	*C. hawaiiensis*	1	17
C. gaimard	1	24	*G. meleagris*	1	90	*C. hawaiiensis*	1	15
						C. hawaiiensis	1	14
						Kyphosus spp.	2	22
						Kyphosus spp.	2	26
						M. vanicolensis	1	14
						M. vanicolensis	1	16
						P. johnstonianus	1	6
						A. vaigiensis	4	13
						A. vaigiensis	2	10
						A. abdominalis	5	13
						A. abdominalis	1	8

NPPE	5/7/16									
50'				35'				*15'*		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		***Species***	**Individuals**	**Size (cm)**
A. nigrofuscus	6	7		*A. nigrofuscus*	5	12		*A. nigrofuscus*	13	10
A. nigrofuscus	5	12		*A. nigrofuscus*	1	14		*A. nigrofuscus*	8	8
A. nigrofuscus	13	10		*A. nigrofuscus*	3	5		*A. nigrofuscus*	12	12
A. nigrofuscus	4	12		*A. nigrofuscus*	3	6		*A. nigrofuscus*	4	14
A. nigrofuscus	4	8		*A. nigrofuscus*	5	8		*C. strigosus*	7	12
C. strigosus	2	8		*C. strigosus*	3	10		*C. strigosus*	10	14
C. strigosus	7	10		*C. strigosus*	3	8		*C. strigosus*	5	10
C. strigosus	2	12		*C. strigosus*	8	12		*Z. flavescens*	13	10
C. strigosus	3	5		*C. strigosus*	1	14		*Z. flavescens*	10	15
G. varius	1	12		*C. strigosus*	3	5		*Z. flavescens*	2	14
G. varius	1	16		*P. johnstonianus*	2	6		*Z. flavescens*	8	12
C. sordidus	1	18		*G. varius*	1	14		*Z. flavescens*	6	14
C. sordidus	1	25		*C. sordidus*	3	16		*M. vidua*	1	19
C. sordidus	1	30		*C. sordidus*	1	17		*C. multicinctus*	3	8
C. sordidus	1	14		*C. sordidus*	1	21		*T. duperrey*	2	9
C. sordidus	1	16		*T. duperrey*	1	8		*T. duperrey*	1	13
C. sordidus	1	22		*T. duperrey*	3	13		*T. duperrey*	2	6
T. duperrey	2	14		*T. duperrey*	2	12		*T. duperrey*	2	8
T. duperrey	1	12		*T. duperrey*	1	15		*T. duperrey*	1	4
T. duperrey	1	9		*Z. flavescens*	3	13		*C. vanderbilti*	20	3
Z. flavescens	8	14		*Z. flavescens*	2	15		*C. vanderbilti*	20	2
Z. flavescens	1	10		*Z. flavescens*	8	12		*C. vanderbilti*	9	2
Z. flavescens	1	13		*Z. flavescens*	6	10		*C. vanderbilti*	9	3
Z. flavescens	2	12		*Z. flavescens*	3	8		*N. literatus*	1	22
C. multicinctus	1	8		*P. arcatus*	1	8		*N. literatus*	2	21
C. multicinctus	1	6		*S. bursa*	1	16		*C. sordidus*	1	13
C. agilis	16	5		*C. jactator*	1	4		*Z. cornutus*	1	13
P. multifasciatus	1	13		*C. hanui*	1	3		*C. argus*	1	22
N. literatus	2	24		*H. ornatissimus*	1	14		*A. olicaceus*	1	28
N. literatus	1	20		*C. ornatissimus*	1	12		*M. niger*	2	22
N. literatus	2	23		*C. ornatissimus*	2	15		*M. niger*	3	23
N. literatus	1	17		*N. literatus*	3	17		*M. niger*	1	20
M. vidua	1	18		*N. literatus*	2	19		*C. ornatissimus*	1	12
S. bursa	1	17		*N. literatus*	1	15		*S. rubroviolaceus*	1	13
S. bursa	1	10		*N. literatus*	1	22		*P. forsteri*	1	12
S. bursa	1	13		*N. literatus*	2	16		*A. meleagris*	1	16
C. ornatissimus	2	12		*N. literatus*	2	18		*A. triostegus*	3	13
C. ornatissimus	2	14		*N. literatus*	1	30		*P. cyclostomus*	1	23
X. auromarginatus	1	14		*A. nigricans*	1	9		*P. multifasciatus*	1	16
Z. cornutus	1	12		*A. nigricans*	1	12		*P. imparipennis*	1	3
C. dumerilii	1	13		*A. olivaceus*	1	24				
A. nigricans	1	7		*A. olivaceus*	1	28				
F. flavissimus	1	12		*S. rubroviolaceus*	1	32				
P. arcatus	1	6		*C. agilis*	4	5				
				C. multicinctus	3	8				
				C. agilis	1	16				
				A. abdominalis	7	15				

12 Pipe North	5/7/16									
50'				35'				15'		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**
A. nigrofuscus	1	8		*A. nigrofuscus*	1	9		*A. nigrofuscus*	1	12
A. nigrofuscus	1	10		*A. nigrofuscus*	2	12		*A. nigrofuscus*	2	10
A. nigrofuscus	2	12		*A. nigrofuscus*	6	13		*C. strigosus*	2	10
C. strigosus	1	13		*C. strigosus*	8	12		*C. strigosus*	13	14
C. strigosus	8	14		*C. strigosus*	8	14		*C. strigosus*	7	12
C. strigosus	2	9		*C. strigosus*	1	16		*G. varius*	1	14
C. strigosus	3	11		*C. strigosus*	11	12		*G. varius*	1	6
C. strigosus	10	12		*C. gaimard*	1	10		*C. gaimard*	3	14
C. strigosus	5	10		*C. sordidus*	1	27		*C. sordidus*	2	18
C. strigosus	5	16		*C. sordidus*	1	26		*C. sordidus*	1	22
P. johnstonianus	2	7		*C. hawaiiensis*	1	17		*T. duperrey*	1	9
P. johnstonianus	1	8		*T. duperrey*	2	9		*T. duperrey*	1	7
G. varius	1	14		*T. duperrey*	1	12		*Z. flavescens*	15	10
C. gaimard	1	13		*T. duperrey*	1	14		*Z. flavescens*	20	16
C. sordidus	1	26		*T. duperrey*	1	7		*Z. flavescens*	20	12
C. sordidus	2	16		*T. duperrey*	1	15		*Z. flavescens*	29	14
C. sordidus	1	24		*Z. flavescens*	4	16		*C. multicinctus*	1	11
C. sordidus	1	30		*Z. flavescens*	15	14		*C. multicinctus*	1	12
C. sordidus	2	13		*Z. flavescens*	8	13		*P. arcatus*	1	11
C. hawaiiensis	1	14		*Z. flavescens*	12	12		*C. vanderbilti*	26	2
T. duperrey	1	13		*P. arcatus*	1	7		*C. vanderbilti*	26	3
T. duperrey	1	14		*P. arcatus*	1	9		*N. literatus*	1	22
T. duperrey	1	12		*P. forsteri*	1	18		*C. jactator*	2	7
T. duperrey	1	9		*C. vanderbilti*	28	3		*C. jactator*	1	6
Z. flavescens	6	15		*C. vanderbilti*	10	2		*C. quadrimaculatus*	2	14
Z. flavescens	21	14		*C. vanderbilti*	2	4		*C. quadrimaculatus*	2	12
Z. flavescens	8	10		*A. xanthopterus*	1	44		*C. argus*	1	24
Z. flavescens	3	8		*S. bursa*	1	19		*C. argus*	1	26
Z. flavescens	16	12		*N. literatus*	1	25		*A. triostegus*	11	15
Z. flavescens	9	16		*C. ornatissimus*	1	16		*A. blochii*	4	36
C. multicinctus	1	12		*H. polylepis*	2	14		*A. blochii*	3	40
C. multicinctus	3	11		*C. argus*	1	25		*A. blochii*	3	30
C. multicinctus	1	9		*C. argus*	1	30		*A. blochii*	3	50
P. arcatus	1	10		*C. melampygus*	1	27		*A. leucopareius*	2	14
P. forsteri	1	15		*M. berndti*	6	19		*A. nigricans*	1	12
C. agilis	3	6		*P. aspricaudus*	1	12		*C. ornatissimus*	2	15
C. agilis	5	5		*A. nigroris*	1	16		*Z. cornutus*	1	15
C. agilis	6	3		*A. nigricans*	1	13		*S. fasciolatus*	2	10
F. flavissimus	1	16		*A. nigricans*	1	10		*S. fasciolatus*	1	12
H. thompsoni	1	15		*F. commersonii*	1	142		*S. rubroviolaceus*	1	22
H. ornatissimus	1	12						*S. rubroviolaceus*	1	47
P. multifasciatus	1	21						*S. psittacus*	1	24
C. vanderbilti	23	2						*Decapterus spp.*	26	24
C. vanderbilti	24	3								
S. balteata	1	9								
A. olivaceus	2	29								
A. xanthopterus	2	36								
A. xanthopterus	1	42								
S. bursa	1	19								
N. literatus	2	24								
M. vidua	1	22								
P. insularis	1	18								
P. pleurostigma	1	19								

12 Pipe South 5/7/16

50'

Species	Individuals	Size (cm)
A. nigrofuscus	4	10
A. nigrofuscus	3	14
C. agilis	35	3
C. agilis	35	4
C. strigosus	4	8
C. strigosus	5	14
C. strigosus	5	11
C. vanderbiliti	100	2
C. vanderbiliti	50	4
C. vanderbiliti	50	3
N. literatus	1	17
N. literatus	3	28
N. literatus	1	24
N. literatus	2	25
N. literatus	3	30
T. duperrey	12	12
S. bursa	1	13
C. sordidus	1	23
C. sordidus	1	30
C. sordidus	1	8
C. sordidus	1	15
C. sordidus	1	25
P. arcatus	2	9
G. varius	1	7
G. varius	1	12
H. ornatissimus	1	10
H. ornatissimus	1	13
C. potteri	1	6
C. gaimard	1	26
T. duperrey	1	14
T. duperrey	13	27
T. duperrey	9	28
H. polylepis	25	14
H. polylepis	2	15
H. polylepis	14	16
H. polylepis	10	13
A. thomnpsoni	11	16
A. thomnpsoni	7	13
A. thomnpsoni	6	14
A. thomnpsoni	11	16
N. hexacanthus	1	30
N. hexacanthus	1	38
N. hexacanthus	3	40
N. hexacanthus	2	34
N. hexacanthus	2	42
H. ornatissimus	1	12
C. multicinctus	1	10
C. multicinctus	2	8
A. nigricans	1	7
C. hanui	1	4
A. xanthopterus	1	32
A. xanthopterus	1	35
Z. cornutus	1	14
Z. cornutus	1	13
P. multifasciatus	1	17
A. furca	1	28
Z. flavescens	2	15
Z. flavescens	1	12
Z. flavescens	1	6
Z. flavescens	1	8
Z. flavescens	1	10
C. melampygus	1	40
C. melampygus	1	42
M. vidua	1	21
A. olivaceus	2	24
A. olivaceus	1	28
N. brevirostris	1	36
N. brevirostris	1	32
M. geoffroyi	1	7
O. unifasciatus	1	20
O. unifasciatus	1	17
C. gaimard	1	26
L. phthirophagus	1	6

35'

Species	Individuals	Size (cm)
A. nigrofuscus	9	12
A. nigrofuscus	8	10
A. nigrofuscus	9	8
A. nigrofuscus	8	10
C. vanderbiliti	54	2
C. vanderbiliti	15	4
C. vanderbiliti	54	3
N. literatus	1	34
N. literatus	1	28
N. literatus	3	25
N. literatus	4	23
N. literatus	3	26
N. literatus	2	20
N. literatus	3	28
T. duperrey	3	9
T. duperrey	2	12
T. duperrey	1	8
C. sordidus	2	15
C. sordidus	1	28
C. sordidus	1	18
C. multicinctus	3	9
C. multicinctus	2	6
P. arcatus	1	10
H. ornatissimus	1	9
H. polylepis	17	3
H. polylepis	10	15
F. flavissimus	1	9
Z. flavescens	3	13
Z. flavescens	3	15
Z. flavescens	3	16
C. dumerilii	1	14
C. strigosus	2	12
C. strigosus	3	13
C. hawaiiensis	1	15
C. hawaiiensis	2	17
S. bursa	1	18
C. gaimard	1	6
C. gaimard	1	16
C. gaimard	1	28
M. geoffroyi	1	7
A. thompsoni	3	13
G. varius	1	8
A. olivaceus	1	21
A. olivaceus	2	25
S. rubroviolaceus	1	39
C. quadrimaculatus	2	12
C. unimaculatus	1	11

15'

Species	Individuals	Size (cm)
A. nigrofuscus	10	9
A. nigrofuscus	10	12
A. nigrofuscus	13	10
C. vanderbiliti	30	2
C. vanderbiliti	35	3
N. literatus	1	30
N. literatus	1	26
N. literatus	2	20
Z. flavescens	6	12
Z. flavescens	5	16
Z. flavescens	8	10
Z. flavescens	7	15
Z. cornutus	2	13
C. strigosus	5	10
C. strigosus	5	14
C. strigosus	3	12
A. olivaceus	1	14
Kyphosus spp.	1	26
Kyphosus spp.	1	23
Kyphosus spp.	1	24
Kyphosus spp.	3	17
T. duperrey	1	8
T. duperrey	2	10
T. duperrey	2	14
A. guttatus	1	15
A. olivaceus	1	14
C. lunula	2	13
C. gaimard	1	7
C. quadrimaculatus	2	13
C. ornatissimus	1	16
S. bursa	1	14
S. bursa	1	16
M. vidua	1	17
C. carolinus	1	16
G. meleagris	1	40
S. psittacus	1	22

18	5/8/16									
50'				35'				15'		
Species	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**		**Species**	**Individuals**	**Size (cm)**
A. nigrofuscus	11	6		*A. nigrofuscus*	8	12		*A. nigrofuscus*	10	8
A. nigrofuscus	9	12		*A. nigrofuscus*	18	10		*A. nigrofuscus*	10	13
A. nigrofuscus	19	10		*A. nigrofuscus*	7	11		*A. nigrofuscus*	11	12
P. ewaensis	1	6		*C. agilis*	7	4		*C. strigosus*	5	8
C. agilis	4	5		*C. agilis*	2	5		*C. strigosus*	10	12
C. agilis	26	4		*C. strigosus*	5	12		*C. strigosus*	5	10
C. strigosus	6	12		*C. strigosus*	7	16		*C. strigosus*	9	18
C. jactator	1	3		*C. vanderbiliti*	45	3		*C. strigosus*	7	15
C. jactator	2	4		*C. vanderbiliti*	34	2		*N. literatus*	1	24
C. vanderbiliti	42	3		*C. vanderbiliti*	13	12		*N. literatus*	1	27
C. vanderbiliti	42	4		*C. vanderbiliti*	13	3		*T. duperrey*	2	13
T. duperrey	1	4		*S. bursa*	1	18		*T. duperrey*	1	15
T. duperrey	1	12		*M. vidua*	1	23		*T. duperrey*	3	10
T. duperrey	4	9		*C. gaimard*	1	22		*T. duperrey*	3	12
T. duperrey	2	10		*C. lunula*	2	15		*C. multicinctus*	3	10
S. bursa	1	8		*F. flavissimus*	1	13		*C. multicinctus*	2	11
S. bursa	1	23		*N. literatus*	1	22		*P. arcatus*	1	9
C. multicinctus	2	5		*T. duperrey*	3	8		*Z. flavescens*	4	15
C. multicinctus	1	4		*T. duperrey*	1	9		*Z. flavescens*	9	13
C. multicinctus	1	2		*T. duperrey*	1	6		*Z. flavescens*	9	16
A. olivaceus	1	7		*T. duperrey*	2	12		*Z. flavescens*	9	14
A. olivaceus	2	26		*T. duperrey*	1	7		*S. fasciolatus*	2	9
A. olivaceus	1	20		*T. duperrey*	4	13		*G. varius*	1	7
P. octotania	1	9		*T. duperrey*	1	16		*C. ornatissimus*	2	16
P. octotania	2	7		*T. duperrey*	1	3		*C. jactator*	1	6
Z. flavescens	5	7		*T. duperrey*	1	8		*C. jactator*	2	7
Z. flavescens	3	9		*C. multicinctus*	3	9		*C. sordidus*	1	19
Z. flavescens	5	14		*P. arcatus*	1	9		*F. flavissimus*	1	11
C. gaimard	1	21		*P. arcatus*	1	7		*F. longirostris*	2	14
C. gaimard	1	6		*P. arcatus*	1	11		*C. lunula*	3	17
C. ornatissimus	2	14		*P. multifasciatus*	1	18		*C. hawaiiensis*	4	17
P. evanidus	1	7		*P. multifasciatus*	1	12		*C. hawaiiensis*	3	16
P. evanidus	1	5		*P. multifasciatus*	1	16		*C. hawaiiensis*	6	20
N. literatus	2	26		*Z. flavescens*	4	12		*C. hawaiiensis*	3	18
N. literatus	4	28		*Z. flavescens*	13	14		*C. hawaiiensis*	3	25
N. literatus	1	26		*Z. flavescens*	10	13		*C. hawaiiensis*	1	7
G. varius	2	13		*Z. flavescens*	1	15		*C. hawaiiensis*	3	8
C. potteri	2	5		*G. varius*	1	9		*C. hawaiiensis*	1	18
H. ornatissimus	2	6		*G. varius*	1	7		*A. leucopareius*	2	14
H. ornatissimus	1	8		*G. varius*	1	11		*A. leucopareius*	3	18
H. ornatissimus	2	10		*A. olivaceus*	1	21		*A. leucopareius*	2	15
H. ornatissimus	2	9		*A. olivaceus*	1	25		*C. vanderbiliti*	157	2
P. arcatus	1	12		*C. quadrimaculatus*	1	13		*C. vanderbiliti*	55	3
P. arcatus	2	7		*H. ornatissimus*	1	11		*C. vanderbiliti*	50	4
P. arcatus	1	9		*G. meleagris*	30			*M. burndti*	3	15
S. rubroviolaceus	1	29		*P. tetrataenia*	1	4		*Kyphosus spp.*	3	22
S. rubroviolaceus	1	24		*C. sordidus*	1	22		*Kyphosus spp.*	3	24
P. tetrataenia	1	5		*C. sordidus*	1	15		*O. unifasciatus*	1	25
				C. sordidus	1	19		*P. insularis*	1	23
				C. sordidus	1	28		*C. quadrimaculatus*	2	13
				C. sordidus	1	21		*M. vanicolensis*	6	21
								M. vanicolensis	11	18
								M. vanicolensis	11	20
								P. forsteri	1	16
								C. unimaculatus	2	12
								A. triostegus	6	15
								P. johnstonianus	1	7
								S. bursa	1	17
								S. fasciolatus	1	8
								L. phthirophagus	1	6
								M. grandoculis	1	44
								M. grandoculis	3	40
								M. grandoculis	1	38
								S. rubroviolaceus	1	40
								S. rubroviolaceus	1	48
								C. melampygus	1	50
								C. melampygus	3	42
								C. melampygus	2	45
								M. vidua	1	21
								M. vidua	1	24
								A. olivaceus	1	22
								A. olivaceus	1	24
								Z. veliferum	1	24
								Z. veliferum	1	27

Wawa	5/8/16							
50'			35'			15'		
Species	**Individuals**	**Size (cm)**	**Species**	**Individuals**	**Size (cm)**	**Species**	**Individuals**	**Size (cm)**
C. strigosus	1	4	*A. nigrofuscus*	1	16	*A. nigrofuscus*	14	11
C. vanderbiliti	18	2	*A. nigrofuscus*	1	10	*A. nigrofuscus*	6	12
C. vanderbiliti	7	4	*A. nigrofuscus*	7	9	*A. nigrofuscus*	9	14
C. vanderbiliti	15	3	*A. nigrofuscus*	8	11	*N. literatus*	4	23
T. duperrey	1	11	*T. duperrey*	1	12	*N. literatus*	6	30
S. bursa	2	19	*T. duperrey*	2	14	*N. literatus*	1	33
A. olivaceus	1	28	*T. duperrey*	2	15	*N. literatus*	1	19
A. olivaceus	1	25	*T. duperrey*	2	10	*N. literatus*	4	27
O. unifasciatus	1	10	*C. vanderbiliti*	28	4	*T. duperrey*	1	9
X. pavo	1	22	*C. vanderbiliti*	90	3	*T. duperrey*	2	12
C. gaimard	1	20	*C. vanderbiliti*	4	5	*T. duperrey*	2	16
X. auromarginatus	1	19	*C. vanderbiliti*	24	2	*T. duperrey*	3	14
N. literatus	1	22	*Z. flavescens*	3	15	*T. duperrey*	1	9
P. evanidus	1	5	*S. brursa*	1	19	*T. duperrey*	1	10
P. evanidus	1	7	*H. ornatissimus*	2	12	*T. duperrey*	2	5
P. evanidus	2	10	*H. ornatissimus*	1	9	*S. bursa*	1	14
P. evanidus	1	9	*H. ornatissimus*	1	6	*Z. flavescens*	1	13
G. meleagris	1	90	*H. ornatissimus*	1	7	*Z. flavescens*	6	15
			G. varius	*1*	*11*	*Z. flavescens*	1	17
			A. olivaceus	2	21	*C. vanderbilti*	13	2
			A. olivaceus	2	24	*C. vanderbilti*	5	3
			A. olivaceus	4	19	*C. quadrimaculatus*	1	12
			A. olivaceus	1	27	*P. multifasciatus*	1	18
			C. jactator	1	7	*F. flavissimus*	2	13
			H. ornatissimus	2	12	*C. lunula*	1	16
			H. ornatissimus	1	9	*C. ornatissimus*	1	16
			H. ornatissimus	1	6	*A. abdominalis*	7	13
			H. ornatissimus	1	7	*Z. cornutus*	1	14
			P. evanidus	1	4	*S. rubroviolaceus*	1	24
			P. evanidus	1	7	*P. insularis*	1	18
			P. evanidus	1	6	*S. psittacus*	1	26
			C. lunula	1	16	*R. rectangulus*	1	17
			A. nigroris	1	18			
			A. nigroris	1	4			

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

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	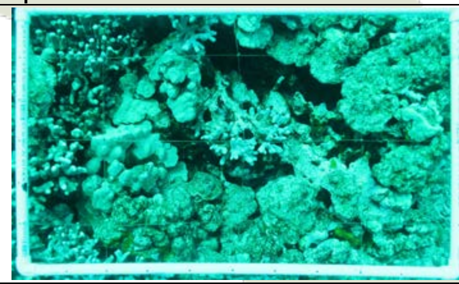
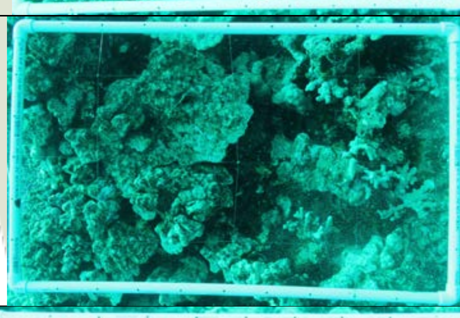	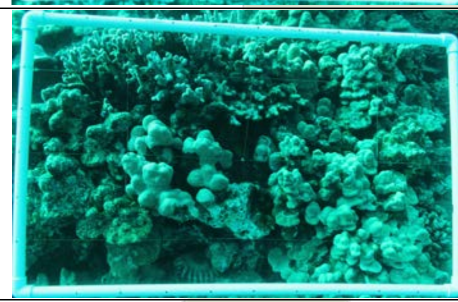
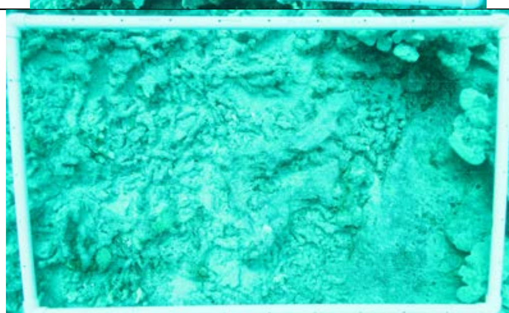	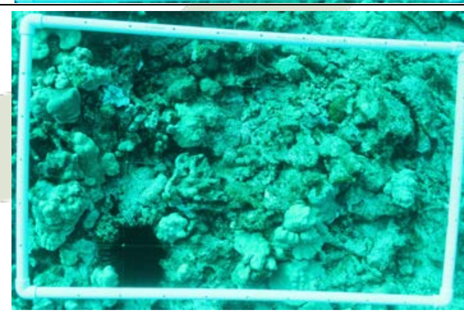
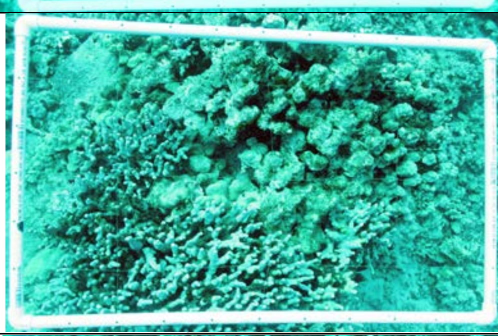	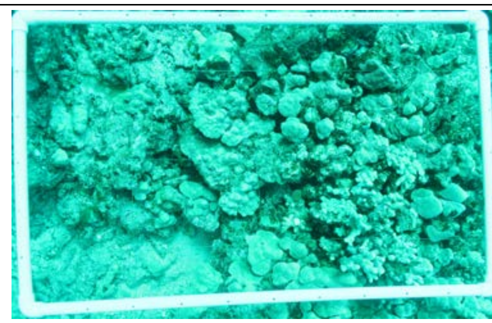
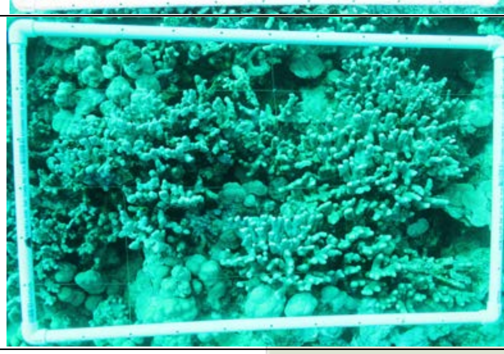	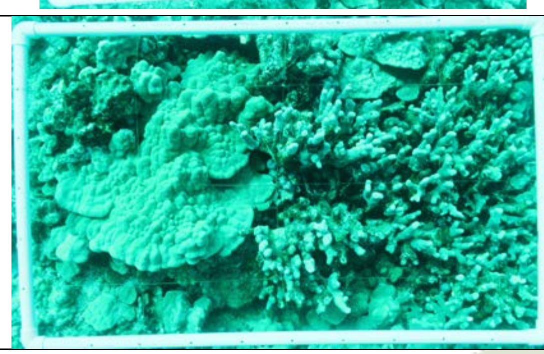

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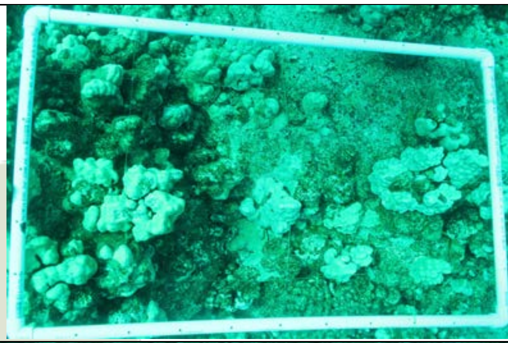	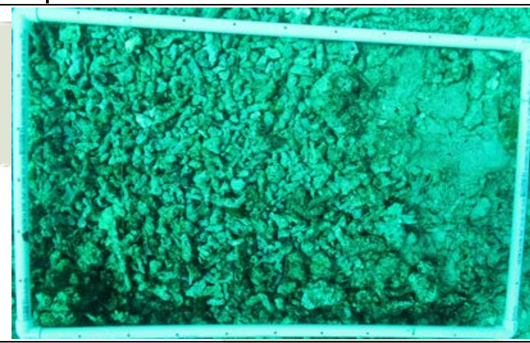
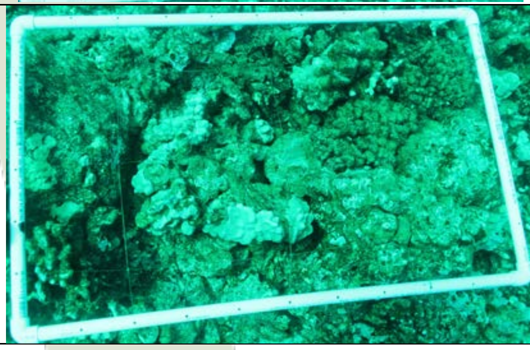	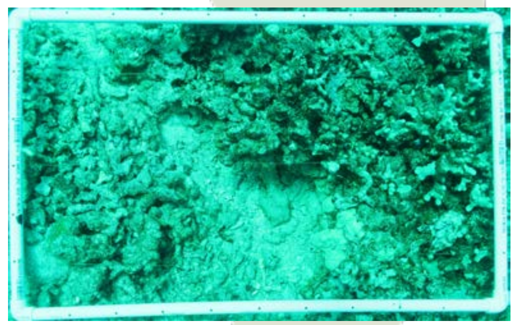
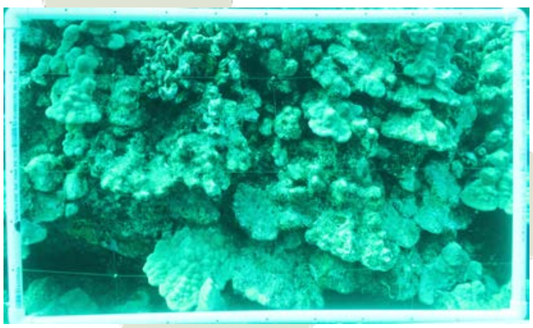	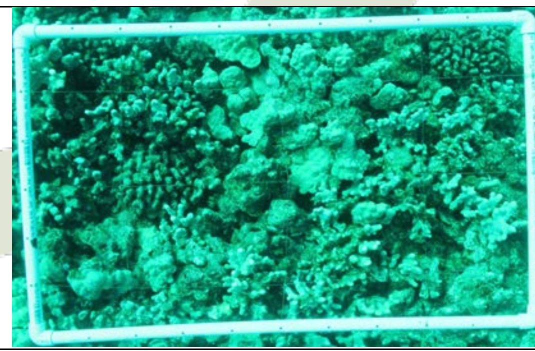
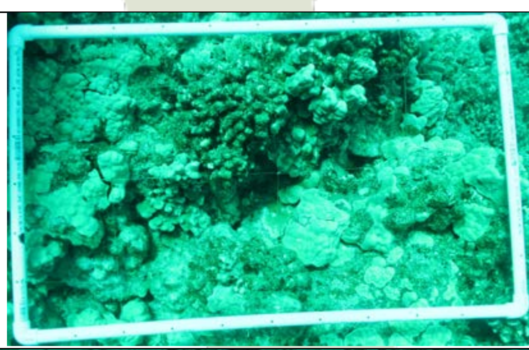	
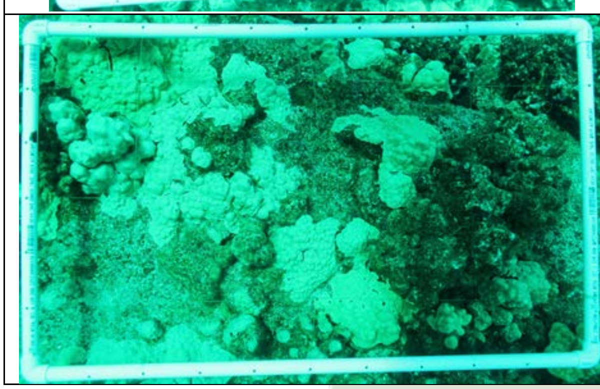	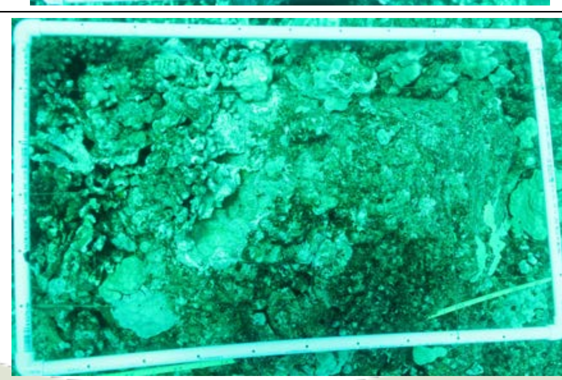

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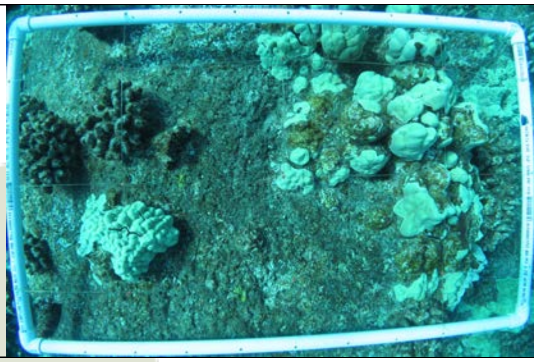	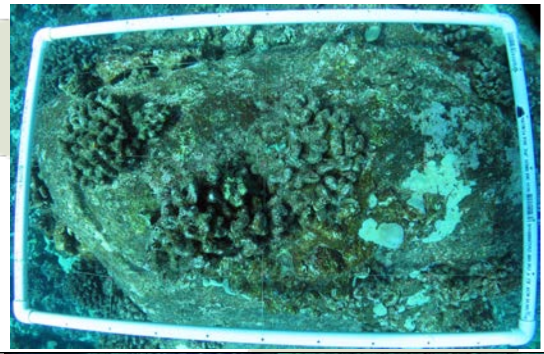
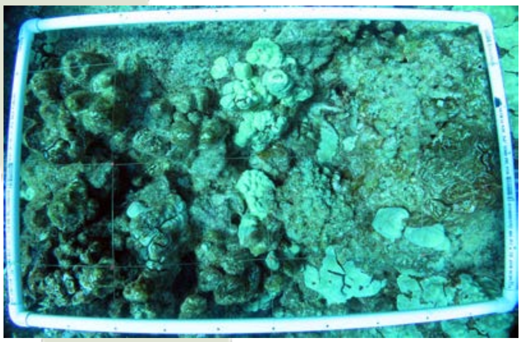	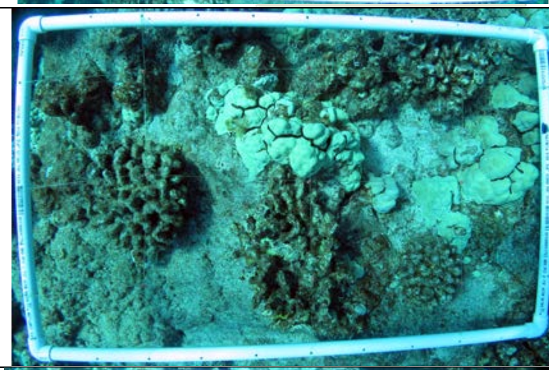
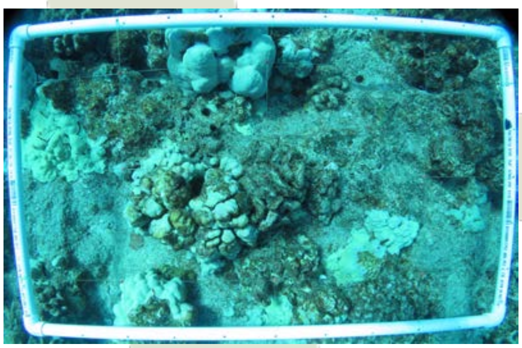	
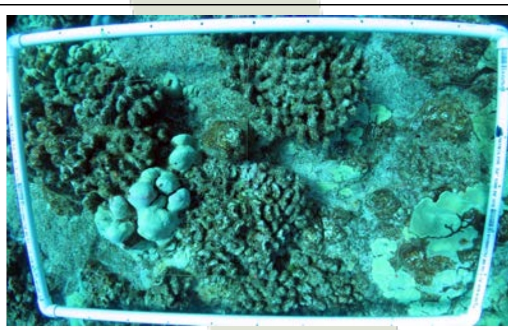	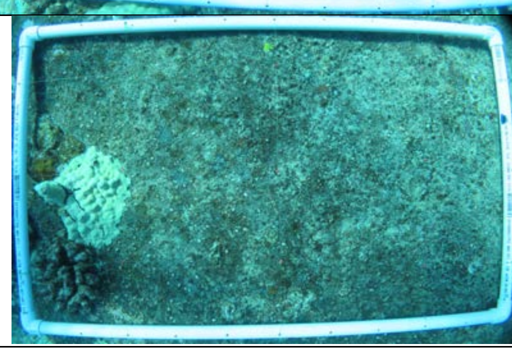
	

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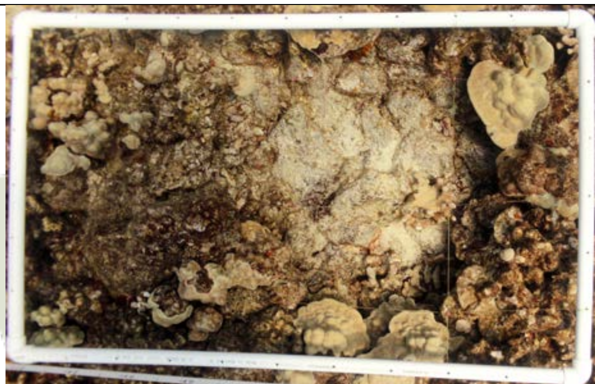
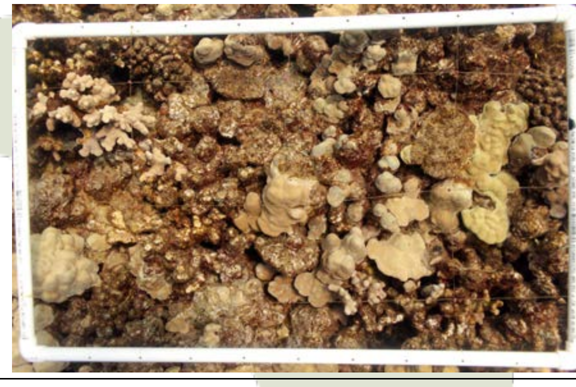
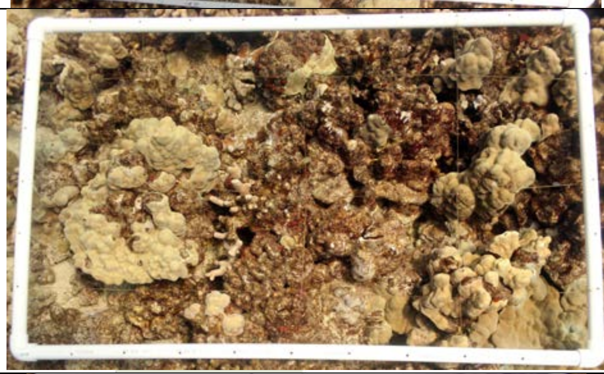
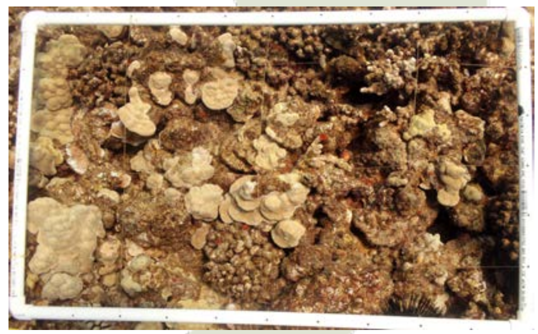

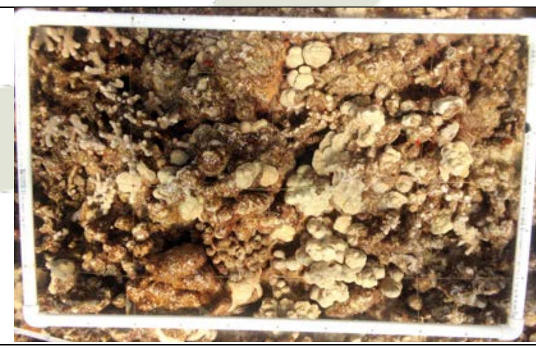

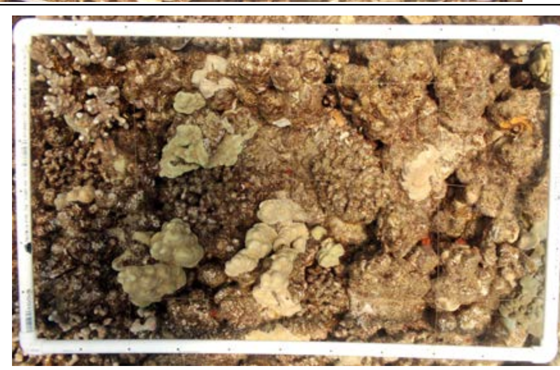
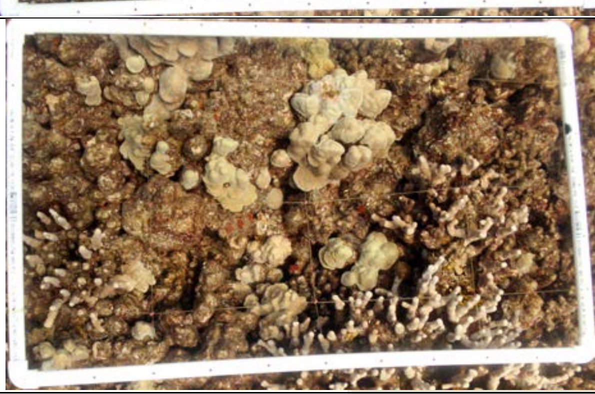
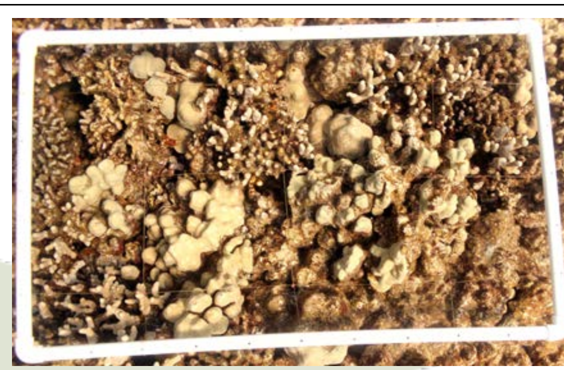

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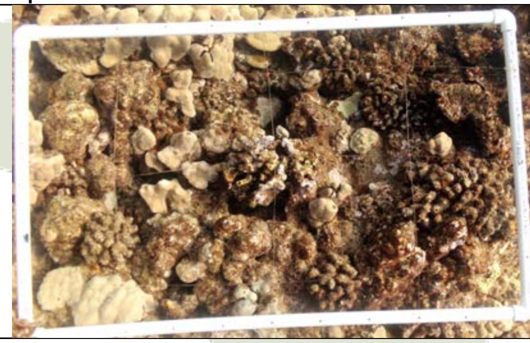
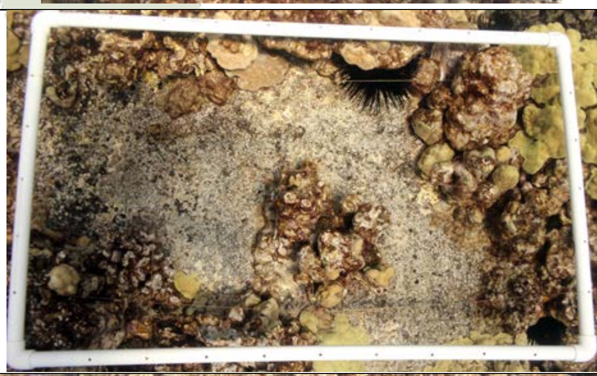
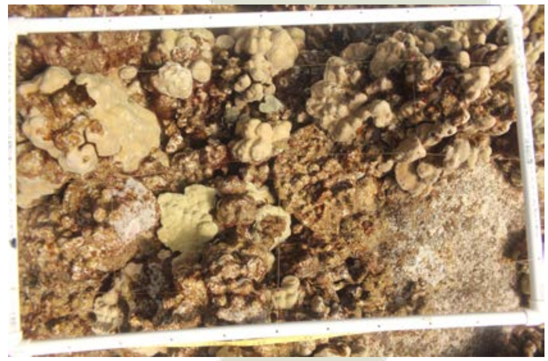
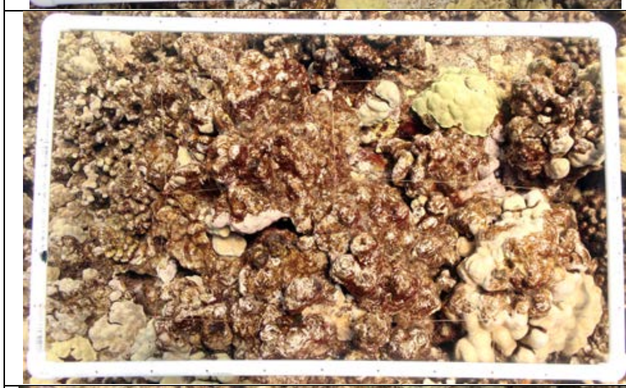
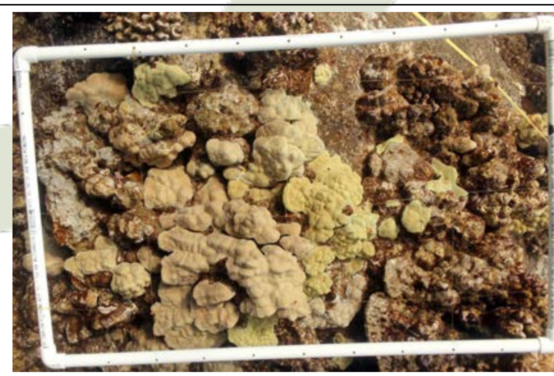
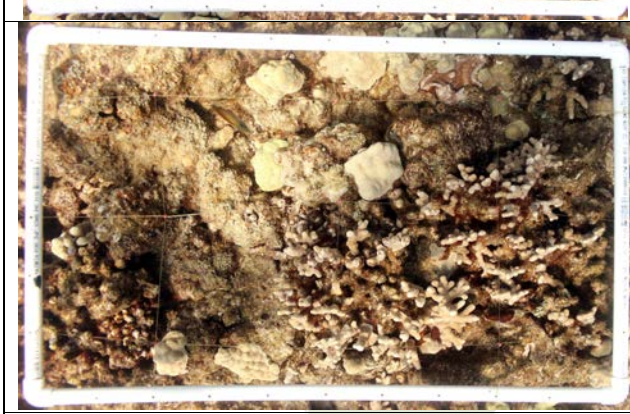
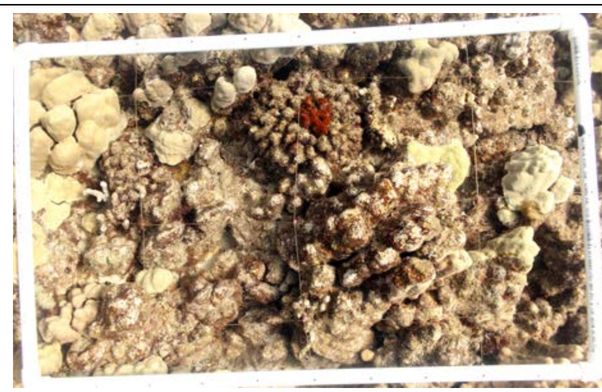
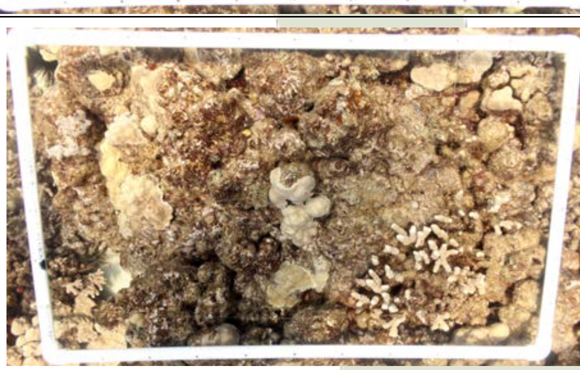
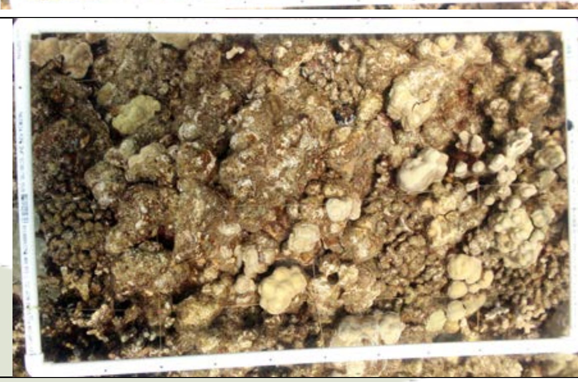

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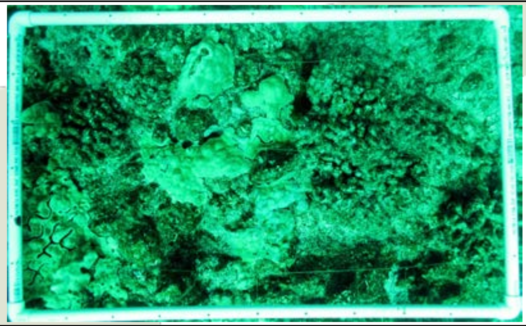	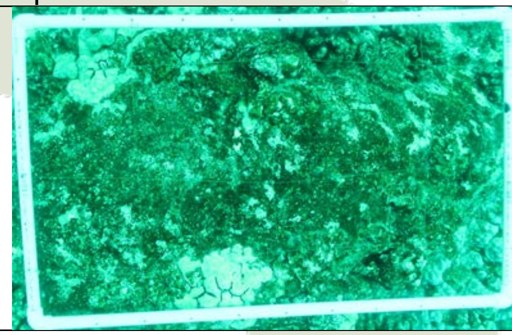
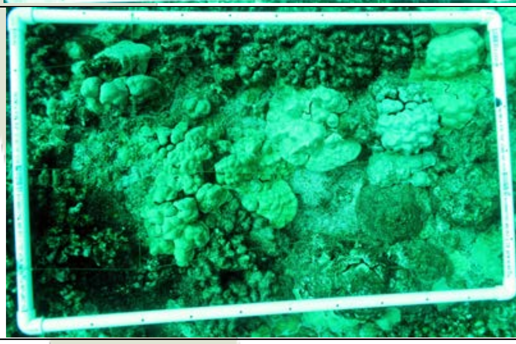	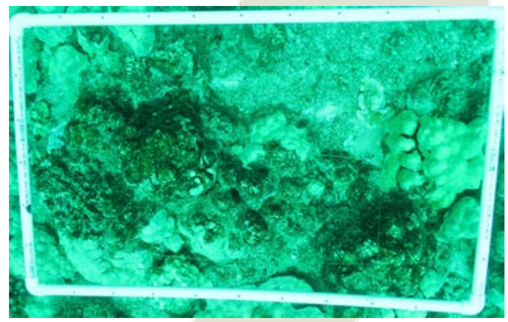
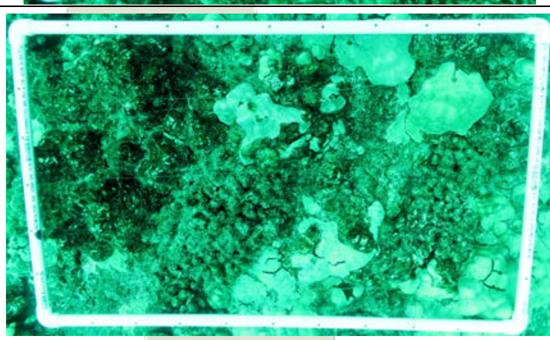	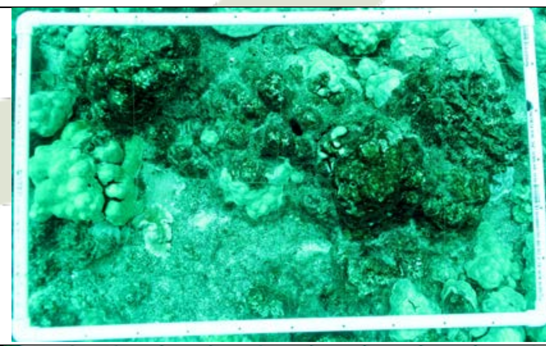
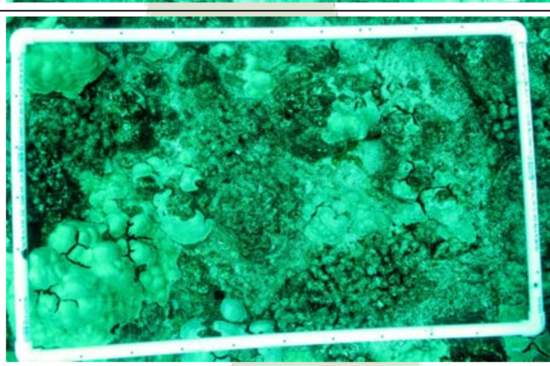	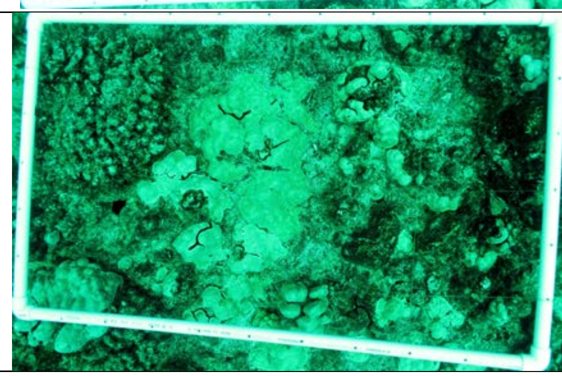
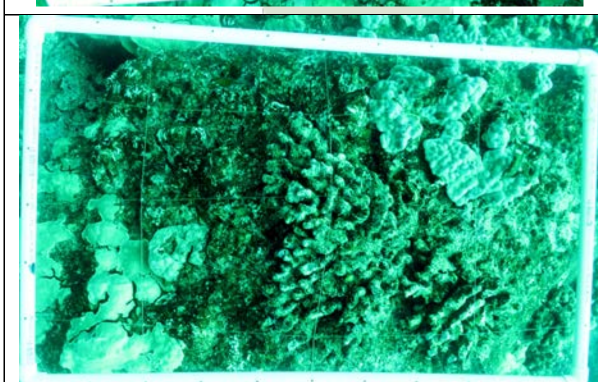	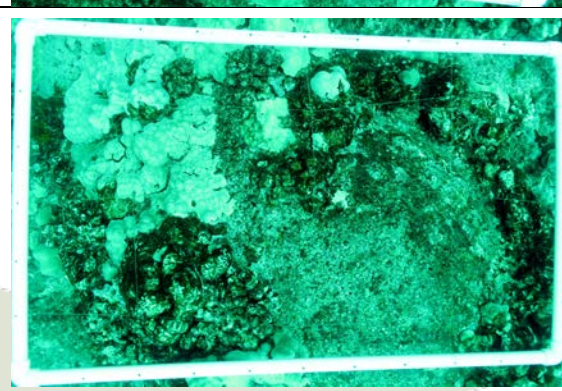

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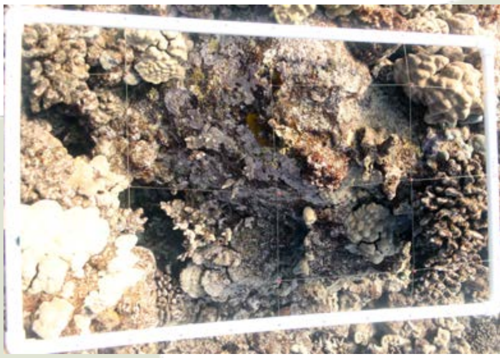	
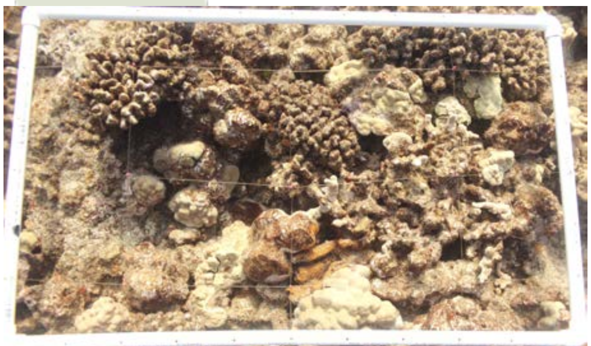	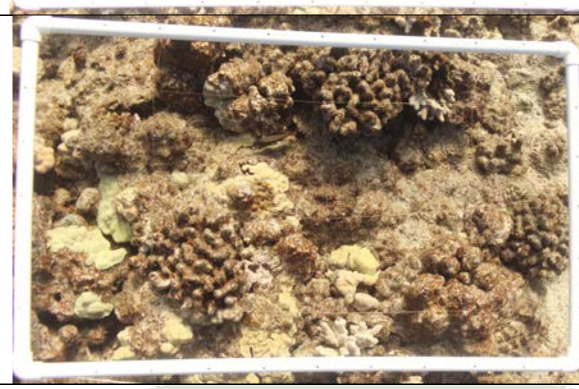
	
	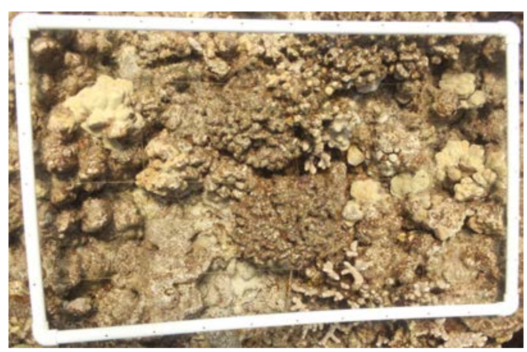
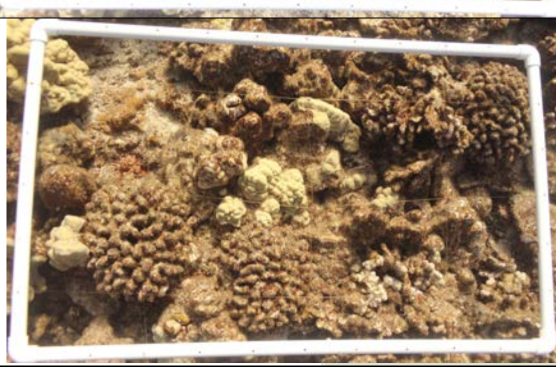	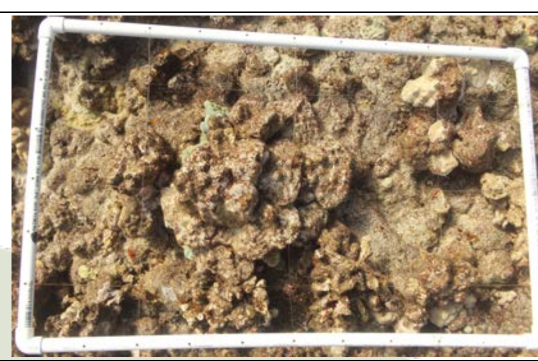

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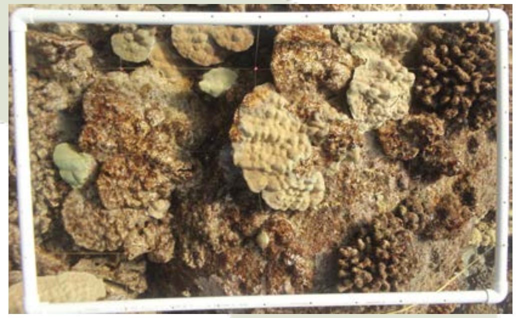
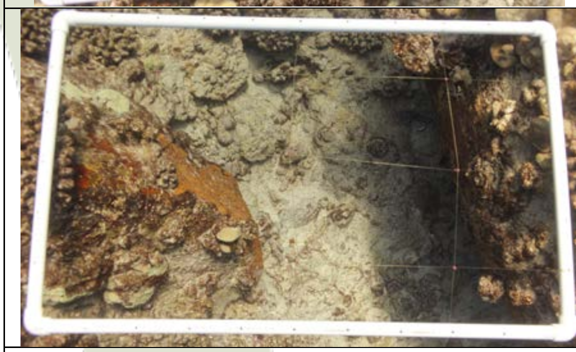
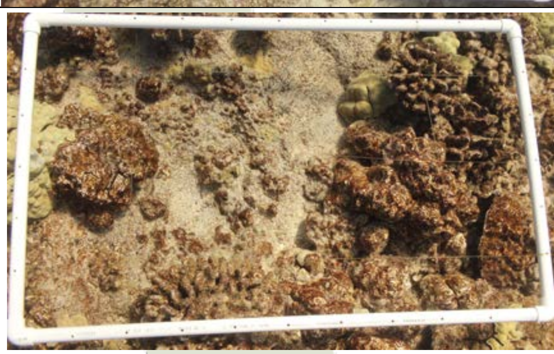
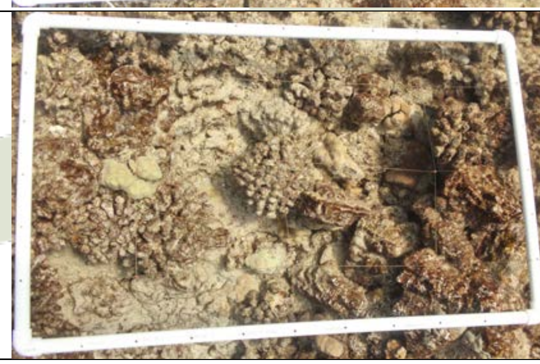
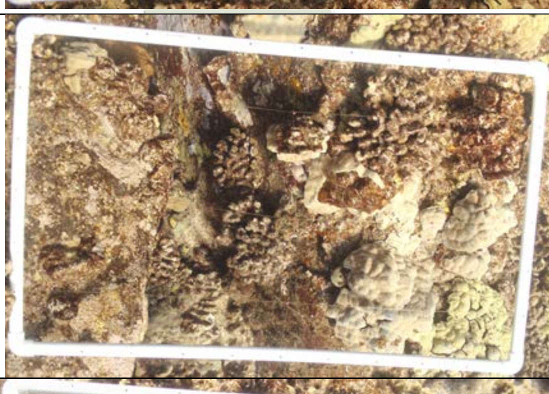
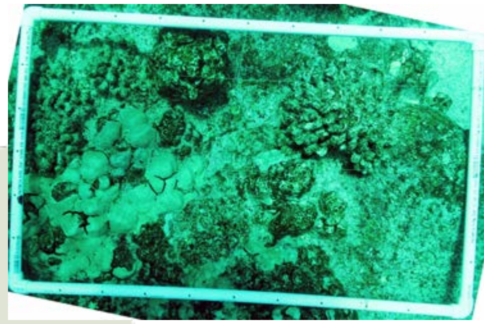
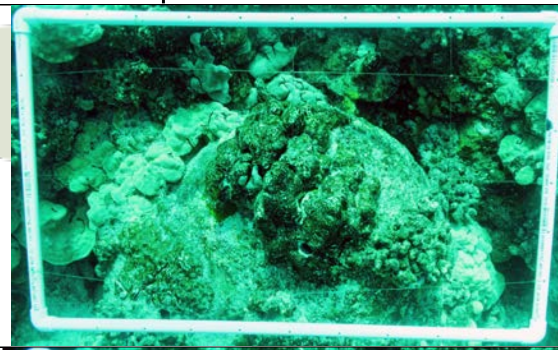
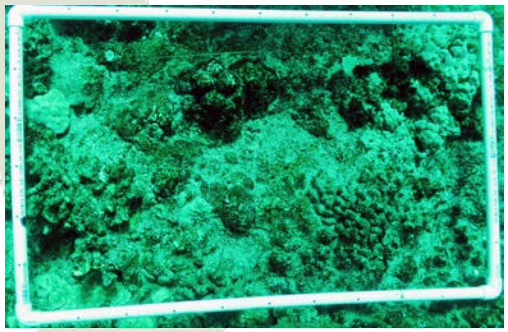
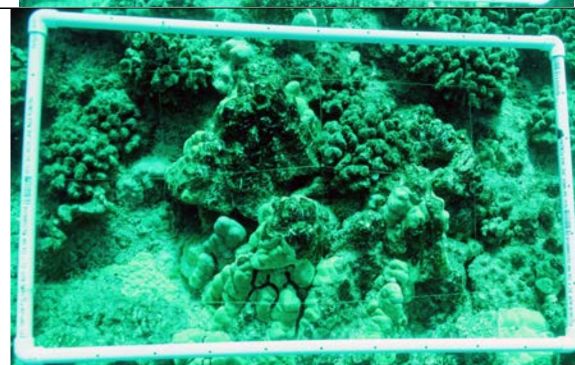
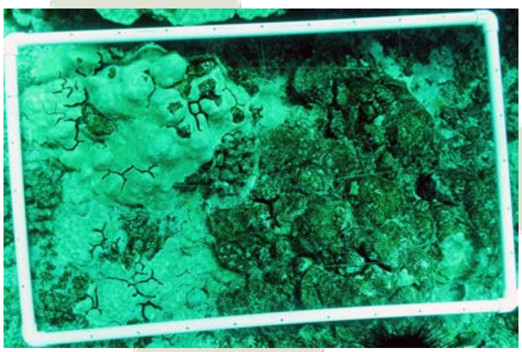
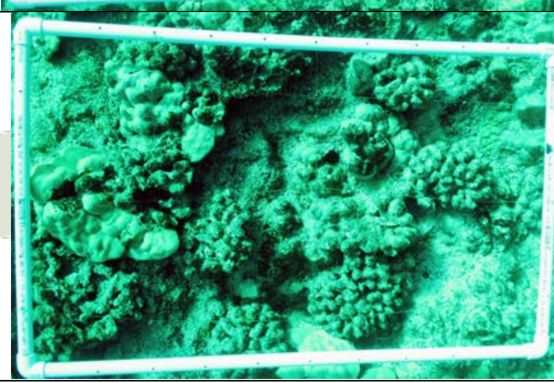
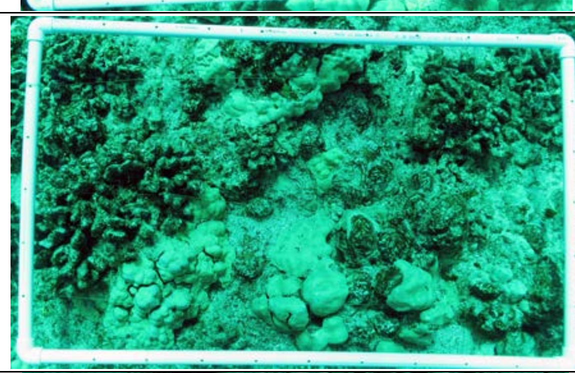
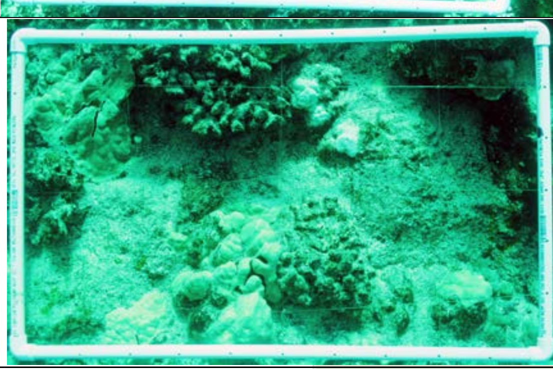
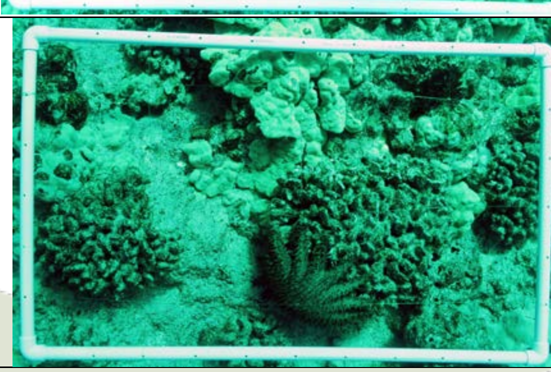
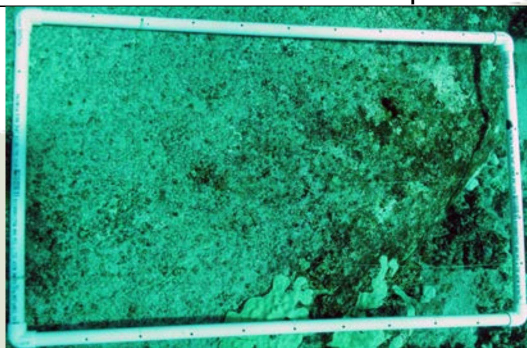
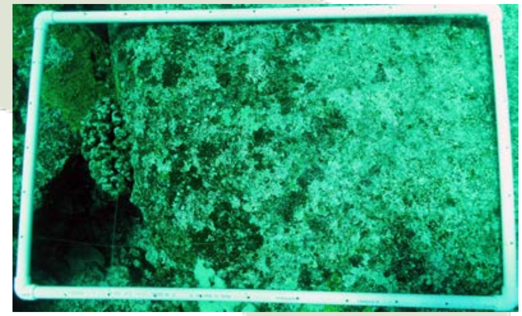
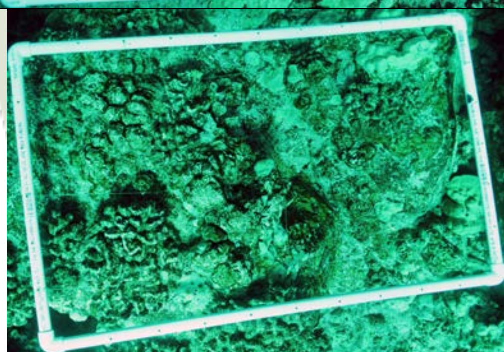
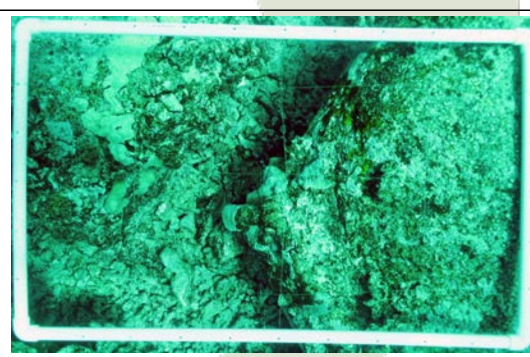
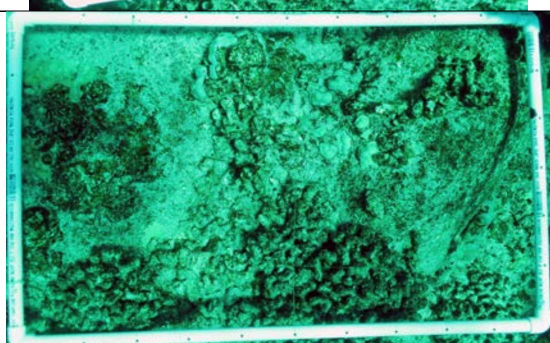
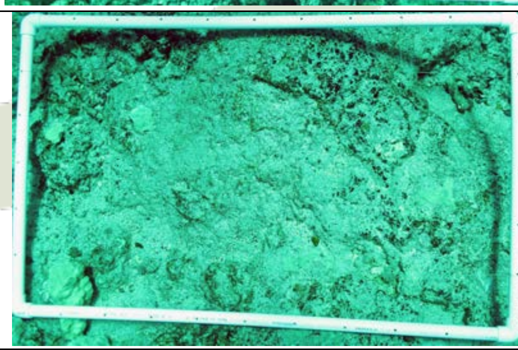
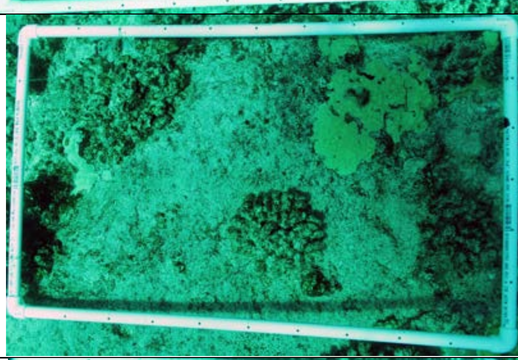
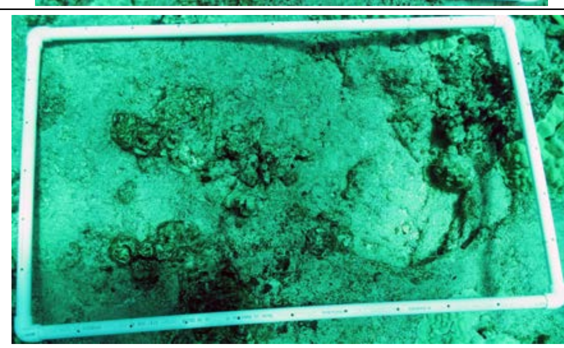
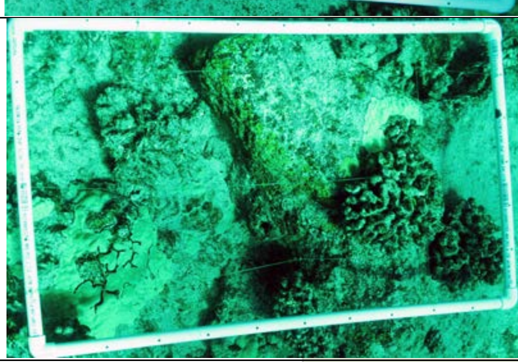
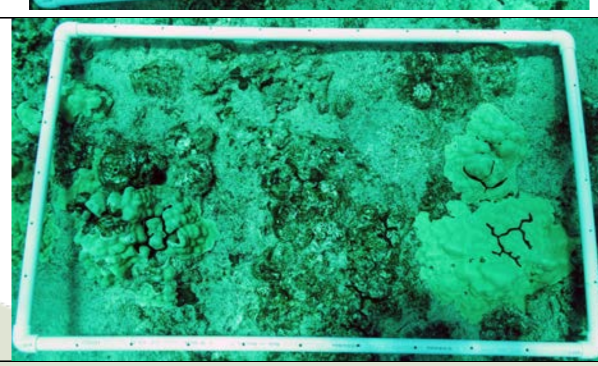
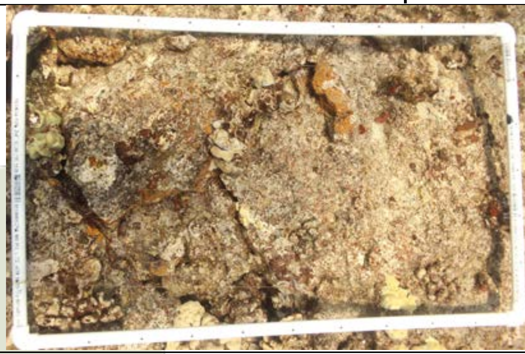
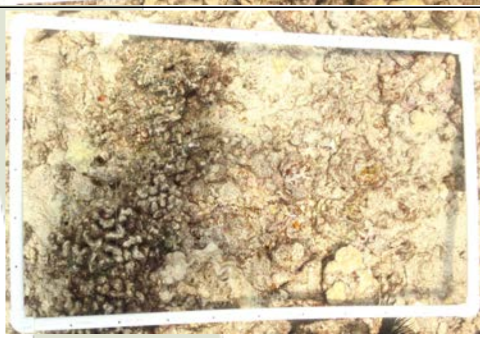
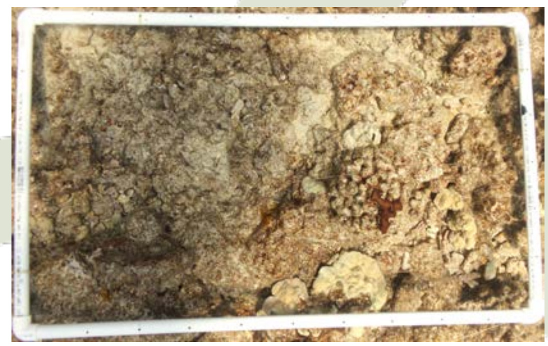
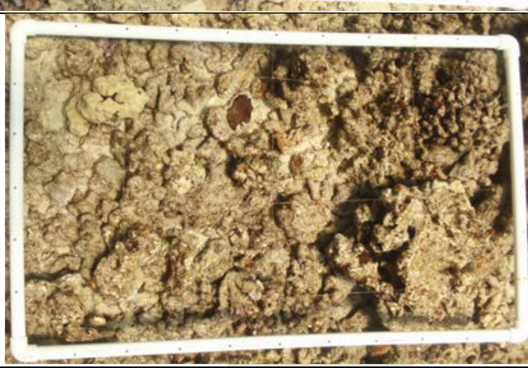
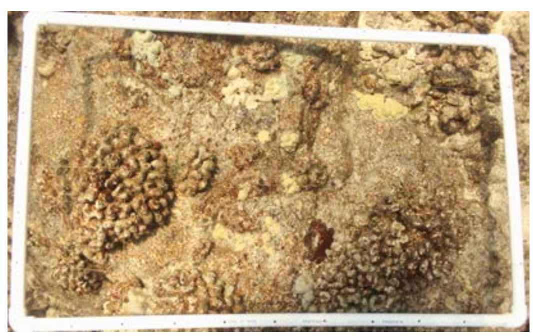
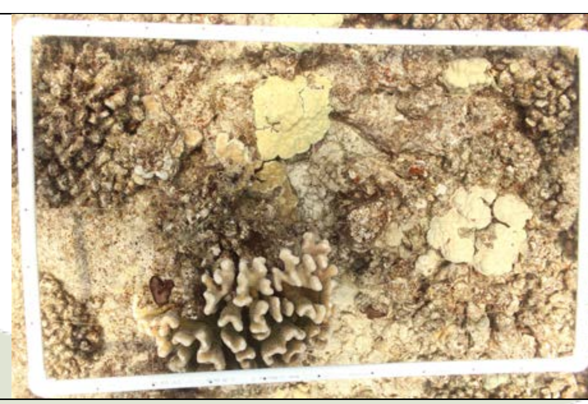
	
	
	
	
	

Site: 12 Pipe North	Depth: 15fsw
	
	
	
	
	

Site: 12 Pipe South	Depth: 50fsw
	
	
	
	
	

Site: 12 Pipe South	Depth: 30fsw
	
	
	
	
	

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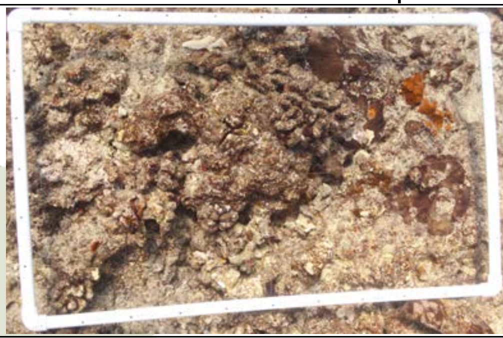	
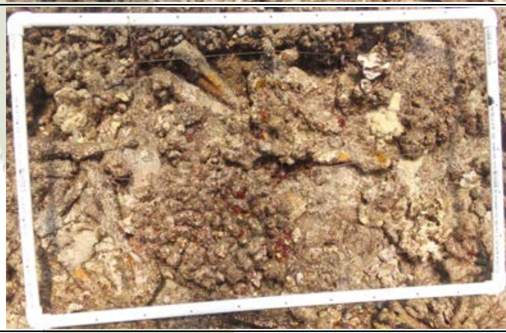	
	
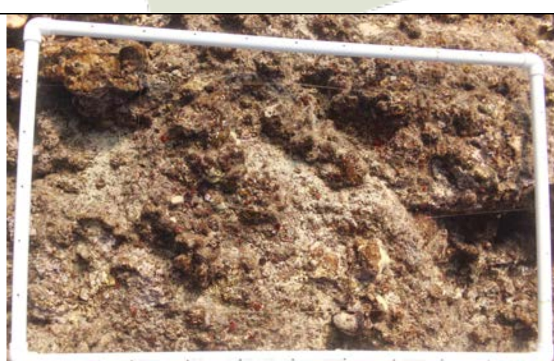	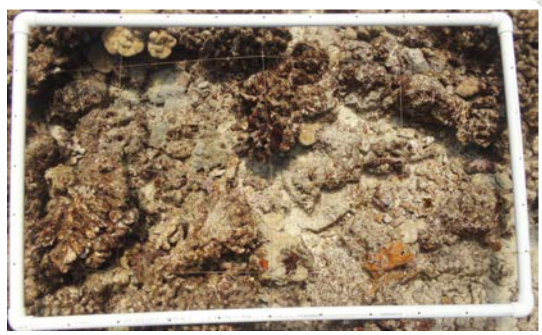
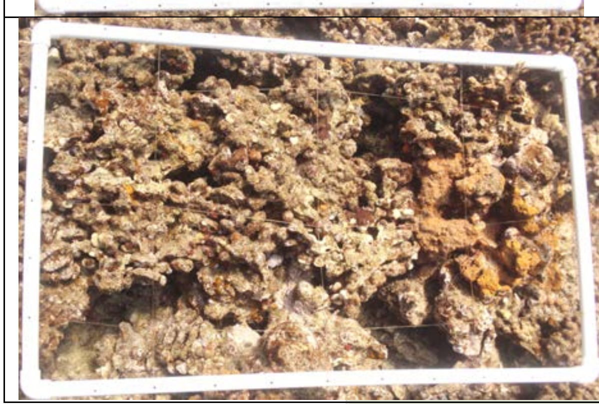	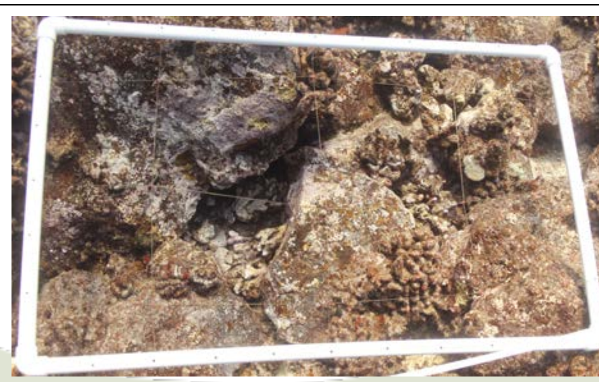

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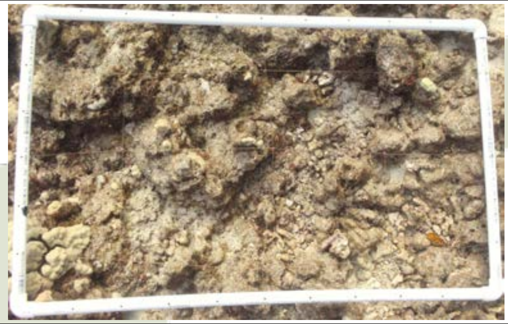	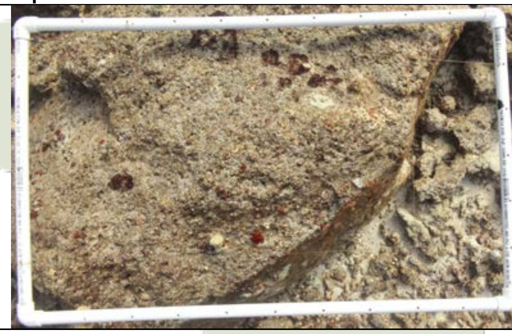
	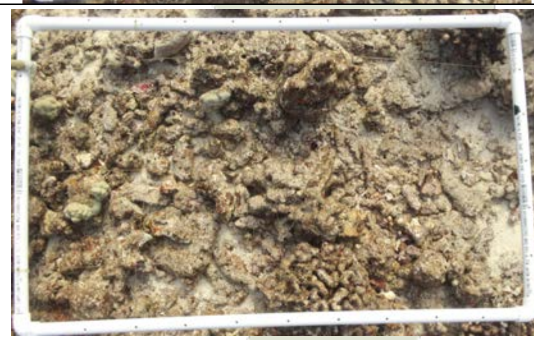
	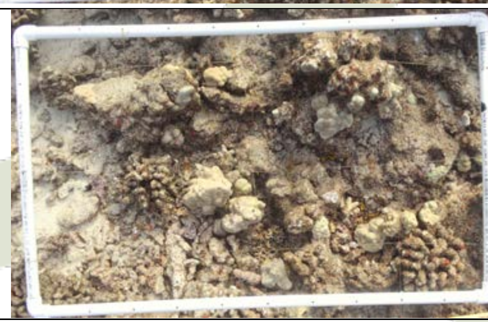
	
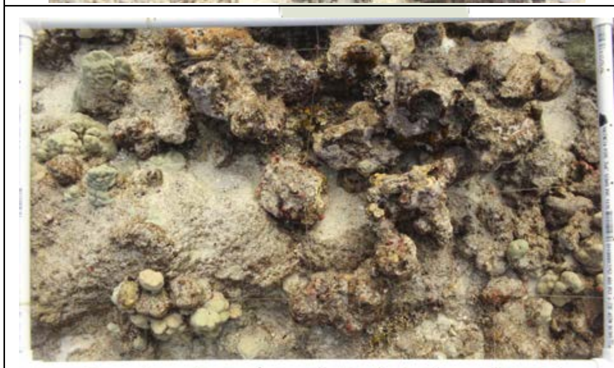	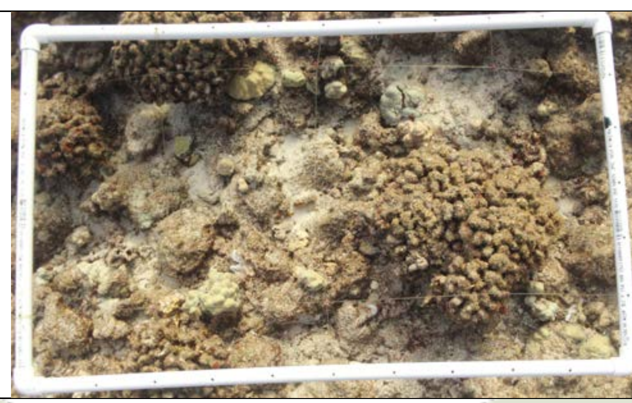

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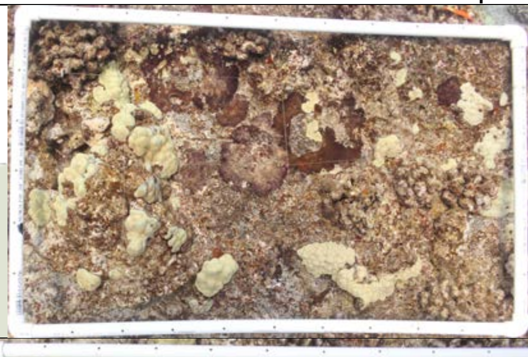	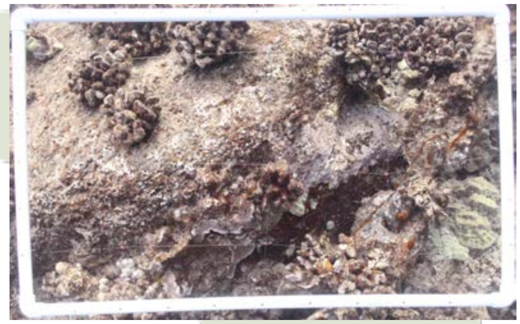
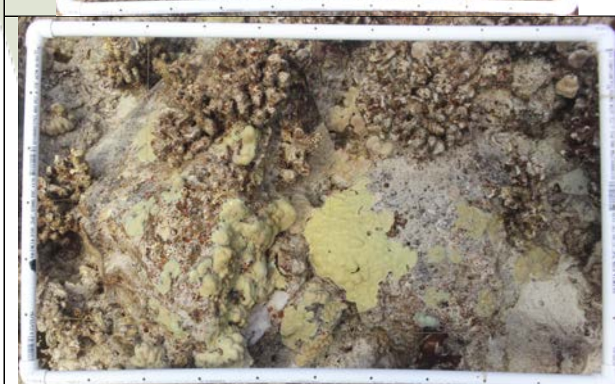	
	
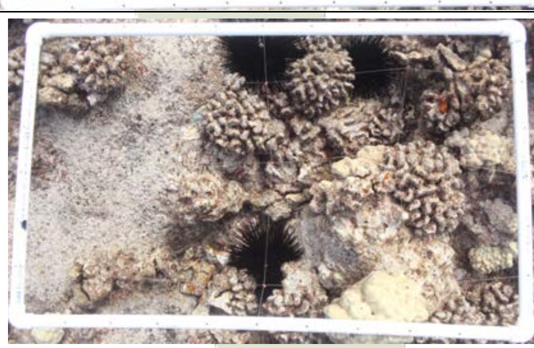	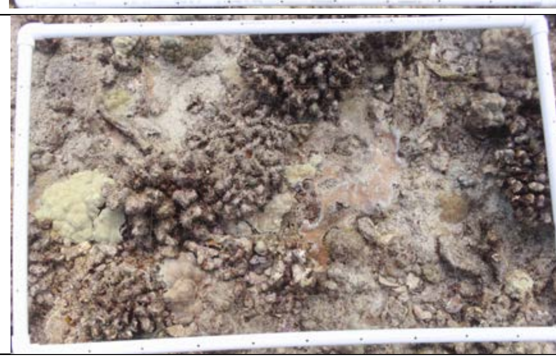
	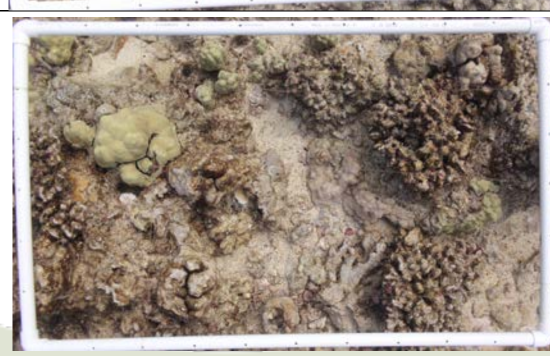

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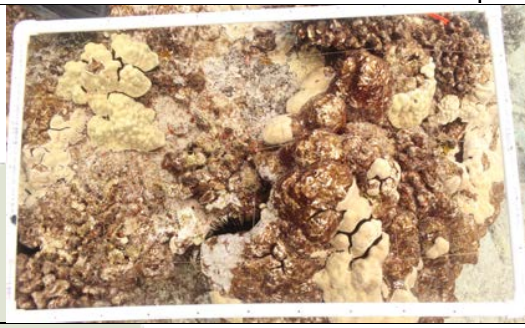
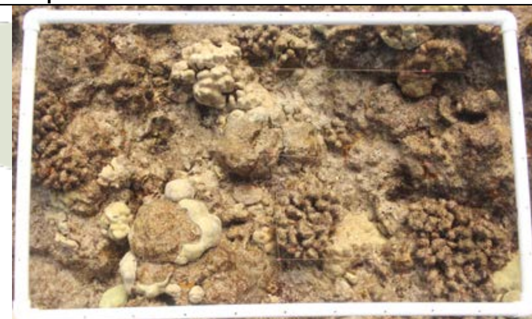
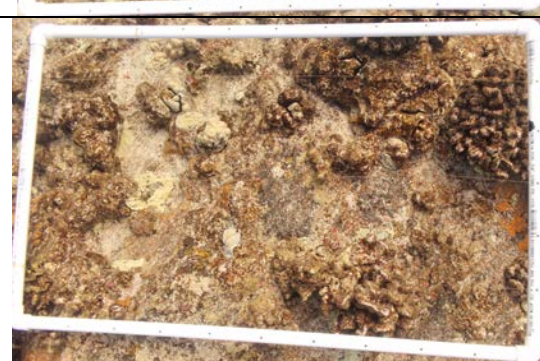
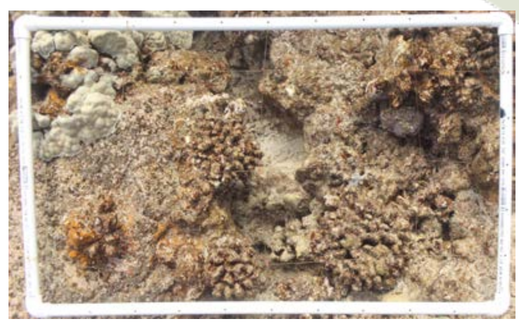
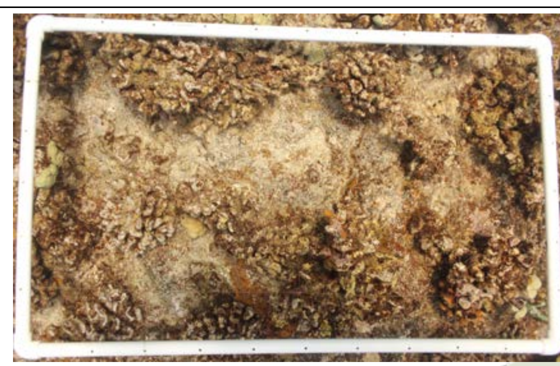
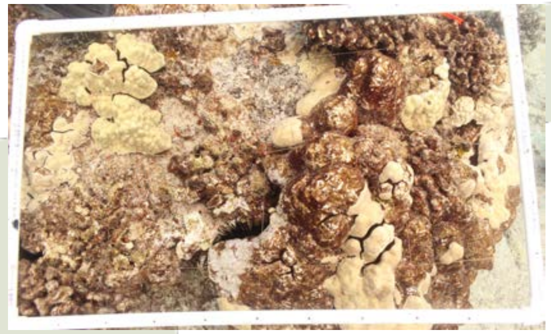
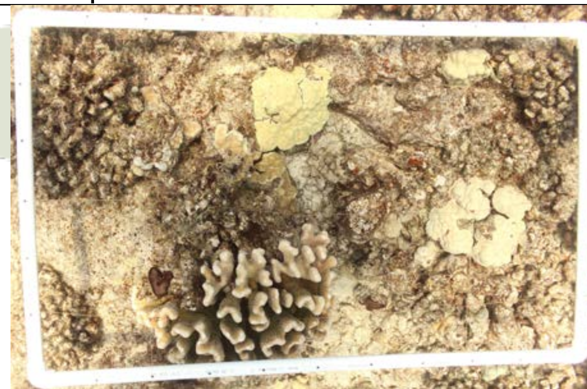
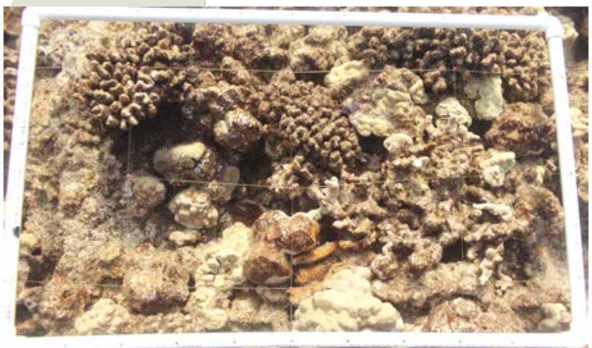
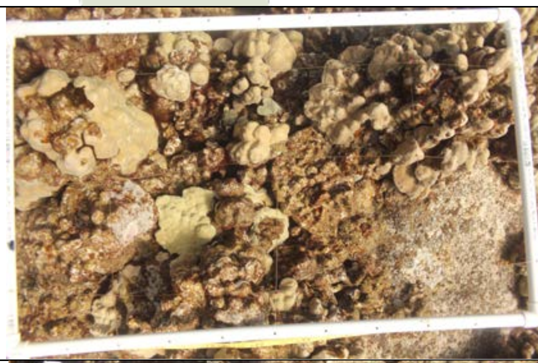
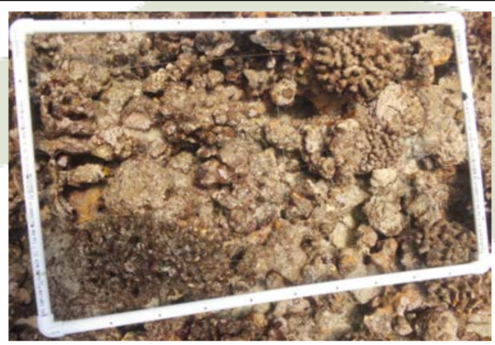
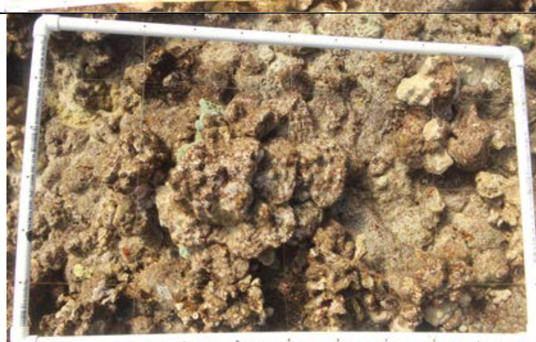
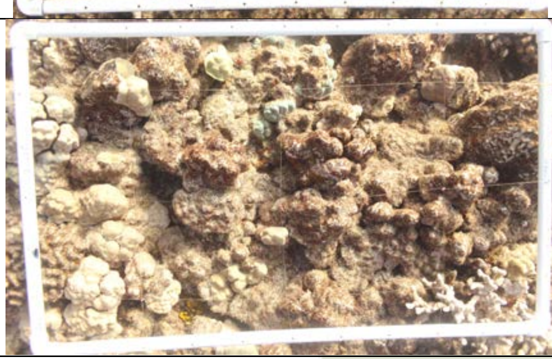
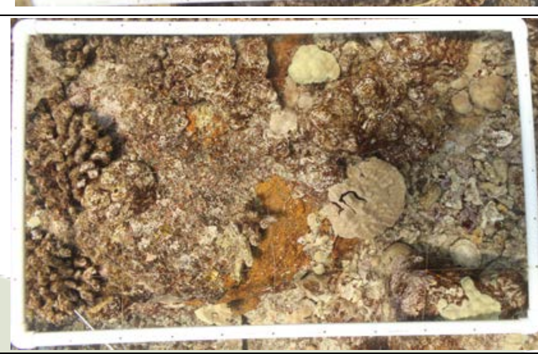
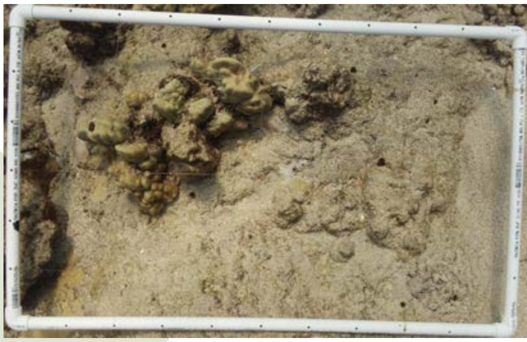
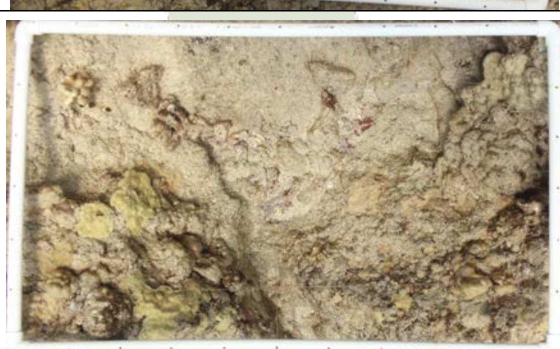
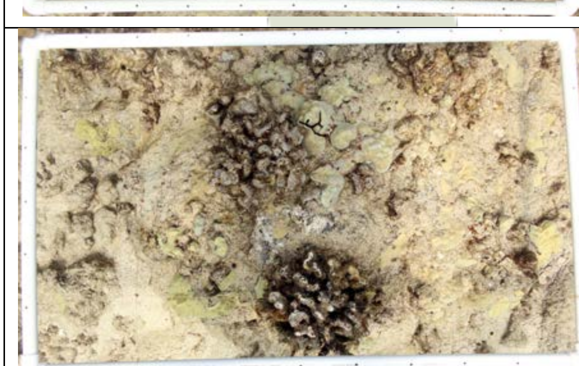
	
	
	
	
	

Site: Wawaloli	Depth: 50fsw
	
	
	
	
	

Site: Wawaloli Depth: 30fsw	
	
	
	
	
	

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	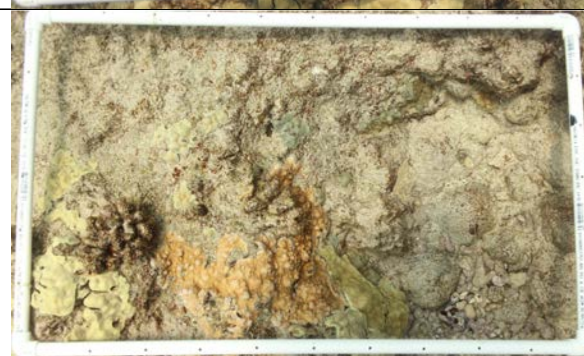
	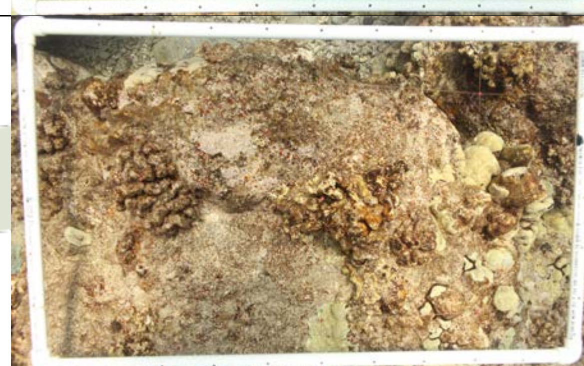
	
	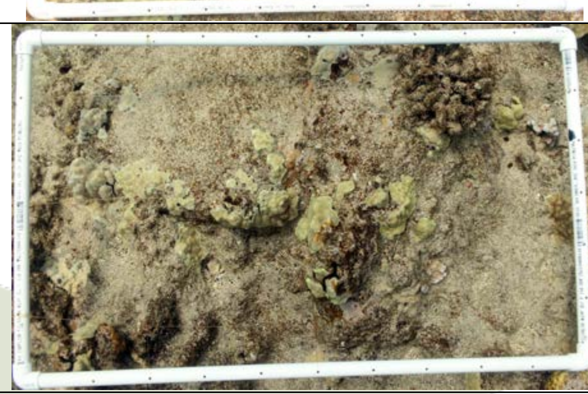

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