MARINE ENVIRONMENTAL MONITORING PROGRAM

FOR THE NATURAL ENERGY LABORATORY OF HAWAII AUTHORITY

SURVEY REPORT MAY 2012

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EXECUTIVE SUMMARY

The Natural Energy Lab of Hawaii Authority is a state agency that operates an ocean science and Technology Park at Kailua-Kona on the Island of Hawaii focused on research, education, and commercial activities that support sustainable industry development in Hawaii. Near shore marine resources in this area (Keahole Point) have been long been recognized as very abundant and diverse, especially the near shore fish community. After the building of NELHA, which included infrastructure on the reef, a comprehensive monitoring program was commenced to ensure the long term health and protection of marine systems in the area. This monitoring program includes water quality, anchialine shrimp ponds, benthic communities and near shore fish communities.

Since 1989 a series of more than 30 surveys has been conducted and extensive reports have been prepared. Results, summaries and references for these reports can be found throughout this report which presents the results of the 2012 survey.

The anchialine ponds in the vicinity of the NELHA facility form northern and southern complexes consisting of five ponds in the North group and nine in the South group. A faunal census of each pond in the vicinity of the NELHA facility was undertaken between 17 and 20 May 2012. Temperature and salinity measurements were taken and visual observations of organisms within each pond were supplemented by photographs and high-definition video.

The results of the 2012 anchialine pond survey were consistent with previous surveys. Based on the faunal census performed the anchialine ponds in the vicinity of the NELHA facility in which exotic fish were not present supported communities of abundant and diverse native organisms. Further, ponds with fish had clear water and were not overgrown by opportunistic algae. This may indicate that the ōpae ʻula were still active in the ponds at night to avoid predation by the introduced fish.

There are six survey sites located along the NELHA coastline, containing three 50 m transects at one of three depths, 15 ft., 30 ft., and 50 ft. representing three different habitat zones. The benthic biota studies have shown a gradual increase in coral cover over time with *Porites meandrina* and *Porities lobata* always among the dominant species. Data from the present study show a similar pattern.

Over all coral cover across the six study sites in 2012 was 44%. The two most dominant corals were *Porities lobata* (22.14%) and *Pocillopora meandrina* (8.86%) which were present on all transects. Other corals present were *Lepastrea purpurea, Montipora capitata, Montipora flabellata, Montipora patula,* *Pavona varians, Pocillapora eydouxi, Pocillopora lingulata, Pocillopora meandrina, and Poritis compressa.* These corals accounted for approximately 6% of the coral cover.

The fish community was monitored at the same 6 sites as the benthic community but on 25 meter transects. Historical results show a highly variable fish community from year to year. Data from 2012 were significantly different than 2010 data. Some of that may be attributable to natural variation but much of it is likely due to a survey technique which will be modified in future surveys.

The results of the anchialine pond biota, benthic biota and nearshore fish biota studies all support the conclusion that the habitats and communities adjacent to the NELHA facility are not impacted by human-mediated inputs.

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ANCHIALINE POND SURVEY

INTRODUCTION

The anchialine habitat is characterized by land-locked brackish bodies of water influenced by input from terrestrial groundwater and tidal influx from the marine environment. Interest in this habitat, described by Holthuis' (1973), stemmed from observations of a group of shrimp species that shared red coloration and an apparent restriction to this habitat that is distributed globally throughout the tropics. Anchialine systems are reported from over 30 islands within in the Pacific Ocean, the Western Indian Ocean, on Ascension Island in the Atlantic Ocean, as well as inland sites in North America, Mesoamerica, and at Ras Muhammad in the Red Sea (Chace & Manning, 1972; Holthuis, 1973; Maciolek, 1983; Iliffe, 1991; Hobbs, 1994; Brock & Bailey-Brock, 1998). Anchialine systems are commonly found along the shoreline of West Hawaiʻi, but are also occur on Oʻahu, Maui, Molokaʻi, and Kahoʻolawe (Brock *et al*., 1987; Bailey-Brock & Brock, 1993).

The environmental conditions of anchialine systems often result in groups of native and/or endemic species (Peck, 1994). As elsewhere, the organisms found in the anchialine system throughout Hawaiʻi are uniquely suited to this habitat including plants, mollusks, arthropods, and other taxa. Table 1 summarizes the species previous reported from the ponds located near Keāhole Point, Hawaiʻi. However, these sites are primarily distinguished by the presence of two decapod shrimp species *Halocaridina rubra* (ʻōpae ʻula) and *Metabetaeus lohena*. Due to the critical role in the ecology of this unique habitat in Hawaiʻi, the fate of the habitat is intimately tied to that of *Halocaridina rubra*.

Ōpae ʻula utilize the ponds to feed, but most of the reproduction and dispersal within the anchialine system occurs in the subterranean (hypogeal) portion of the habitat. *Halocaridina rubra*, through its grazing mode of feeding, maintains a standing crop of plants, bacteria, diatoms, and protozoans that prevents overgrowth by opportunistic algae (Bailey-Brock & Brock, 1993). This 'gardening' contributes to the overall health of the anchialine communities in Hawaiʻi allowing other species to exploit the sunlit (epigeal) portion of the habitat. This shrimp, therefore, plays the role of keystone species. However, the effect on and response of ʻōpae ʻula to the introduction of exotic fish species into the anchialine habitat has been to either reduce their abundance through increased predation or to precipitate a shift in their foraging behavior (Capps *et al*., 2009) forcing them to be active at night. This has led to ponds in which exotic fish have become established being devoid of shrimp species during the day.

Additionally, the coastal areas of Hawaiʻi in which anchialine systems are found have been the focus of development, which has led to efforts to conserve and manage these resources from possible anthropogenic impacts. Recent investigations using techniques to examine the DNA of this species has provided a better understanding of their population dynamics and contributed to effective planning and management of anchialine resources in Hawaiʻi. A study to elucidate the structure of *Halocaridina rubra* populations from the island of Hawaiʻi has shown there to be two distinct lineages on the

Table 1. List of species previously reported from anchialine ponds and surrounding areas adjacent to the NELHA facility (Compiled from Brock, 2008, and Ziemann & Conquest, 2008).

	Taxon	Common Name
Anchialine ponds	*Cladophora* sp.	Algae
	Enteromorpha sp.	Algae
	Rhizoclonium sp.	Algae
	Trichocorixa reticulata	Algae
	Lygnbya sp.	Cyanophyte mat
	Schizothrix clacicola	Cyanophyte mat
	Ruppia maratima	Aquatic flowering plant
	Halocaridina rubra	Ōpae ʻula, shrimp
	Metabataeus lohena	Shrimp
	Macrobrachium grandimanus	Ōpae ʻoʻhaʻa, shrimp
	Metopograspus messor	Black rock crab
	Graspsus tenuicrustatus	Shore crab
	Assemenia sp.	Snail
	Melania sp.	Gastropod snail
	Theodoxus cariosa	Hihiwai, limpet
	Oligochaeta sp.	
Terrestrial	*Bacopa* sp.	Pickleweed
	Cladium sp.	Sedge
	Ipomoea pes-caprae	Pōhuehue
	Morinda citrifolia	Noni
	Pennisetum setaceum	Fountain grass
	Pluchea odorata	Pluchea
	Prosopis pallida	Kiawe
	Scaevola taccada	Naupaka
	Schinus terebinthifolius	Christmas berry
	Sesuvium portulacastrum	ʻĀkulikuli
Anchialine ponds, exotic	*Poecilia* sp.	Topminnows, mosquito fish
	Palaemon debilis	Glass shrimp, ʻōpae
	Macrobrachium lar	Prawn

east and west coasts, and that within small geographic areas along each coast the populations are structured with low levels of gene flow (Santos, 2006). This suggests that monitoring of the anchialine ecosystem in Hawaiʻi should be center at local scales, i.e. at the level of ponds and pond complexes, as is the case at the NELHA facility at Keāhole Point. While the pools offer windows into the cryptic habitat of *Halocaridina rubra*, generally, the two groups of ponds in the vicinity of the NELHA facility have been surveyed for more than 35 years (see Brock, 1995, 2002, 2008; Oceanic Institute, 1997, 2007; Ziemann & Conquest, 2008; and included citations). Through the continuing monitoring program at these sites, a change in the community of organisms has been noted by surveys after 1989 with the endemic shrimp species becoming absent in a number of the ponds (Brock, 2008; and Ziemann & Conquest, 2008). This may be explained by the establishment of exotic, poecilid fish species in ponds south of the NELHA facility. The findings of the 2012 anchialine ponds survey as part of NELHA's Comprehensive Environmental Monitoring Program (CEMP) are reported herein.

METHODS

The anchialine ponds in the vicinity of the NELHA facility form northern and southern complexes (Figure 1) consisting of five ponds in the North group and nine in the South group. The northern pond complex, ponds N -1 to N - 5, was roughly 100 m inland of the cobble beach at Hoona Bay (Figure 2), and the southern complex, ponds S – 1 to S – 9, were 200 – 225 m from the shore at Wawaloli Beach Park adjacent to Makako Bay Drive (Figure 3). Table 2 details the location and size of each pond at the NELHA site. A Garmin hand-held GPS unit was used to record latitude and longitude coordinates for each pond. Pond size was calculated from measurements reported by Brock (2008); furthermore, pond dimensions and basin characteristics are included in Appendix 1.1 (Brock, 2008 Table 1).

As anchialine habitats are characterized by tidal influences, the water level and appearance of ponds varied with tide level. For instance, pond N – 1 is substantially shallower with less surface area at low versus high tide (Figures 4A and 4B, respectively). The effect of tide level was also apparent in the group of pools N – 2 through N – 5. At high tide the pools essentially form a single body of water (Figure 5, 6A, and 7A) as the channels between them filled up. This was enhanced by the rock wall construction surrounding these ponds. However, the pools were discrete and separated at lower tidal levels (Figures 6B – D, and 7B). The change is illustrated by the largest of these ponds (N – 5) in Figures 7A and 7B (arrows included to mark point of reference). Observations of organisms within the ponds, then, were taken at tide levels below the daily maximum that provided sufficient water in order to sample each pond separately. While the water levels in the ponds in the southern complex (Figures 8 – 10) were likewise affected by the tide level, the continuity of each pond remained unchanged in all but pond S – 9. This pond is filled with water at "exceptionally" high tides (Brock, 2008), and was found dry during this survey. Sampling of the ponds was conducted at tidal levels ranging from +0.6 to +2.0 feet.

Figure 1. The study area included northern and southern anchialine pond complexes in the vicinity of the NELHA facilities (Inset highlights the study site on the west coast of Hawai‘i, Map generated using Google Earth 6.2).

Figure 2. Locations of northern complex of anchialine ponds (N – 1 through N – 5) inland of the cobble beach at Hoona Bay (Map generated using Google Earth 6.2).

Figure 3. Locations of southern group of anchialine ponds adjacent to Wawaloli Beach Park (Map generated using Google Earth 6.2).

Table 2. Site locations and sizes anchialine ponds in the vicinity of the NELHA facility (*calculated from measurements reported in Brock (2008)).

Pond No.	Latitude (Degrees)	Longitude (Degrees)	Size (m^2) *****
N-1	19.7313	-156.0568	93.0
N-2	19.7314	-156.0566	1.0
N-3	19.7315	-156.0566	22.5
N-4	19.7316	-156.0566	4.0
N-5	19.7315	-156.0567	22.5
S-1	19.7168	-156.0490	1.68
S-2	19.7167	-156.0489	1.0
S-3	19.7168	-156.0487	1.0
S-4	19.7168	-156.0487	0.01
S-5	19.7168	-156.0487	5.0
S-6	19.7169	-156.0482	0.01
S-7	19.7166	-156.0481	1.4
S-8	19.7165	-156.0481	1.0
S-9	19.7168	-156.0481	0.01

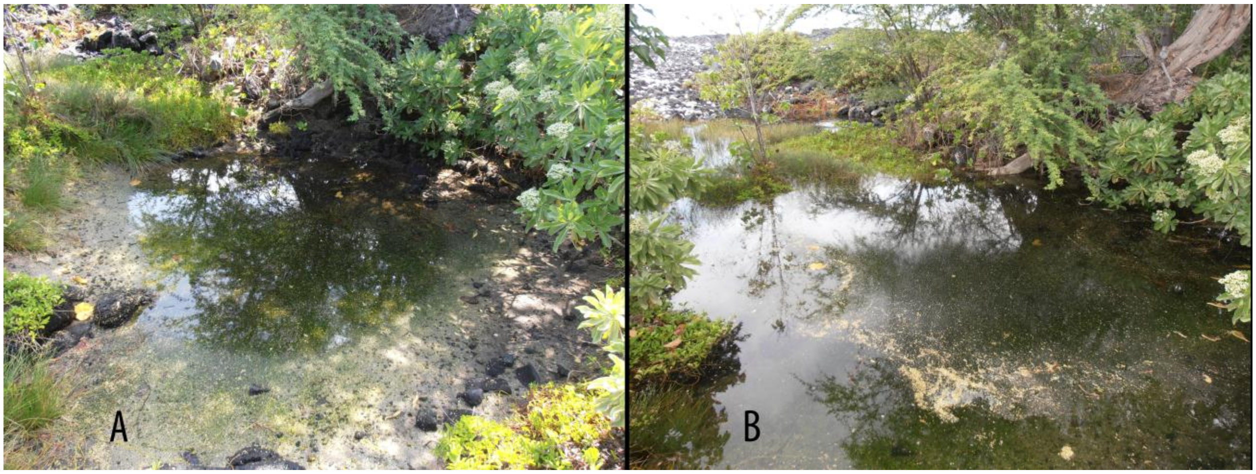

Figure 4. Pond N – 1 water levels at low (A, +0.7 ft.) and high (B, +2 ft.) tides.

Figure 5. High tide (+2 ft.) at ponds N – 2 through N – 5 with inter-connecting channels filled.

Figure 6. Ponds N – 2 through N – 5 as one continuous pond at high tide (A, +2 ft.), and separate ponds at lower tide levels (B – D, +0.7 ft.).

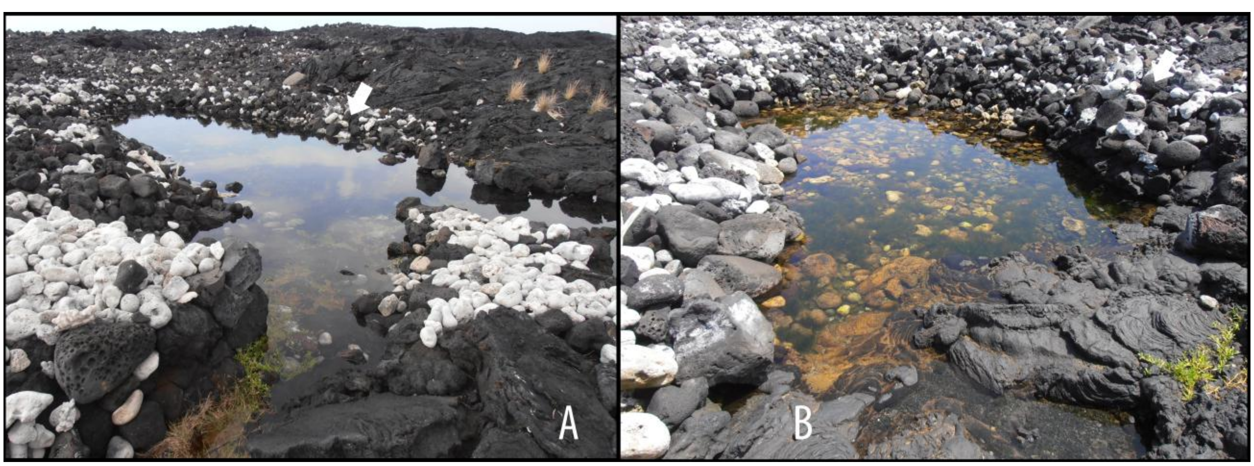

Figure 7. The change in water level at pond N – 5 between high (A, +2 ft.) and lower tide levels (B, +0.7 ft.) with arrows marking point of reference.

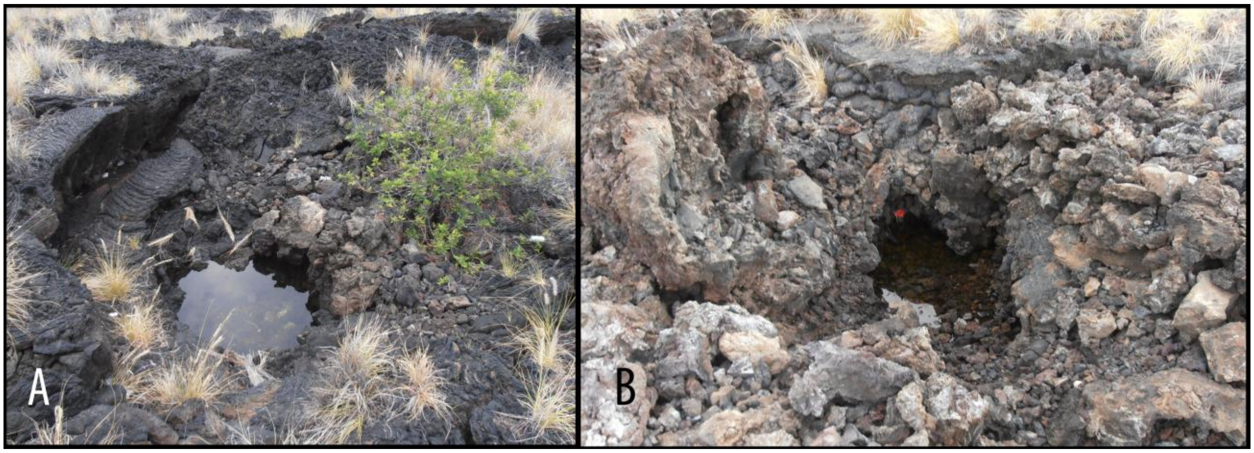

Figure 8. Southern ponds S – 1 (A, +1.8 ft.) and S – 2 (B, +1.4 ft.).

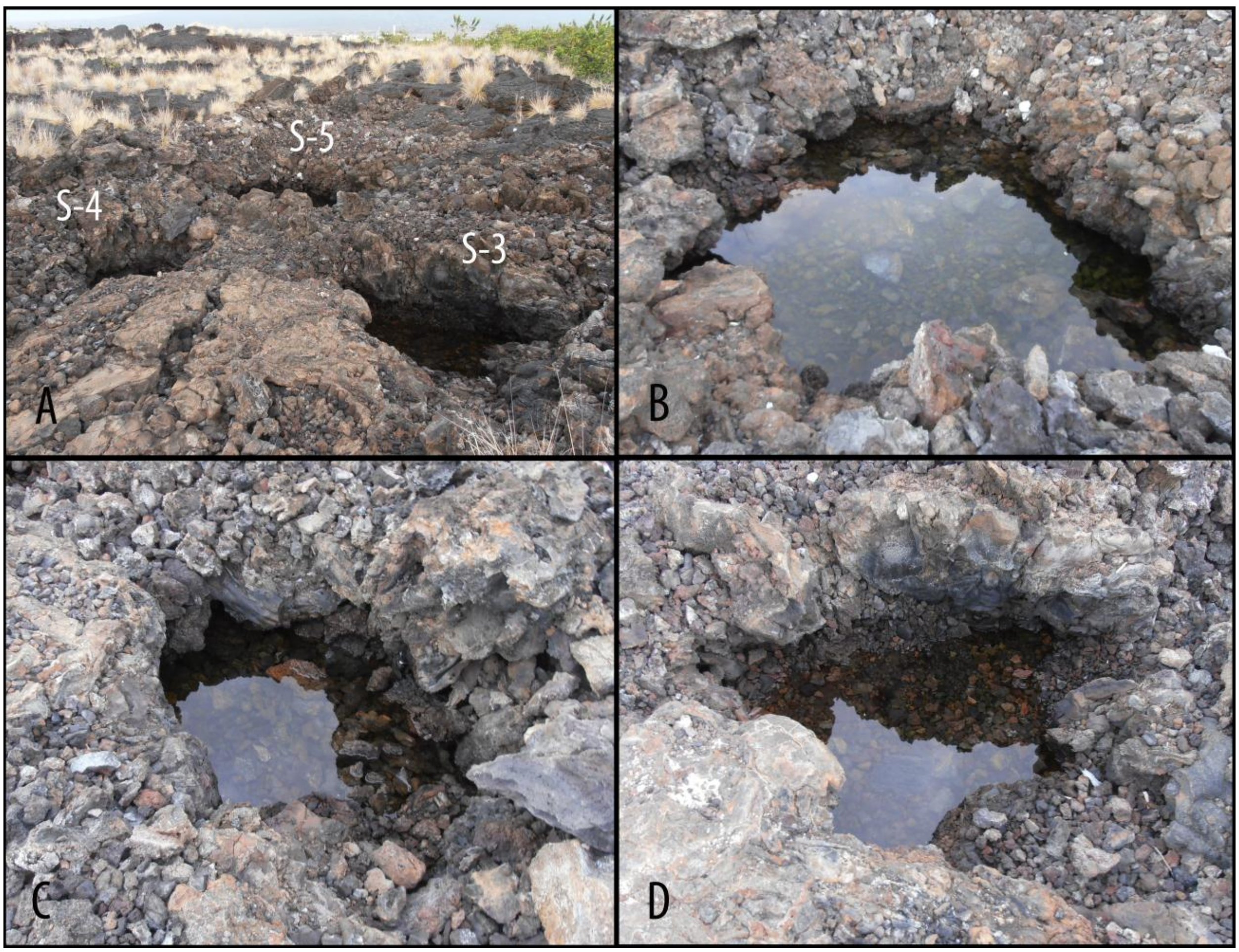

Figure 9. Cluster of ponds (A): S -3 (D), S – 4 (C), and S – 5 (B) (Tide level: +1.4 ft.).

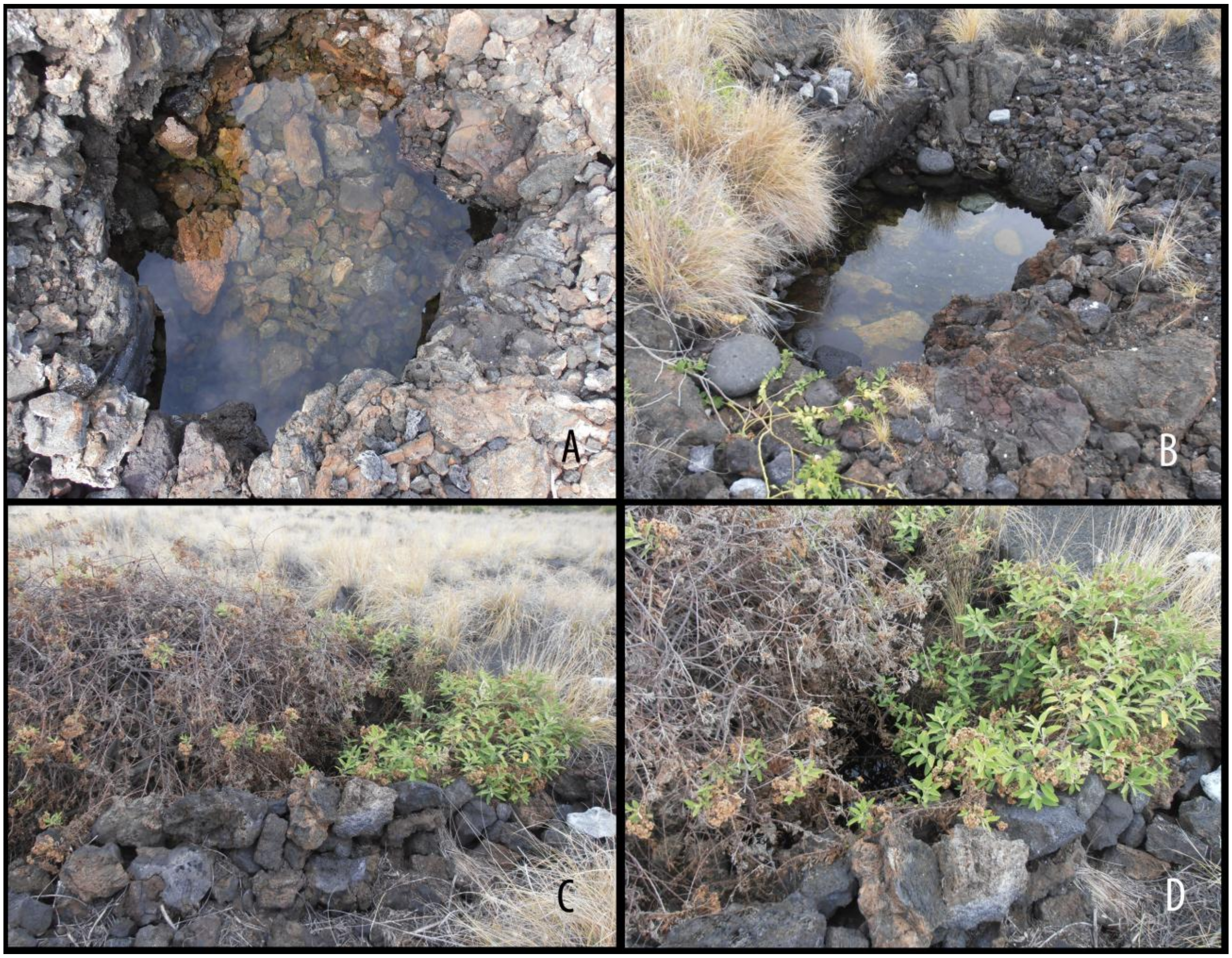

Figure 10. Ponds S – 6 (A, +2 ft.), S – 7 (B, +1.6 ft.), and S – 8 showing rock wall construction and overgrowth of vegetation (D).

A faunal census of each pond in the vicinity of the NELHA facility was undertaken between 16 and 18 May 2012. Temperature and salinity measurements were taken concurrently employing a digital thermometer and hand-held refractometer (Model RHS-10ATC) which was calibrated by measuring the using distilled water. Visual observations of organisms within each pond were supplemented by photographs and high-definition video taken with an Olympus VR-320 14 megapixel digital camera and waterproof housing. A minimum of 10 randomly selected photo-quadrates ranging in size from 0.02 to 0.07 m² (Figure 11) were isolated from video footage obtained by floating the camera and housing on the surface of the pond were used to identify organisms and measure their densities. However, two ponds with low water levels were surveyed visually by counting all organisms which were within a 0.1 m² quadrate after five minutes of placement on the substrate. All densities were calculated for an area of 0.1 m² to facilitate comparisons among ponds within this survey and with previous anchialine pond surveys at these sites (see Appendices 1.2 and 1.3). In addition, three one-minute segments of video from each pond were examined to qualitatively assess the community of organisms found. Videos were not taken in ponds in which exotic fish were present, as visual inspection determined a lack of common native organisms. Only the presence or absence of non-native organisms was recorded for this survey.

RESULTS

The anchialine ponds found in the vicinity of Keāhole Point, Hawai‘i were surveyed as partial fulfillment of NELHA's 2012 Comprehensive Environmental Monitoring Program (CEMP). The measurements of physical characteristics and results of the faunal census undertaken between the 17th and 20th of May 2012 of 14 ponds representing a northern group of five ponds and group of nine southern ponds are summarized in Table 4. While ponds within each group share a similar composition of organisms, the differences between the two groups stem from the physical features of the local areas in which they are found, as well as the introductions of exotic species and active management of the ponds. The historical introductions of poecilid fish have affected the species composition anchialine ponds reducing the abundance of the keystone species of the habitat, ōpae ‘ula. Moreover, the modification through building of rock walls has changed the ponds over time, especially in the northern group of ponds. This activity has, at higher tidal levels, led to ponds N – 2 through N – 5 to fill and constitute a single water body allowing motile organisms to expand and contract their distribution throughout these ponds. The results of 2012 anchialine pond survey, still, were consistent with previous surveys reviewed by Brock (2008) and reported in Ziemann & Conquest (2008).

Northern anchialine ponds were dominated by *Halocaridina rubra* at higher densities than in the southern ponds. While ponds N – 1 and N – 2 in which the aquatic flowering plants *Ruppia maratima* were present had a relatively uniform distribution of these shrimp, ponds N – 3 and N – 5 were not. The observation that the ōpae ‘ula utilized the well-lit rocky substrates for feeding, and swam through or took refuge in *Ruppia maratima* explained the differences in the distribution within these ponds. The

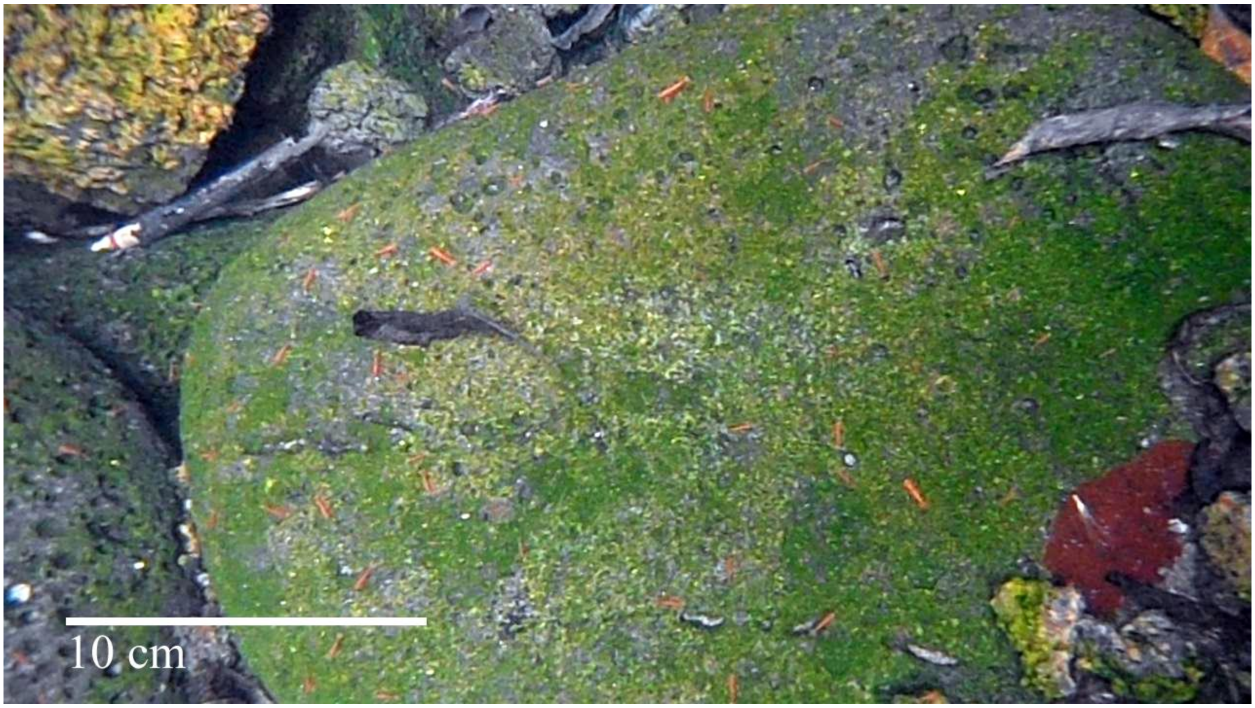

Figure 11. An example of a photo-quadrate showing individual *Halocaridina rubra*. The quadrate was extracted from the high-definition video taken from pond S – 8 on 19 May 2012 and used to perform the quantitative faunal census.

Table 3. Temperature and salinity measurements made from 17 – 20 May 2012 at northern and southern groups of anchialine ponds. Sampling was performed at a tide above a +1 foot level.

Pond No.	Salinity (ppt)	Temperature (ºC)
N-1	9	24.5
N-2	9	29.7
N-3	10	29.7
N-4	8	27.8
N-5	8	28.4
S-1	7	24.2
S-2	8	24.0
S-3	8	24.5
S-4	8	24.0
S-5	8	23.8
S-6	8	24.9
S-7	8	24.5
S-8	8	23.8
S-9*	-	-

Table 4. Faunal census data collected from northern and southern groups of anchialine ponds sampled from 17 to 20, 2012 at a tide above a +1 foot level. Poecilid fish were recorded as present or absent, other organism densities are reported as mean individuals per 0.1 square meters (± one standard deviation), and the presence of *Ruppia maratima* in ponds and quadrates was noted.

	Halocaridina rubra	*Ruppia maratima*		Poecilids	*Metabetaeus lohena*	*Macrobrachium grandimanus*	Amphipoda
Pond No.	**Mean ± St. Dev. (Ind./0.1 m²)**	**Pond**	**Quadrate**		**Mean ± St. Dev. (Ind./0.1 m²)**	**Mean ± St. Dev. (Ind./0.1 m²)**	**Mean ± St. Dev. (Ind./0.1 m²)**
N - 1	62.8 ± 46.0	Absent	-	Absent	0	0	0
N - 2	77.9 ± 13.1	Absent	-	Absent	0	0	0
N - 3	62.9 ± 25.3	Present	Present	Absent	0	0	0
N - 3	175.6 ± 18.8	Present	Absent	Absent	0	0	0
N - 4	0	Absent	-	Absent	0	0	0
N - 5	0	Present	Present	Absent	0	0	0
N - 5	52.2 ± 24.2	Present	Absent	Absent	0	0	0
S - 1	0	Absent	-	Present	0	0	0
S - 2	34.5 ± 7.0	Absent	-	Absent	0	0	0.2 ± 0.8
S - 3	18.4 ± 6.0	Absent	-	Absent	0.3 ± 0.7	0.3 ± 0.8	
S - 4	51.6 ± 11.9	Absent	-	Absent	0	0	0
S - 5	0	Absent	-	Present	0	0	0
S - 6	0	Absent	-	Present	0	0	0
S - 7	0	Absent	-	Present	0	0	0
S - 8	51.5 ± 25.9	Absent	-	Absent	0	0	0.7 ± 0.8
S – 9*	-	-	-	-	-	-	-

majority of individuals were feeding at the time of the survey and only very few individuals were observed in the *Ruppia maratima*. This is reflected in the results from quadrates in pond N – 5 with those over stands of *Ruppia maratima* had no *Halocaridina rubra*, and those without these plants had a mean density of 52.2 (± 24.2) individuals per 0.1 m^2. This effect was also seen in pond N – 3, but to a lesser degree due to the quadrates with *Ruppia maratima* also containing an exposed rock that allowed for feeding. When the remaining pond (N – 4) was sampled at +0.7 foot tidal level, there were no organisms observed. Few ōpae ʻula (ca. 2 to 4 total) were present in pond N – 4 at the high tidal level (+2.0 feet); however, the pond was contiguous with the others in the area at this point.

The clearest difference between the communities of organisms found in the two groups of ponds this year was the absence of exotic poecilid fish in the northern ponds and their presence in four of nine ponds in the southern group. *Halocaridina rubra* and other native species were not observed in ponds S – 1, S – 5, S – 6, and S - 7, those with exotic fish. As in the northern ponds, southern ponds S – 2, S – 3, S – 4, and S – 8 were dominated by *Halocaridina rubra*; yet, the crustacean diversity in these ponds that resulted from the photo-quadrates was greater as the census also included individuals of *Metabetaeus lohena* (S – 3), *Macrobrachium grandimanus* (S – 8), and large white amphipods (S – 2 and S – 8). Pond S – 9 was found to be dry during the survey, a state commonly encountered in previous studies (reviewed in Brock, 2008).

Additional qualitative results utilizing sections of video and field notes augmented data collected from photo-quadrates to account for the mobile, cryptic, or less abundant taxa in the ponds. Differentiating between live and dead *Melania* sp. individuals was difficult, as noted by Brock (2008), but those observed in pond N – 1 were actively foraging making it possible to determine that there density was roughly half that of *Halocaridina rubra* in the videos of this pond. These snails were found to be less abundant (ca. less than 5 individuals per pond) in northern ponds N – 3 and N – 5, and none were observed in N – 2 and N - 4. *Melania* sp. were not observed in the southern ponds; however, the videos showed a high number of small motile amphipods and few larger white amphipods in ponds S – 2 and S - 8, as well as native shrimp species in three ponds. *Metabetaeus lohena* were enumerated from the videos of ponds S – 2 (6 individuals) and S – 3 (2 individuals), and three *Macrobrachium grandimanus* shrimps were recorded in pond S – 8. Lastly, two individuals of the insect *Trichocorixa reticulata* (water boatmen) were noted in pond S – 7.

DISCUSSION

The anchialine ecosystem is unique in Hawaiʻi, and the monitoring of two complexes of ponds adjacent to the NELHA facility is essential to continuing to build knowledge and improve management of this resource locally and throughout the island. This year's survey echoed the results of previous studies of the site showing that the ponds within the two groups have similar communities of organisms, but that the two groups are distinguishable based on their physical features, effects of exotic fish introductions, and modification of the ponds.

The northern complex of ponds have been modified through wall construction producing a single large pond encompassing ponds N – 2 through N – 5 at high tidal levels which provides the potential for organisms to move among the ponds both in the epigeal and hypogeal portion of the habitat; however, the surface boundaries of pond N-1 are separate and distinct from the other ponds in the complex. A community of native species characterized by high abundances of ōpae ʻula has been able to re-colonize and become established in the northern ponds following the removal of exotic fish in 2007 (Brock, 2008). These shrimp contribute to the water quality of the ponds by maintaining a standing crop of plants, bacteria and diatoms preventing the overgrowth of algae which allows other native organisms to exploit the anchialine habitat (Bailey-Brock & Brock, 1993). If the introduction of exotic fish can continue to be prevented, the current community of organisms and quality of ponds in this complex would be expected to remain in the currently robust state.

The complex of ponds south of the NELHA facility, on the other hand, continued to be affected by the presence of poecilid fish. No native shrimp species were found in the four southern ponds with exotic fish. Findings of Capps *et al*. (2009) suggest that the *Halocaridina rubra* may have been excluded from the pond through predation, or they have changed their behavior and were feeding at night in response to the introduction of the fish. As the ponds were surveyed during daylight hours, it was not possible to assess whether the ōpae ʻula were present but not active during the day at the NELHA sites. The ponds lacking exotic fish were found to have a greater crustacean diversity of native organisms than in the northern complex. While ōpae ʻula were the dominant members of the community, *Metabetaeus lohena*, *Macrobrachium grandimanus*, and amphipods were present albeit at lower abundances and densities. The prospect of future recovery in the southern ponds that are infested with alien fish through re-colonization from other ponds in the complex seems good in the event these fish could be removed.

The 2012 anchialine pond survey augmented field observations with photo-quadrates extracted from high-definition video taken in ponds. This allowed for both quantitative and qualitative results to be gathered for the faunal census, provided the ability to record abundances and the behavior of various native organisms, and aided in noting the presence of motile and cryptic species. The use of a floating video camera appeared not to affect the behavior of the organisms in the being surveyed. Observations of *Halocaridina rubra* feeding behavior, for example, showed the shrimp were not disturbed and continued to feed in the same areas throughout the length of the videos. This meant that no changes that might be attributed to the presence of the camera in the pond were apparent. This technique also facilitated the survey of taxa more motile than *H*. *rubra* such as *Metabetaeus lohena, Macrobrachium grandimanus*, and small amphipods as well as large white amphipods that appeared to prefer the large interstices of the aʻa lava rubble which made up the floor of southern ponds such as S – 2 and S – 3. Abundance estimates of the motile and cryptic taxa, then, were made more effective by this technique.

Based on the faunal census performed between the 17^{th} and 20^{th} of May 2012, the anchialine ponds in the vicinity of the NELHA facility in which exotic fish were not present supported communities of abundant and diverse native organisms. Further, ponds with fish had clear water and not overgrown by opportunistic algae. This may indicate that the ōpae ʻula were still active in the ponds at night to avoid predation by the introduced fish. The results also support the conclusion that the anchialine ponds adjacent to the NELHA facility are not impacted by human-mediated inputs.

MARINE BENTHIC BIOTA SURVEY

INTRODUCTION

The Natural Energy Lab of Hawaii Authority is a state agency that operates an ocean science and Technology Park at Kailua-Kona on the Island of Hawaii focused on research, education, and commercial activities that support sustainable industry development in Hawaii. One of the unique technological aspects of the park is the pumping of deep cold sea water to the surface through large pipes that have been installed along the reef in specific locations. The nutrient rich water is used in a variety of aquaculture activities on land. Concerns over water discharge from aquaculture facilities and the potentially negative impacts to the adjacent reef communities have prompted regular monitoring. Benthic communities are often sensitive indicators of environmental change (Gray and Pearson 1982).

Since 1991, more than 30 surveys have been conducted on the benthic communities adjacent to NELHA. Extensive reports have been prepared detailing the results of each survey. Results and summaries of reports can be found in the following references: 1991-1995 are summarized in Marine Research Consultants, 1995. Surveys for 1995 and 1997 are reported in Oceanic Institute, 1997. Surveys conducted between 1997-2002 are in Marine Research Consultants, 2002. Surveys from July 2005 to January 2007 are found in Oceanic Institute 2007. For October 2007 and July 2008 surveys, summary is in Marine Research Consultants 2008. For October 2008, May 2009 and May 2010 surveys are reported in Ziemann 2008, 2009 and 2010. The results of the May 2012 survey are reported here.

METHODS

There are six survey sites located along the NELHA coastline with three 50 m transects at each site, at one of three depths (15 ft., 30 ft., and 50 ft.) (Figure 12). On all transect lines, 10 quadrats, each 1.0 m x 0.6 m, were defined at random locations along the transect. The occurrence of all invertebrate species in the quadrats were enumerated by divers using SCUBA and assessed in terms of percent cover of the bottom. Substrate was also evaluated in terms of percent area coverage.

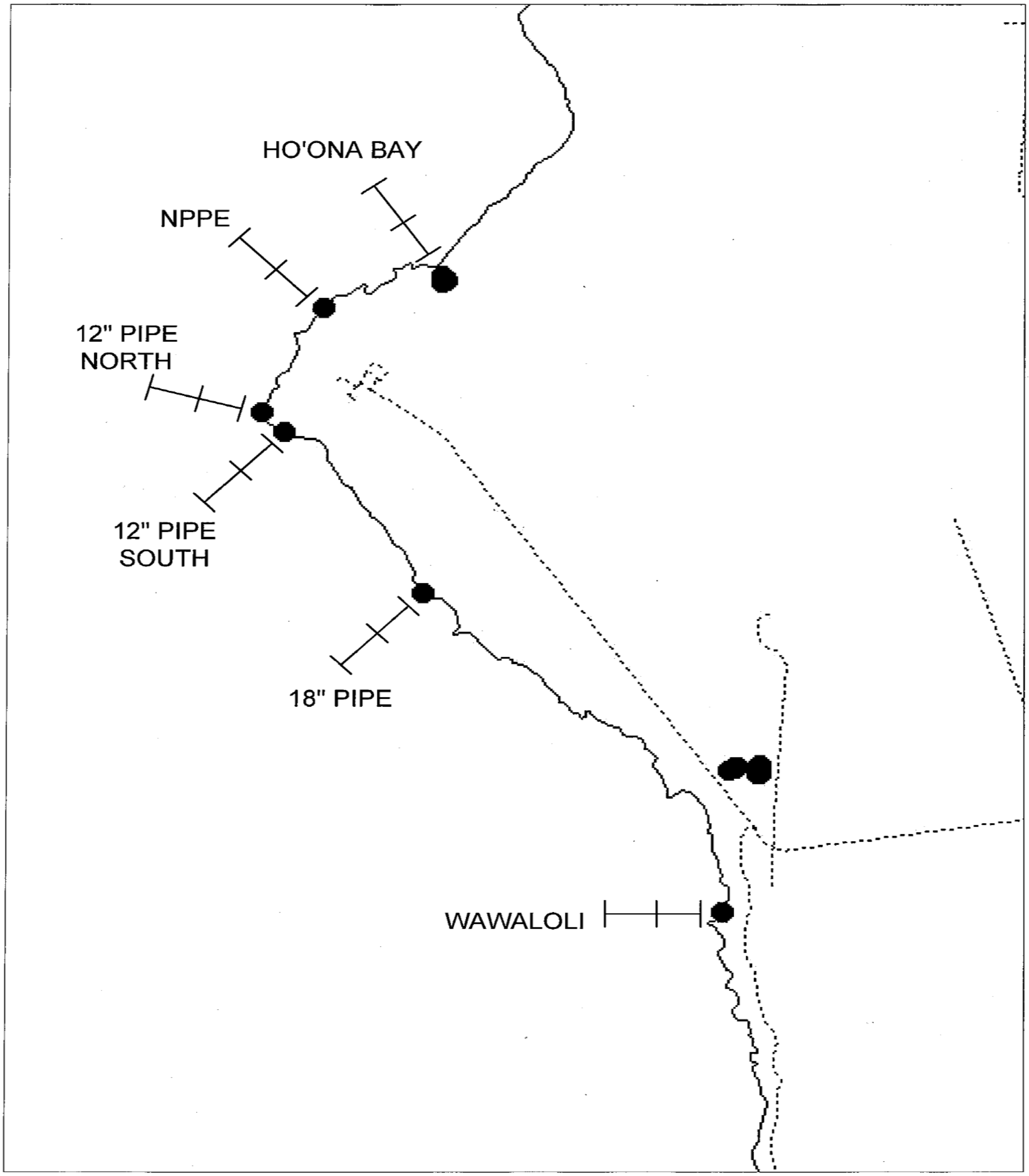

Figure 12. Six stations with three transects per station along the NELHA coastline.

In addition, each permanent quadrat was photographed using an underwater camera with a super wide angle lens mounted on a quadruped frame. Each photograph was separately labeled to designate the location of each frame within each transect. Photographs were taken using high resolution digital photography. In the laboratory, accurate estimates of the benthic cover of biota and substrata were performed using the software Coral Point Count with Excel Extensions (Kohler 2006) overlaying a 10 x 20 grid to divide the photographs into 200 equal sized segments and biota and substrate type at each point were identified.

RESULTS

Benthic biota observed in this study included stony corals, coralline algae, turf algae, echinoderms (sea urchins), sponges, and gastropod molluscs. All were present in very small numbers except for the stony corals which comprised the vast majority of the benthic biota. Percent cover and diversity of corals and other benthic biota as well as non-coral substrate are presented in detail in Appendix 2 and summarized in Table 5.
Over all coral cover across the six study sites was 44%. The two most dominant corals were *Porities lobata* (22.14%) and *Pocillopora meandrina* (8.86%) which were present on all transects. Other corals present were *Lepastrea purpurea, Montipora capitata, Montipora flabellata, Montipora patula, Pavona varians, Pocillapora eydouxi, Pocillopora lingulata, Pocillopora meandrina, and Poritis compressa.* These corals accounted for approximately 6% of the coral cover.

Poritis compressa was abundant in the deepest transects (50 feet) only at the three northern sites (Ho'ona Bay, NPPE and 12" Pipe North). *Poritis compressa* was also present in smaller numbers in the middle transects (30 feet) at all sites except for 12" Pipe North. In the shallow transects (15 feet) *P. compressa* occurred only at NPPE and 12" Pipe South and in very low numbers. Color photographs of all quadrats are presented in Appendix 4.

Table 5 shows a comparison of the percent coral cover between sites and habits. The NPPE site was the highest in total coral cover (61.7%) due mostly to its abundant *P. lobata* and *P. compressa*. The three northern sites (Ho'ona Bay, NPPE and 12" Pipe North) had more total coral and more *P. lobata* than the southern stations, but *P. meandrina* was evenly distributed between northern and southern transects. The lowest overall coral cover (24.7%) was observed at Wawaloli, the southernmost site and increased moving northward. The highest *P.lobata* cover was observed at NPPE (39.5%) followed by Ho'ona Bay (33.6%) and Wawaloli (20.4%). The lowest concentration of *P. lobata* occurred at 12" Pipe South (7.79%). The highest concentration of *Pocillopora meandrina* occurred at 12" Pipe South (21.36%) and 12" Pipe North (17.53%).

Coral cover was higher in the middle and deep transects (47.8% and 45.02%) than the shallow stations (39.8%). Among the deep stations coral was most abundant at NPPE and 12"Pipe North (77.26% and 72.22%) followed by Ho'ona Bay (56.45%). At 12" Pipe

North *P. lobata* (25%) was dominant while at NPPE and Ho'ona Bay both *P. lobata* (39.5% and 33.6%) and *P. compressa* (29% and 26%) were dominant.

Though measurable, none of the above mentioned differences were statistically significant. The only significant difference in this study was diversity and it was observed between habitats (p = .02, ANOVA). Shallow stations were higher in diversity than deep station.

Other Benthic Invertebrates

At all stations except for 12" Pipe South there were clusters of gastropod molluscs visible on some of the rocks. They were small, oval in shape and only noted while analyzing photos in the lab so no specimens were collected in the field for species identification. Sea urchins were observed in low numbers at all stations.

Table 5. Summary of photoquadrats from benthic surveys conducted May 16-18, 2012											
station		Wawaloli Beach				18" Pipe				12" Pipe South	
transect	Shallow	Mid	Deep		Shallow	Mid	Deep		Shallow	Mid	Deep
% total coral	33.6	28.25	12.3		43.35	33.85	13.7		41.5	49.92	38.2
% P. lobata	30.45	22.4	8.2		22.15	17	11.24		10.3	26.75	26.1
% P. compressa	0	0.2	3.7		0	0.2	0.3		1.4	0.7	2.1
% Poc. Meandrina	0.25	4.1	0.15		11.1	13	0.5		24.6	32.8	6.7
Species	5	5	4		7	6	5		6	8	7
Diversity	1.1	0.77	0.77		1.17	1.18	0.62		1.16	1.13	0.85
station		12" Pipe North				NPPE				Ho'ona Bay	
transect	Shallow	Mid	Deep		Shallow	Mid	Deep		Shallow	Mid	Deep
% total coral	40.62	45.27	72.22		36.4	71.37	77.26		43.9	58.15	56.45
% P. lobata	8.8	23.2	24.8		21.8	52.95	43.8		25.4	45.7	29.9
% P. compressa	0	0	4.7		0.1	4.3	28.6		0	1.2	26
% Poc. Meandrina	24.36	19.77	8.45		9.1	5.35	1.65		15.9	7.8	0
Species	7	6	6		6	8	6		5	6	4
Diversity	0.92	0.86	0.81		1.3	0.89	0.65		0.69	0.59	0.56
Survey Means	Wawaloli	18" pipe	12" Pipe S	12" Pipe N	NPPE	Ho'ona Bay	P value	Shallow	Middle	Deep	p value
% Total coral	24.7	30.3	43.2	52.7	61.7	52.8	0.05	39.89	47.8	45.02	0.76
% P. lobata	20.35	16.79	21.05	18.93	39.51	33.67	0.12	19.81	31.32	24	0.22
% Poc. Meandrina	1.5	8.2	21.36	17.53	5.3	7.9	0.07	14.22	13.8	2.9	0.9
Species	4.66	6	7	6.3	6.7	5	0.05	6	6.5	5.3	**0.009**
Diversity	0.88	0.99	1.04	0.53	0.95	0.61	0.27	0.92	0.82	0.75	0.36

Comparative analysis

Extensive analyses have been done comparing data from previous surveys at these same sites from 1992-2010 (Ziemann 2010). The goal of the current study is not to duplicate that information but instead to discuss some of the main points of those previous analyses in light of the current data from 2012.

In previous reports total coral abundance estimates showed “a clear pattern over time” (Ziemann 2010). This pattern was one of general increase from 1992 - July 2008 ranging from 16.9% to 54.7%. In the years following, reported estimates declined to 39.5% in 2008, 39.5% in 2009 and rose to 43.2% in 2010. The present survey records a total coral abundance very near the 2010 data (44%).

Though mean coral abundance did differ significantly between some sites over the 18 year period (Ziemann 2010), it did not differ significantly between sites in 2010 or in the present study. There were no statistically significant differences between coral abundance when 2010 and 2012 data were compared to each other ($p = .83$, two-way ANOVA). The observed pattern of highest coral abundance at NPPE and a decrease through Ho’ona, 12” Pipe N and S, 18” Pipe with a low at Wawaloli was also evident in 2012.

The mean *P. lobata* cover has been similar to total coral cover in its pattern of change over time (1992-2010) ranging from 10.0 to 30.7%. The current survey shows a range of 16.8 (18” Pipe) to 39.5% (NPPE). No significant difference was detected between 2010 and 2012 data ($p = .49$, two-way ANOVA).

Mean *Pocillopora meandrina* cover over time has exhibited the same general pattern of increase seen in mean total coral cover and mean *Poritis lobata* cover (Ziemann 2010). The results of the current study show a wide range of 1.5 to 21.36% with an average of 10.29% cover, though not significantly different between sites or habitats. Data for *P. meandrina* cover in 2010 did not differ significantly from 2012 data ($p = .44$, two-way ANOVA). The same is true for comparisons of species and diversity between the two years ($p = .32$).

DISCUSSION

As noted by previous authors (Dollar 1975, Dollar and Tribble 1993, Ziemann 2010), there is a recognizable zonation on many parts of Hawaii’s coral reefs. Those zonation patterns (*Pocillpora meandrina* and *Poritis compressa* co-dominant in the upper regions and *Poritis compressa* dominant on the deeper reefs) are visible off the shore of NELHA and were observed in this study as they have been in the past (Ziemann 2010, MRC 2008).

The overall total coral cover and *Poritis lobata* cover have been observed to increase from south to north and from shallow to deep (Ziemann 2010). In this study the south to north increase is apparent but there was no detectable increase in total coral cover or *Poritis lobata* cover from shallow to deep.

Pocillopora meandrina decreased in abundance from shallow to deep (not statistically significantly) and was abundant at all shallow and middle stations except for Wawaloli where it was rare throughout the entire station. Its role as a colonizer of disturbed habitat and rough water (Dollar 1982) areas makes the shallower stations in this study ideal for settlement.

The varied results found between different monitoring teams throughout the past 20 years may become less of an issue in the future if permanent transect starting points are reinstalled along the pipes at specific depths. This wouldn’t make much of a difference at Wawaloli, Ho’ona Bay or NPPE but the other 3 sites would be more standardized, minimizing a potentially confounding variable.

Taking into consideration the historical data from previous monitoring reports showing a general increase in coral cover over time and the concurring data presented herein for 2012, there is no indication that the benthic community is being negatively impacted by the presence or activities of NELHA.

MARINE FISH BIOTA SURVEY

INTRODUCTION

The near shore fish populations off Keahole point where NELHA is located have long been noted for their unusual abundance and diversity among the Hawaiian Islands (Brock 1954, Brock, 1985; Brock, 1995). As such, they should be the focus of efforts in conservation, management, research and monitoring. Concerns over the possible decline in water quality due to activities at NELHA have prompted regular surveys of fish populations to monitor any detectable changes that might indicate negative impacts linked to the NELHA facilities.

METHODS

The fish community was monitored at the same 6 sites (18 transects total) as the benthic community (Figure 1). Fish communities were assessed using a visual census to estimate the abundance and biomass of fish present (Brock 1954). Data collected include a listing of all species present, the numbers of individual species and the estimated length of each for estimates of standing crop using linear regression techniques. The census was conducted over the entire length of a 4 X 25 meter transect line. All fish within the transect area to the water's surface were counted by SCUBA divers (with slate and pencil as well as underwater video).

In previous studies, permanent transects were marked with subsurface floats to pinpoint transect lines (Brock 2008). In 2012 these markers were not present, so surveys were conducted at 15, 30 and 50 feet respectively at each of the six stations. At one site (12" Pipe South, 50 ft.) the diver doing the fish surveys was injured and had to be assisted to the surface by his dive buddy while benthic photoquadrats continued to be taken by the other divers. The remainder of the sites were surveyed over the following two days, mistakenly overlooking the fact that no fish data was collected for 12" Pipe South at 50 feet. Thus, in the analysis for the present study, data from the two transects on either side of 12" Pipe South (18" Pipe, 50 ft. and 12" Pipe North, 50 ft.) were averaged and used in lieu of the missing data.

Visual length estimates were converted to weight using the formula $M = a * L^b$ where M = mass in grams, L = standard length in mm and a and b are fitting parameters. Fitting parameters were obtained from Fishbase (Froese and Pauley 2000).

RESULTS

A summary of the major variables measured during this study (total number of individuals, number of species, diversity and biomass) is found in Table 6 and the complete data set is found in Appendix 3.

Total number of individual fish per transect was not significantly different between sites (.82, ANOVA) with a range of 17-149 individuals. Nor was it significantly different between habitats (.07, ANOVA). The highest number of individuals occurred at the 12" Pipe North deep transect (149 individuals). Total number of fish was higher at the deep stations (though not significantly).

Number of Species

Table 6 shows the number of species per transect recorded during the present study.
The mean number of species per transect ranged from 10.8 on the middle transects to 12.2 at the shallow sites. Overall there was no statistically significant difference observed between the sites ($p = 0.68$, ANOVA). The highs occurred at 12" Pipe South, middle transect (15 species) and 12" Pipe North, deep transect (16 species). The lows occurred at 18" Pipe and Ho'ona Bay middle transects (9 species) and the NPPE shallow transect (8 species). There was no significant difference in number of species between habitats ($p = 0.54$, ANOVA).

The most abundantly represented families in this survey were the chaetodontids (butterflyfish), pomacentrids (damsel fish) and acanthurids (surgeon fish). The most abundant species were *Chromis vanderbilti, Zebrasoma flavescens, Ctenochaetus strigosus, Thalassoma duperrey* and *Acanthurus nigrofuscus.* They were present in almost all habitats and transects.

Species Diversity and Biomass

Species diversity ranged from 2.26 at Wawaloli to 6.54 12" Pipe North. None of the differences between station or habitat were statistically significant ($p = .09$ and $.56$ respectively, ANOVA).

Biomass was highest 12" Pipe South and lowest at NPPE. The family Acanthuridae contributed most to overall biomass. No significant differences in mean biomass were detected between sites or habitats ($p = 0.61$ and 0.48 respectively, ANOVA).

Table 6. Summary of quantitative fish transects conducted May 16-18, 2012.
A complete data set is presented in Appendix 3

station		Wawaloli Beach				18" Pipe				12" Pipe South	
transect	Shallow	Mid	Deep		Shallow	Mid	Deep		Shallow	Mid	Deep
Total number	148	17	118		90	63	70		71	51	109.5
Number of species	13	12	13		14	9	11		10	15	11
Diversity	3.13	1.55	2.11		4.6	3.29	7.58		4.79	2.66	6.72
Biomass (g/m^2)	69.03	30.25	100.7		74.65	13.17	47.82		82	76.82	76.82
station		12" Pipe North				NPPE				Ho'ona Bay	
transect	Shallow	Mid	Deep		Shallow	Mid	Deep		Shallow	Mid	Deep
Total number	57	89	149		54	43	86		88	65	57
Number of species	16	10	11		8	10	11		12	9	14
Diversity	6.04	7.74	5.86		2.71	5.84	4.5		4.03	5.97	5.47
Biomass (g/m^2)	56.93	65.67	48.51		22.47	19.15	62.18		39.84	17.8	26.03
Survey Means	Wawaloli	18" pipe	12" Pipe S	12" Pipe N	NPPE	Ho'ona Bay	P value	Shallow	Middle	Deep	p value
Total number	94.3	74.3	77.16	98	61	70	0.82	84.7	54.6	98.25	0.07
Number of species	12.7	11.3	12	12.3	9.7	11.7	0.68	12.2	10.8	11.8	0.54
Diversity	2.26	5.15	4.72	6.54	4.35	5.15	0.09	4.22	4.51	5.37	0.56
Biomass (g/m^2)	66.67	45.25	79.4	57.03	34.6	72.89	0.61	57.48	37.16	60.34	0.48

Comparative Analysis

Extensive analyses have been done comparing data from previous surveys at these same sites from 1992-2010 (Ziemann 2010). The goal of the current study is not to duplicate that information but instead to discuss some of the main points of those previous analyses in light of the current data from 2012.

Previous studies have determined that even though much year to year variation has been observed, there have been no significant overall changes to fish populations, during an 18-year study period, that can be attributed to anthropogenic affect (Ziemann 2010). This year's data is an extreme example of the wide variation mentioned above. Total number of fish per transect, number of species, diversity and biomass were all significantly lower ($p < .001$, two way ANOVA) than 2010 measurements. The possible significance of this observation is discussed below.

DISCUSSION

Ziemann (2010) noted the presence of large schools of fish that roamed between zones and had a dramatic impact on the abundance calculations. During the present study none of these large schools crossed transect lines during data collection.

He also concluded that these fish communities are "highly variable in nature over very small time and space scales" and that "any conclusions of change in fish community abundance or distribution need to be examined carefully in the context of natural variability." As an illustration of that point, there are significant differences between 2010 and 2012 data as mentioned above. Although this difference may be partially the result of natural variability it is much more likely to be the result human variability in implementation of the survey method used.

In the present study a team of multiple divers worked each transect simultaneously. The transect line was laid out by the 3 divers going from north to south. Upon reaching the 25 meter mark two of the divers turned around and moved along the transect line from south to north taking photoquadrats of the benthic community. Slightly behind them another diver moved from north to south collecting fish data along the same transect line. It is highly likely that many fish were disturbed by this activity and stayed out of sight the majority of the time. Anecdotal observations support this idea. We observed a great abundance of fish on the reef while in transit between transects but noticeably fewer on each measured transect line. A positive change in methodology for future surveys may be for a single diver to feed the transect line out as he goes thus reducing the amount of disturbance to fish communities. The diver will also spend more time on each transect in order to increase the chances of seeing and accurately recording many more of the fish present.

The general observation in previous years was that the fish community seemed least developed off Wawaloi beach but in 2012 that site had the highest total number of fish and among the highest number of species. It also had the lowest diversity index. This seems to be another example of high variability over short periods of time and space.

In summary, when taking into account all data from this long term study of the fish biota off NELHA, despite much variability from year to year and site to site there is no evidence that activities at NELHA are negatively affecting the reef fish community.

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APPENDICES

Appendix 1: Environmental and biological data reported from anchialine pond surveys conducted 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; and Ziemann & Conquest, 2008).

Pond No.	Dimensions (m)	Basin Characteristics	2009 salinity (ppt)
N-1	15.5 x 6	Deep mud bottom; in pahoehoe/basalt cobble	10
N-2	1 x 1	Rubble basin; in pahoehoe	10
N-3	7.5 x 3	Cobble basin; in pahoehoe	9
N-4	2 x 2	Rubble & mud bottom; in pahoehoe	9
N-5	7.5 x 3	Two interconnected basins in cobble	10
S-1	1.4 x 1.2	Pahoehoe and rubble	5
S-2	1 x 1	Pahoehoe and rubble	7
S-3	1 x 1	Pahoehoe and rubble	8
S-4	0.075 x 0.075	Pahoehoe and rubble	8
S-5	2 x 2.5	Pahoehoe and rubble	8
S-6	0.2 x 0.05	Pahoehoe and rubble	8
S-7	1 x 1.4	Pahoehoe and rubble	9
S-8	1 x 1	Pahoehoe and rubble	8
S-9	0.2 x 0.05	In 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 exotic fish species (Poecilid/*Poecilia*) recorded as present (x) or absent (0).

Census Data (no./0.1m^2)

Pond No.	Species	May 89	Oct 91	Mar 92	May 92	Oct 92	May 93	Dec 93	May 94	Jun 94	Oct 94	Mar 95	Jun 95	Dec 97	Jun 98
N-1	*Melania*	78	35	49	56	24	31	42	31	43	19	40	63	39	41
N-1	*Melania*	71	52	31	29	62	54	59	72	68	72	52	50	67	53
N-1	*Poecilia*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
N-1	*M. grandimanus*									2	0	0	1	0	0
N-1	*Palaemon*												2		
N-1	*Metopograpsus*													4	7
N-1	*T. cariosa*														6
N-1	*H. rubra*														
N-2	*Melania*	36	42	72	85	41	22	27	31	28	19	31	28	33	44
N-2	*H. rubra*	22	15	3	0	72	0	0	0	4	0	42	0	0	0
N-2	*Poecilia*	0	0	0	x	0	x	x	x	x	x	0	x	x	x
N-3	*Melania*	62	12	67	29	24	19	31	42	51	72	40	53	49	57
N-3	*Melania*	21	9	23	41	15	26	17	24	33	41	23	19	31	22
N-3	*Melania*		0	0	0	6	0	8	5	6	9	9	14	18	34
N-3	*H. rubra*	1	0	0	0	15	0	0	2	0	0	0	0	0	0
N-3	*H. rubra*	15	28	0	0	38	0	0	0	0	0	0	0	0	0
N-3	*Palaemon*	0	0	0	1	1	2	1	2	1	1	2	3	0	0
N-3	*M. lar*									1	0	1	0	0	0
N-3	*Poecilia*	0	0	x	x	0	x	x	x	x	x	x	x	x	x
N-4	*Melania*	39	0	0	14	10	9	14	12	26	25	26	25	27	33
N-4	*Melania*	115	4	9	3	85	42	61	53	49	19	19	23	17	21
N-4	*H. rubra*	3	0	0	0	12	0	0	0	0	0	0	0	0	0
N-4	*H. rubra*	21	23	0	0	31	0	0	0	0	0	0	0	0	0
N-4	*M. grandimanus*											5	0	0	0
N-4	*Poecilia*	0	0	x	x	0	x	x	x	x	x	x	x	x	x
N-5	*Melania*	2	2	61	9	8	12	23	19	27	51	21	29	33	42
N-5	*Melania*	4	4	2	1	1	1	17	27	6	29	19	16	13	27
N-5	*H. rubra*	0	0	0	0	41	0	0	0	0	0	0	0	0	0
N-5	*M. grandimanus*											3	0	0	0
N-5	*Metopograpsus*													3	5
N-5	*Poecilia*	0	0	x	x	0	x	x	x	x	x	x	x	x	x

Census Data (no./0.1m²)

Pond No.	Species	Nov 98	May 99	Dec 99	Jun 00	Nov 00	May 01	Nov 01	May 02	Dec 02	Dec 07	Aug 08
N-1	*Melania*	38	27	36	42	34	39	37	29	21	0	4
N-1	*Melania*	52	49	68	37	55	27	23	47	17	0	0
N-1	*Poecilia*	x	x	x	x	x	x	x	x	x	0	0
N-1	*M. grandimanus*	0	0	0	0	0	0	0	0	0	0	0
N-1	*Palaemon*			0	0	0	0	0	0	0	0	0
N-1	*Metopograpsus*	9	6	8	9	5	4	6	5	7	0	0
N-1	*T. cariosa*	5	6	3	2	4	3	2	9	5	0	0
N-1	*H. rubra*			0	0	0	0	0	0	0	0	100
N-2	*Melania*	56	47	47	39	51	79	66	72	37	0	3
N-2	*H. rubra*	0	0	0	0	0	0	0	0	0	0	10
N-2	*Poecilia*	x	x	x	x	x	x	x	x	x	0	0
N-3	*Melania*	28	39	37	44	34	41	39	27	41	0	2
N-3	*Melania*	26	24	31	51	29	22	33	19	38	0	0
N-3	*Melania*	14	22	12	6	9	3	3	5	5	0	0
N-3	*H. rubra*	0	0	0	0	0	0	0	0	0	0	25
N-3	*H. rubra*	0	0	0	0	0	0	0	0	0	0	21
N-3	*Palaemon*	0	0	0	0	0	0	0	0	0	0	0
N-3	*M. lar*	0	0	0	0	0	0	0	0	0	0	0
N-3	*Poecilia*	x	x	x	x	x	x	x	x	x	0	0
N-4	*Melania*	29	27	36	29	27	Dry	29	31	27	Dry	2
N-4	*Melania*	26	19	29	17	21		17	20	18		1
N-4	*H. rubra*	0	0	0	0	0		0	0	0		23
N-4	*H. rubra*	0	0	0	0	0		0	0	0		17
N-4	*M. grandimanus*	0	0	0	0	0		0	0	0		0
N-4	*Poecilia*	x	x	x	x	x		x	x	x		0
N-5	*Melania*	23	24	16	12	21	19	17	23	17	0	4
N-5	Melania	19	12	19	26	17	14	12	16	21	0	5
N-5	*H. rubra*	0	0	0	0	0	0	8	0	0	0	80
N-5	*M. grandimanus*	0	0	0	0	0	1	0	0	0	0	0
N-5	*Metopograpsus*	5	4	5	5	5	7	5	6	3	0	0
N-5	*Poecilia*	x	x	x	x	x	x	x	x	x	0	0

Census Data (no./0.1m²)

Pond No.	Species	May 89	Oct 91	Mar 92	May 92	Oct 92	May 93	Dec 93	May 94	Jun 94	Oct 94
S-1	*H. rubra*	56	29	31	61	29	49	37	47	52	84
S-1	*M. grandimanus*	0	0	1	1	0	0	1	2	0	0
S-1	Amphipoda	0	0	0	6	19	12	15	21	18	26
S-1	Poecilids										
S-2	*H. rubra*	71	31	40	14	34	54	Dry	Dry	Dry	
S-2	Amphipoda	185	32	6	2	9	2				
S-2	Poecilids										
S-3	*H. rubra*	38	21	43	64	56	Dry	49	37	86	94
S-3	*M. lohena*									1	0
S-3	Amphipoda	54	14	9	12	9		12	14	3	16
S-3	*Poecilids*										
S-4	*H. rubra*	9	42	6	9	7	Dry	Dry	21	Dry	39
S-4	Amphipoda	0	0	0	2	12			6		12
S-4	*Abudefduf sordidus*										
S-5	*H. rubra*	43	121	131	92	107	113	0	0	0	0
S-5	Amphipoda	94	65	48	27	34	7	0	0	0	0
S-5	*M. grandimanus*						1	0	1	4	1
S-5	Poecilids										
S-6	*H. rubra*	3	3	1	1	7	5	4	7	4	23
S-6	Amphipoda	0	9	2	3	3	2	3	3	3	0
S-6	White Amphipoda	0	2	0	0	2	1	1	3	1	2
S-7	*H. rubra*	97	95	87	96	49	72	68	82	94	113
S-7	Amphipoda	11	17	12	10	13	9	10	18	23	39
S-7	*M. grandimanus*	0.5	0.5	0.5	0.75	1	0.5	1	2	1	1
S-7	Poecilids										
S-8	*H. rubra*				65	72	81	71	68	81	80
S-8	*M. grandimanus*				0.5	0.75	1	1	2	1	1
S-8	Poecilids										
S-9	*H. rubra*					3	Dry	Dry	Dry	Dry	14
S-9	Poecilids										

Census Data (no./0.1m²)

Pond No.	Species	Mar 95	Jun 95	Dec 97	Jun 98	Nov 98	May 99	Dec 99	Jun 00	Nov 00	May 01	Dec 02	Dec 07	Aug 08
S-1	*H. rubra*	61	57	73	49	81	63	65	35	35	55	58	0	0
S-1	*M. grandimanus*	0	0	0	0	0	0	0	0	0	0	0	0	0
S-1	Amphipoda	23	27	24	23	14	12	14	16	9	11	9	0	0
S-1	Poecilids												x	x
S-2	*H. rubra*	Dry		Dry		Dry		Dry	6	Dry	Dry	48	0	0
S-2	Amphipoda	9			12		14		0			1	0	0
S-2	Poecilids												x	x
S-3	*H. rubra*	Dry	78	Dry	14	Dry	29	8	17	Filled w/ sand		0	0	0
S-3	*M. lohena*		2		0		0	0	0			0	0	0
S-3	Amphipoda		21		17		10	12	9			3	0	0
S-3	Poecilids												x	x
S-4	*H. rubra*	Dry	16	Dry	0	Dry	0	15	31	Dry	Dry	38	8	0
S-4	Amphipoda		3		2		3	4	8			1	0	0
S-4	*Abudefduf sordidus*													1
S-5	*H. rubra*	0	0	0	0	0	0	0	0	0	35	49	3	0
S-5	Amphipoda	0	0	0	0	0	0	0	0	0	0	4	0	0
S-5	*M. grandimanus*	2	1	0	0	0	0	0	0	0	0	0	0	0
S-5	Poecilids													x
S-6	*H. rubra*	Dry	17	Dry	12	Dry	6	Dry	4	Dry	Dry	7	Dry	5
S-6	Amphipoda		0		2		3		0			0		0
S-6	White Amphipoda		0		0		0		0			0		0
S-7	*H. rubra*	77	121	86	79	87	59	43	41	56	47	0	0	0
S-7	Amphipoda	25	29	21	31	20	18	14	22	6	9	0	0	0
S-7	*M. grandimanus*	1	3	0	1	2	3	2	1	1	1	1	0	0
S-7	Poecilids											x	x	x
S-8	*H. rubra*	52	61	55	57	63	72	30	38	48	80	81	0	0
S-8	*M. grandimanus*	1	1	0	0	0	1	0	0	0	0	0	0	0
S-8	Poecilids												x	x
S-9	*H. rubra*	Dry	9	Dry	12	Dry	10	4	1	7	Dry	27	0	0
S-9	Poecilids												x	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 & Conquest, 2008).

Pond no.	*Ruppia maratima*	*Melania sp.*	*Assemenia sp.*	*Theodoxus cariosa*	*Graspsus tenuicrustatus*	*Halocaridina rubra*	*Metabateaus lohena*	*Poecilia sp.*	*other species, comment*
N-1				+		++	-	-	Ruppia absent
N-2						+	-	-	Ruppia absent
N-3	+	+				+++	-	-	Ruppia present
N-4						+++	-	-	Ruppia absent
N-5	+	+				++	-	-	Ruppia present
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

Marine Benthic Community Survey Results

Appedix 2. Percent coverage for photo-quadrats taken along benthic transects, the locations of which are given in Figure 12. Data are result of 200 point analyses of digital photos of 0.6 x 1.0 m.

	Wawaloli Shallow			Wawaloli Middle			Wawaloli Bay Deep		
CATEGORIES	# Points	%	SW Index	# Points	%	SW Index	# Points	%	SW Index
Coral									
Lepastrea purpurea	2	0.1	0.02	0	0	0	0	0	0
Montipora capitata	52	2.6	0.2	30	1.5	0.16	5	0.25	0.08
Montipora flabellata	0	0	0	0	0	0	0	0	0
Montipora patula	4	0.2	0.03	2	0.1	0.02	0	0	0
Pavona varians	0	0	0	0	0	0	0	0	0
Pocillopora eydouxi	0	0	0	0	0	0	0	0	0
Pocillopora meandrina	5	0.25	0.04	82	4.1	0.28	3	0.15	0.05
Porites compressa	0	0	0	3	0.15	0.03	74	3.7	0.36
Porites lobata	609	30.45	0.11	448	22.4	0.18	164	8.2	0.61
Total coral	672	33.6	0.4	565	28.25	0.67	246	12.3	1.1
Coralline Algae	0	0	0	0	0	0	226	11.3	0
Dead coral									
Dead coral with algae	0	0	0	0	0	0	0	0	0
old dead coral	167	8.35	0.01	75	3.75	0.03	4	0.2	0
recently dead coral	2	0.1	0.05	2	0.1	0.09	0	0	0
Other live									
Sponge	0	0	0	0	0	0	0	0	0
Mollusc	117	5.85	0.11	0	0	0	0	0	0
Urchin	15	0.75	0.25	6	0.3	0	2	0.1	0.29
Turf algae	0	0	0	1	0.05	0			
Substrate									
Boulder	8.29	4.45	0.17	720	36	0.34	314	15.7	0.33
Coral Rubble	127	6.35	0.26	605	30.25	0.36	1163	58.15	0.2
Limestone	0	0	0	0	0	0	0	0	0
Rock	0	0	0	0	0	0	0	0	0
Sand	71	3.55	0.18	26	1.3	0.08	33	1.65	0.08

Appedix 2. Percent coverage for photo-quadrats taken along benthic transects, the locations of which are given in Figure 12. Data are results of 200 point analyses of digital photos of 0.6 x 1.0 m.

	18" Pipe Shallow			18" Pipe Middle			18" Pipe Deep		
CATEGORIES	# Points	%	SW Index	# Points	%	SW Index	# Points	%	SW Index
Coral									
Lepastrea purpurea	25	1.25	0.1	0	0	0	0	0	0
Montipora capitata	14	0.7	0.07	30	1.5	0.14	17	0.85	0.17
Montipora flabellata	0	0	0	0	0	0	0	0	0
Montipora patula	124	6.2	0.28	36	1.8	0.16	1	0.05	0.02
Pavona varians	1	0.05	0.01	0	0	0	0	0	0
Pocillopora eydouxi	38	1.9	0.14	8	0.4	0.05	0	0	0
Pocillopora meandrina	222	11.1	0.35	260	13	0.37	10	0.5	0.12
Porites compressa	0	0	0	3	0.15	0.02	5	0.25	0.07
Porites lobata	443	22.15	0.34	340	17	0.35	241	12.05	66
Total coral	867	43.35	1.29	677	33.85	1.09			
Coralline Algae	57	2.85	0	14	0.7	0	14	0.7	0
Dead coral									
Dead coral with algae	0	0	0	53	2.65	0.22	0	0	0
old dead coral	234	11.7	0.01	538	26.9	0.09	31	1.55	0
recently dead coral	3	0.15	0.06	3	0.15	0.03	0	0	0
Other live									
Sponge	0	0	0	3	0.15	0	0	0	0
Mollusc	0	0	0	12	0.6	0.25	19	0.95	0
Urchin	13	0.65	0.07	5	0.25	0.36	0	0	0
Turf algae	1	0.05	0	0	0	0	1	1.05	0.26
Substrate									
Boulder	582	29.1	0.23	266	13.3	0.37	138	6.9	0.2
Coral Rubble	76	3.8	0.22	299	14.95	0.36	1453	72.65	0.11
Limestone	0	0	0	0	0	0	0	0	0
Rock	137	6.85	0.3	55	2.75	0.2	0	0	0
Sand	9	0.45	0.05	74	3.7	0.24	56	2.8	0.11

Appedix 2. Percent coverage for photo-quadrats taken along benthic transects, the locations of which are given in Figure 12. Data are results of 200 point analyses of digital photos of 0.6 x 1.0 m.

	12" Pipe South Shallow			12" Pipe South Middle			12" Pipe South Deep		
CATEGORIES	# Points	%	SW Index	# Points	%	SW Index	# Points	%	SW Index
Coral									
Lepastrea purpurea	0	0	0	8	0.67	0.07	0	0	0
Montipora capitata	0	0	0	0	0	0	1	0.05	0.01
Montipora flabellata	37	1.85	0.14	1	0.08	0.01	46	2.3	0.17
Montipora patula	40	2	0.15	51	3.08	0.21	23	1.15	0.11
Pavona varians	29	1.45	0.12	0	0	0	0	0	0
Pocillopora eydouxi	0	0	0	24	2.67	0.18	0	0	0
Pocillopora meandrina	491	24.55	0.31	328	32.83	0.73	133	6.65	0.3
Porites compressa	28	1.4	0.11	14	0.88	0.12	41	2.05	0.16
Porites lobata	205	10.25	0.35	535	57.17	0.64	520	26	0.31
Total Coral	830	41.5	1.18	961	97.38	1.96	764	38.2	1.06
Coralline Algae	406	20.3	0	130	11.83	0	172	8.6	0
Dead coral									
Dead coral with algae	0	0	0	0	0	0	0	0	0
old dead coral	67	3.35	0.01	254	24.3	0	45	2.25	0
recently dead coral	1	0.05	0.06	0	0	0	0	0	0
Other live									
Sponge	0	0	0	0	0	0	0	0	0
Mollusc	0	0	0	0	0	0	0	0	0
Urchin	0	0	0	0	0	0	7	0.35	0
Turf algae	0	0	0	0	0	0	38	1.9	0.07
Substrate									
Boulder	633	31.65	0.08	310	30.96	0.69	1	0.05	0.01
Coral Rubble	55	2.75	0.2	286	27.13	0.72	959	47.95	0.01
Limestone	0	0	0	0	0	0	0	0	0
Rock	0	0	0	43	4.25	0.36	0	0	0
Sand	0	0	0	13	1.33	0.17	9	0.45	0.04

Appedix 2. Percent coverage for photo-quadrats taken along benthic transects, the locations of which are given in Figure 12. Data are results of 200 point analyses of digital photos of 0.6 x 1.0 m.

	12" Pipe North Shallow			12" Pipe North Middle			12" Pipe North Deep		
CATEGORIES	# Points	%	SW Index	# Points	%	SW Index	# Points	%	SW Index
Coral									
Lepastrea purpurea	0	0	0	0	0	0	0	0	0
Montipora capitata	2	0.1	0.01	7	0.39	0.04	150	7.51	0.24
Montipora flabellata	40	2	0.15	9	0.5	0.05	0	0	0
Montipora patula	71	3.55	0.21	20	1.11	0.09	12	0.6	0.04
Pavona varians	6	0.3	0.04	0	0	0	0	0	0
Pocillopora eydouxi	31	1.55	0.12	6	0.33	0.04	28	1.4	0.08
Pocillopora meandrina	487	24.36	0.31	356	19.78	0.36	169	8.46	0.25
Porites compressa	0	0	0	0	0	0	94	4.7	0.18
Porites lobata	175	8.75	0.33	417	23.17	0.34	990	49.55	0.56
Total coral	812	40.61	1.17	815	45.28	0.92	1443	72.22	1.35
Coralline Algae	92	4.6	0	30	1.67	0	3	0.15	0
Dead coral									
Dead coral with algae	1	0.05	0.02	0	0	0	0	0	0
old dead coral	233	11.66	0.07	314	17.44	0.12	273	13.66	0.03
recently dead coral	16	0.8	0.18	47	2.61	0.27	8	0.4	0.1
Other live									
Sponge	0	0	0	0	0	0	0	0	0
Mollusc	2	0.1	0.27	149	8.28	0	0	0	0
Urchin	0	0	0	0	0	0	0	0	0
Turf algae	0	0	0	0	0	0	0	0	0
Substrate									
Boulder	564	28.21	0.26	240	13.33	0.33	3	0.15	0.05
Coral Rubble	10	0.5	0.06	119	6.61	0.47	174	8.71	0.27
Limestone	0	0	0	0	0	0	0	0	0
Rock	204	10.21	0.34	86	4.78	0.32	74	3.7	0.36
Sand	7	0.35	0.04	0	0	0	13	0.65	0.15

Appedix 2. Percent coverage for photo-quadrats taken along benthic transects, the locations of which are given in Figure 12. Data are results of 200 point analyses of digital photos of 0.6 x 1.0 m.

	NPPE Shallow			NPPE Middle			NPPE Bay Deep		
CATEGORIES	# Points	%	SW Index	# Points	%	SW Index	# Points	%	SW Index
Coral									
Lepastrea purpurea	28	1.4	0.13	0	0	0	0	0	0
Montipora capitata	55	2.75	0.2	53	2.65	0.12	19	0.95	0.05
Montipora flabellata	0	0	0	0	0	0	0	0	0
Montipora patula	26	1.3	0.12	51	2.55	0.12	1	0.05	0
Pavona varians	0	0	0	10	0.5	0.03	0	0	0
Pocillopora eydouxi	0	0	0	5	0.25	0.02	0	0	0
Pocillopora meandrina	182	9.1	0.35	107	5.36	0.19	33	1.65	0.08
Porites compressa	1	0.05	0.01	85	4.25	0.17	571	28.59	0.37
Porites lobata	436	21.8	0.31	1058	52.95	0.74	131	6.56	0.53
Total coral	728	36.4	1.12	1369	68.51	1.39	755	37.8	1.03
Coralline Algae	92	4.6	0	20	1	0	3	0.15	0
Dead coral									
Dead coral with algae	0	0	0	0	0	0	2	0.1	0.03
old dead coral	201	10.05	0.13	326	16.32	0.01	394	19.73	0.01
recently dead coral	34	1.7	0.28	4	0.2	0.05	2	0.1	0.03
Other live									
Sponge	0	0	0	0	0	0	0	0	0
Mollusc	122	6.1	0.01	56	2.8	0.03	0	0	0
Urchin	1	0.05	0.04	2	0.1	0.12	3	0.15	0.35
Turf algae	0	0	0	0	0	0	1	0.05	0.21
Substrate									
Boulder	742	37.1	0.09	105	5.26	0.29	1	0.05	0.1
Coral Rubble	42	2.1	0.15	58	2.9	0.37	28	0.4	0.3
Limestone	0	0	0	0	0	0	0	0	0
Rock	24	1.2	0.1	0	0	0	0	0	0
Sand	14	0.7	0.07	1	0.05	0.03	6	0.3	0.3

Appedix 2. Percent coverage for photo-quadrats taken along benthic transects, the locations of which are given in Figure 12. Data are results of 200 point analyses of digital photos of 0.6 x 1.0 m.

	Ho'ona Bay Shallow			Ho'ona Bay Middle			Ho'ona Bay Deep		
CATEGORIES	# Points	%	SW Index	# Points	%	SW Index	# Points	%	SW Index
Coral									
Lepastrea purpurea	0	0	0	0	0	0	1	0.05	0.01
Montipora capitata	13	0.65	0.06	28	1.4	0.09	5	0.25	0.02
Montipora flabellata	0	0	0	0	0	0	0	0	0
Montipora patula	31	1.55	0.12	13	0.65	0.05	0	0	0
Pavona varians	0	0	0	0	0	0	0	0	0
Pocillopora eydouxi	8	0.4	0.04	28	1.4	0.09	0	0	0
Pocillopora meandrina	318	15.9	0.37	156	7.81	0.27	0	0	0
Porites compressa	0	0	0	24	1.2	0.08	525	26.25	0.36
Porites lobata	508	25.4	0.32	913	45.1	0.2	598	29.9	0.59
Total coral	878	43.9	0.91	1162	57.56	0.78	1129	56.45	0.98
Coralline Algae	145	7.25	0	3	0.15	0	13	0.65	0
Dead coral									
Dead coral with algae	0	0	0	0	0	0	0	0	0
old dead coral	273	13.65	0.12	323	16.17	0.06	169	8.45	0.07
recently dead coral	39	1.95	0.26	23	1.15	0.18	13	0.65	0.19
Other live									
Sponge	0	0	0	0	0	0	0	0	0
Mollusc	62	3.1	0.11	35	1.75	0.32	0	0	0
Urchin	8	0.4	0.25	3	0.15	0.15	0	0	0
Turf algae	0	0	0	0	0	0	6	0.3	0
Substrate									
Boulder	503	25.15	0.14	83	4.15	0.32	7	0.35	0.05
Coral Rubble	88	4.4	0.28	314	15.72	0.22	651	32.55	0.03
Limestone	0	0	0	0	0	0	0	0	0
Rock	0	0	0	0	0	0	0	0	0
Sand	4	0.2	0.03	29	1.45	0.18	11	0.55	0.07

Appendix 3

Marine Fish Community Survey Results

Appendix 4. Abundance of fish observed along 25 m transects May 16-18, 2012. Species are listed in taxonomic order.

		Wawaloli			18" Pipe			12" Pipe South			12" Pipe North			NPPE			Ho'ona Bay			Total
Family	Species	Shallow	Middle	Deep	Shallow	Middle	Deep	Shallow	Middle	Deep	Shallow	Middle	Deep	Shallow	Middle	Deep	Shallow	Middle	Deep	
Holocentridae	*Myripristis berndti*																		25	25
	Myripristis amaena										2									2
	Sargocentron xantherythrum																		4	4
Serranidae	*Cephalopholis argus*	0	0	1				0	0				1							2
Cirrhitidae	*Paracirrhites arcatus*	0	2	4	2		6	0	3		1				5	30	12	7		72
	Paracirrhites fosteri		0	4				0												4
Mullidae	*Parupeneus multifasciatus*	4	0	3	1		4	0	1								1			14
	Parupeneus insularis	1	2	0				0	0		1					1				5
Chaetodontidae	*Chaetodon lunula*	1	2	0				0	1							15	2			21
	Chaetodon ephipppium		0					0			1				2					3
	Chaetodon kleinii		0					0						2						2
	Chaetodon multicintus	0	1	1	2	8		0	1		3	4							2	22
	Chaetodon ornatissimus		0													2			2	4
	Chaetodon quadrimaculatus	3	2	0	2	2		0	0		3									12
	Forcipiger longirostris	0	0	1	1	1		1	1			6	1					2	1	15
	hemitaurichthys polylelpis	0	0		4							10								14
Pomacanthidae	*Centropyge potteri*		0																1	1
Pomacentridae	*Abudefduf abdominalis*		0					2	4											6
	Chromis vanderbilti	105	0	37		33		0	0				50		15	25	25	17	27	334
	Chromis hanui	0	0	29				0	0						1				4	34
	Chromis agilis		0			1														1
	Chromis ovalis		0				10					16			3	3				32
	Plectroglyphidodon imparipennis		0																	0
	Plectroglyphidodon johnstonianus		0				8													8

Labridae	*Coris gaimard*	4	0	0	1			0	0											5
	Coris flavovittata		0		1															1
	Gomphosus varius		0	0									2					2	1	5
	Halichoeres ornatissimus	0	0	0				0	1											1
	Labroides phthirophagus	0	0	0				4	0				4							8
	Thalassoma duperrey	4	1	0	17	3		1	14		7	8	40	17	5		6	6	5	134
Zanclidae	*Zanclus cornutus*		0								3		8	6			3			20
Acanthuridae	*Acanthuris achilles*		0														2		3	5
	Acanthurus nigrofuscus	10	1	12	12		8	8	0		6	10		9						76
	Acanthurus nigroris	6	0	1	1			7	0		3		10	2			16	15	2	63
	Acanthurus olivaceus	0	2	0				1	0			2								5
	Acanthurus triostegus	0	1	1				0	2											4
	Ctenochaetus hawaiiensis	0	7	0				5	3		2									17
	Ctenochaetus strigosus	0	3	33	5	3	15	2	2		5	16	18	6	5	20	11	12	10	166
	Naso lituratus	0	0	0	1		4	0	2		2									9
	Zebrasoma flavescens	11	0	4	47	21	15	39	20		26	17	15	12	10	30	21	10	3	301
Balistidae	*Melichthys niger*	1	0	0				0	0								2	1		4
	Sufflamen bursa	0	2	0			4	0	0		1		1		2					10
	Melichthys vidua		0									4								4
	Xanthichthys auromarginatus		0				2													2
Ostraciidae	*Ostracion meleagris*		0												2	2				4
Tetradontidae	*Canthigaster coronata*		0			1	4							2			2			9
	Plectroglyphidodon sindonis		0	0				3	4											7
Scaridae	*Chlorurus perspicillatus*	0	0	0				0	1		2					3				6
	Chlorurus spilurus	1	0	0				0	1							3				5
	Scarus dubius	151	0	0				0	0											151

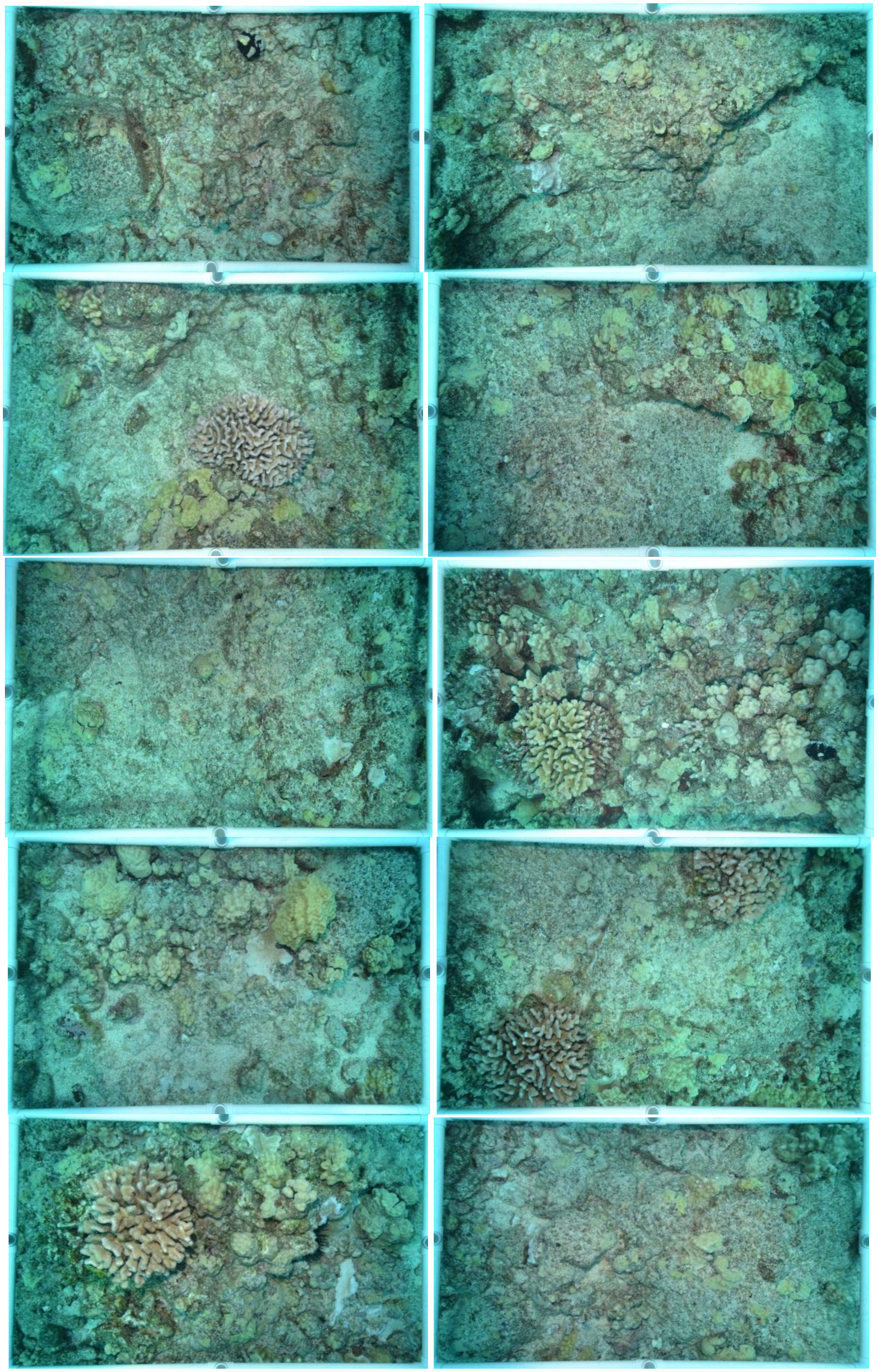
Appendix 4

Digital Photo Quadrats taken May 16-18, 2012

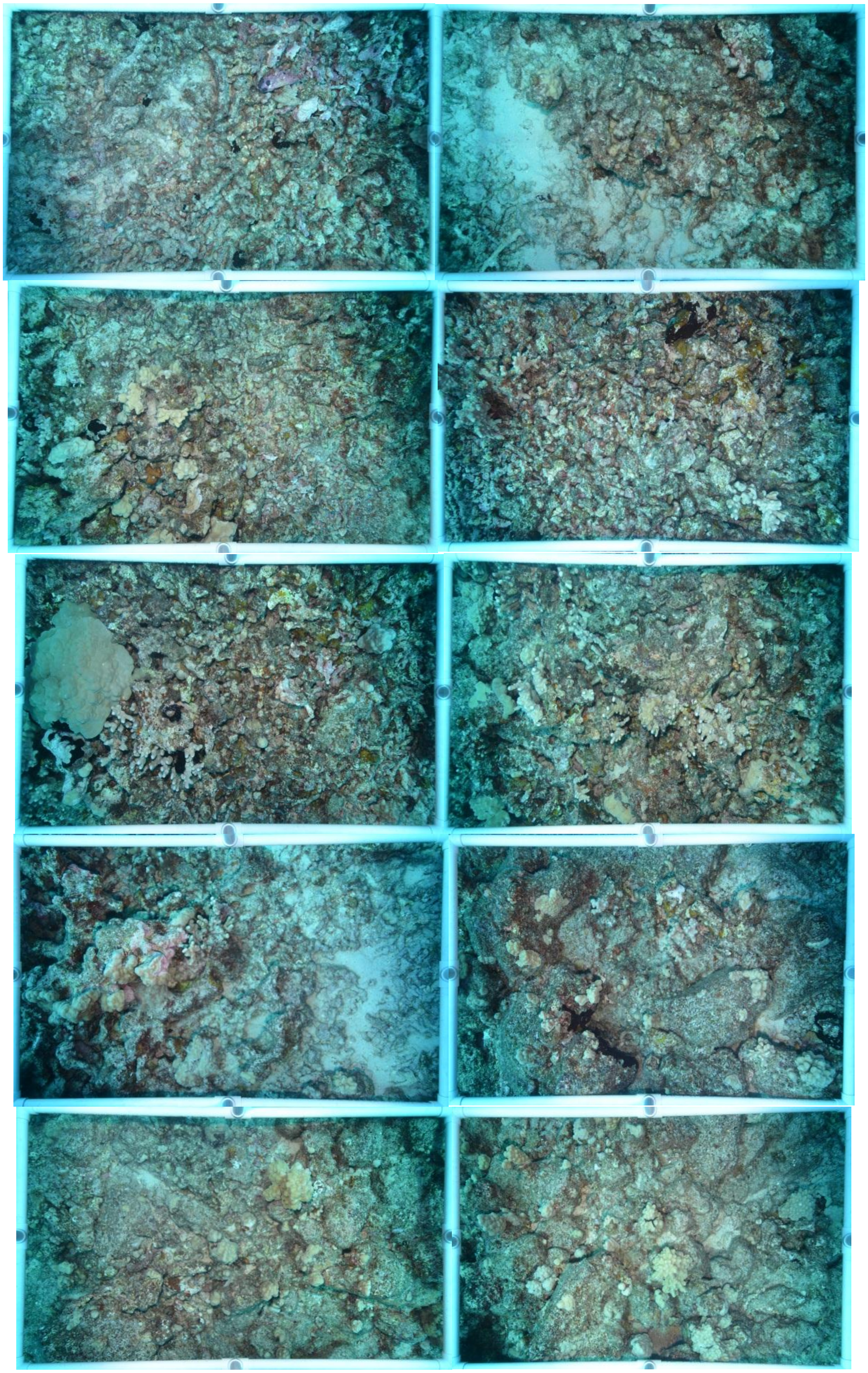
Appendix 3

Digital Quadrat Photos taken May 16-18, 2012

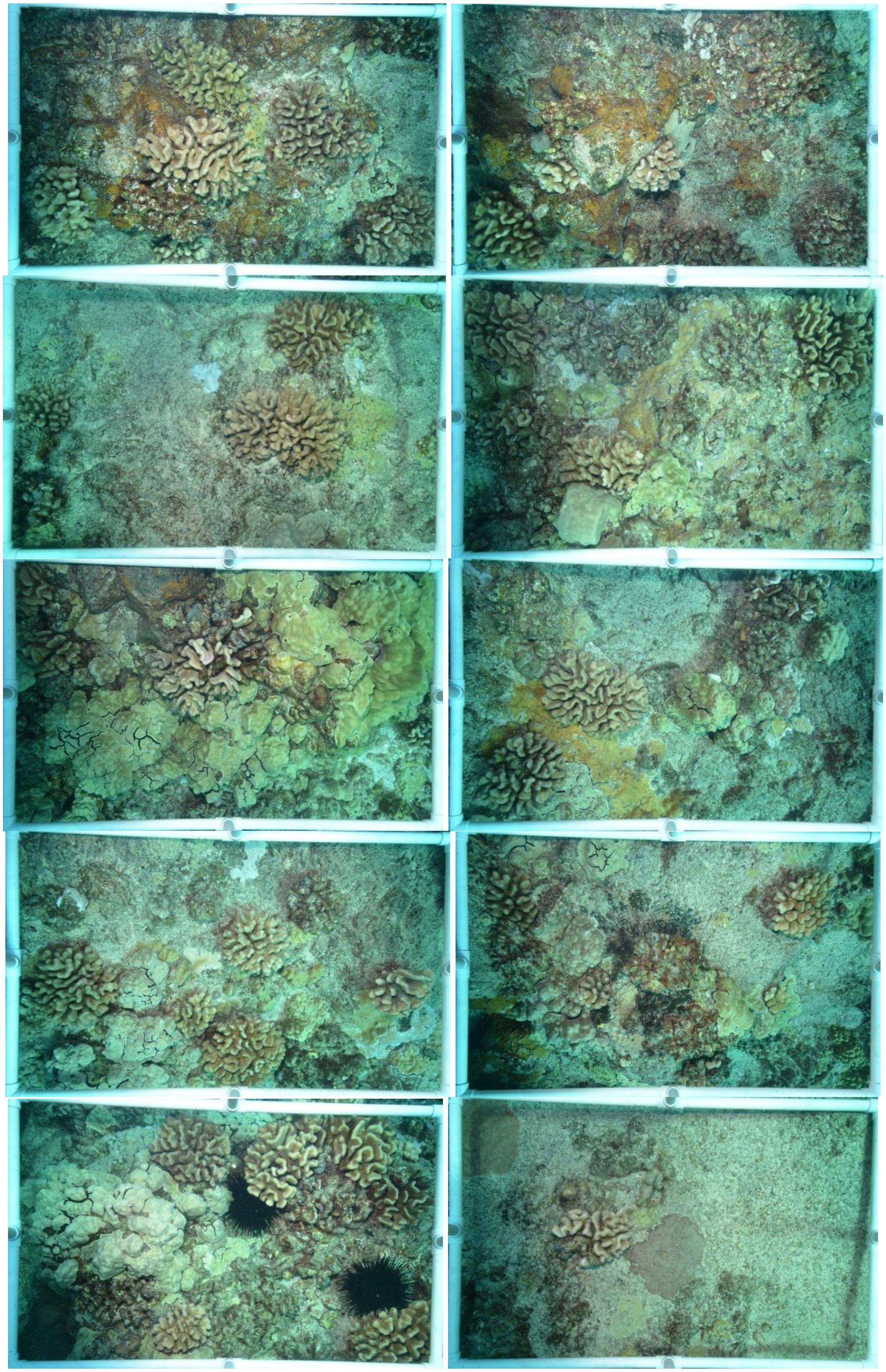
Photoquadrats taken along the 15 ft. transect at Wawaloli



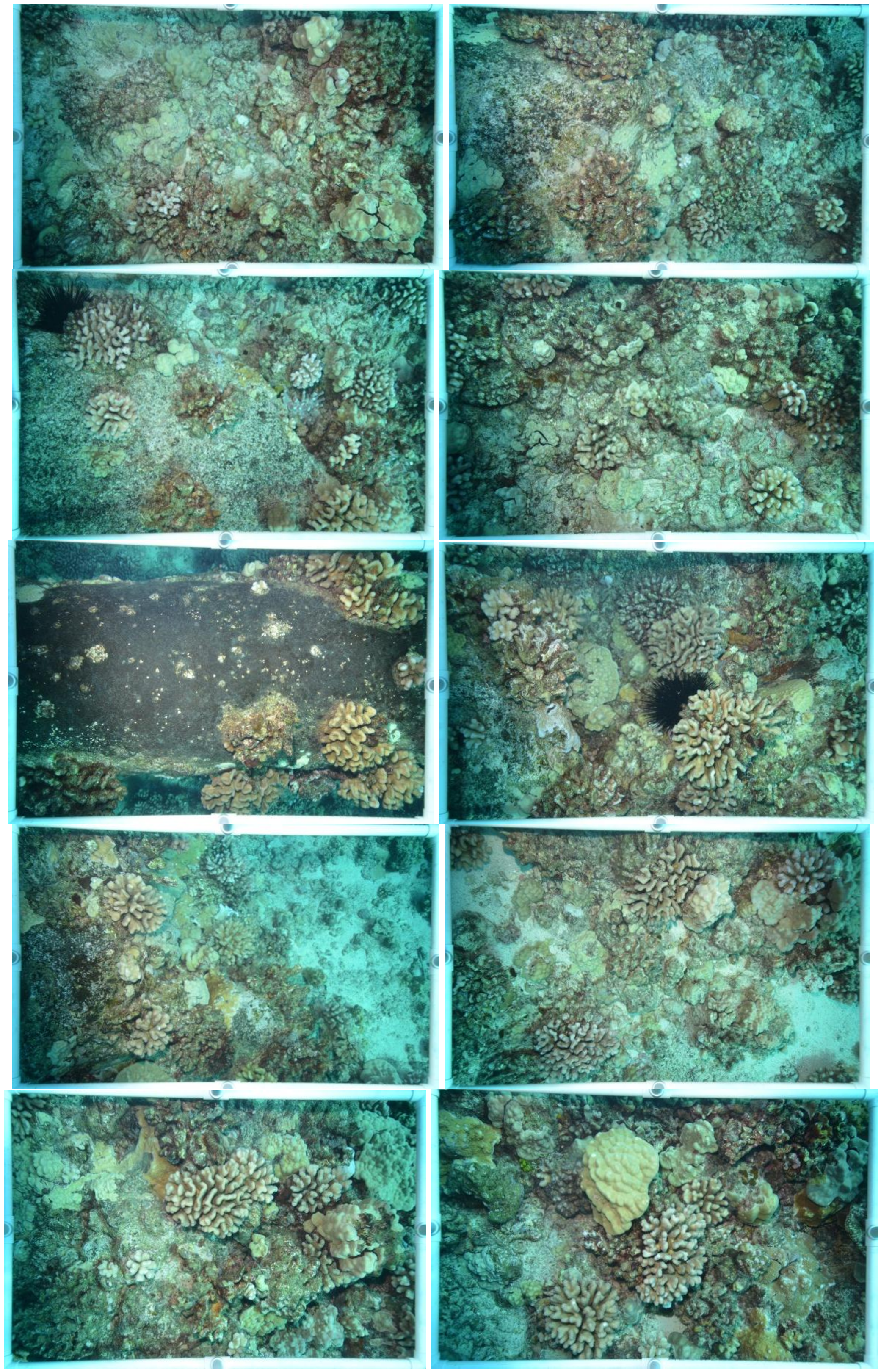
Photoquadrats taken along the 30 ft. transect at Wawaloli



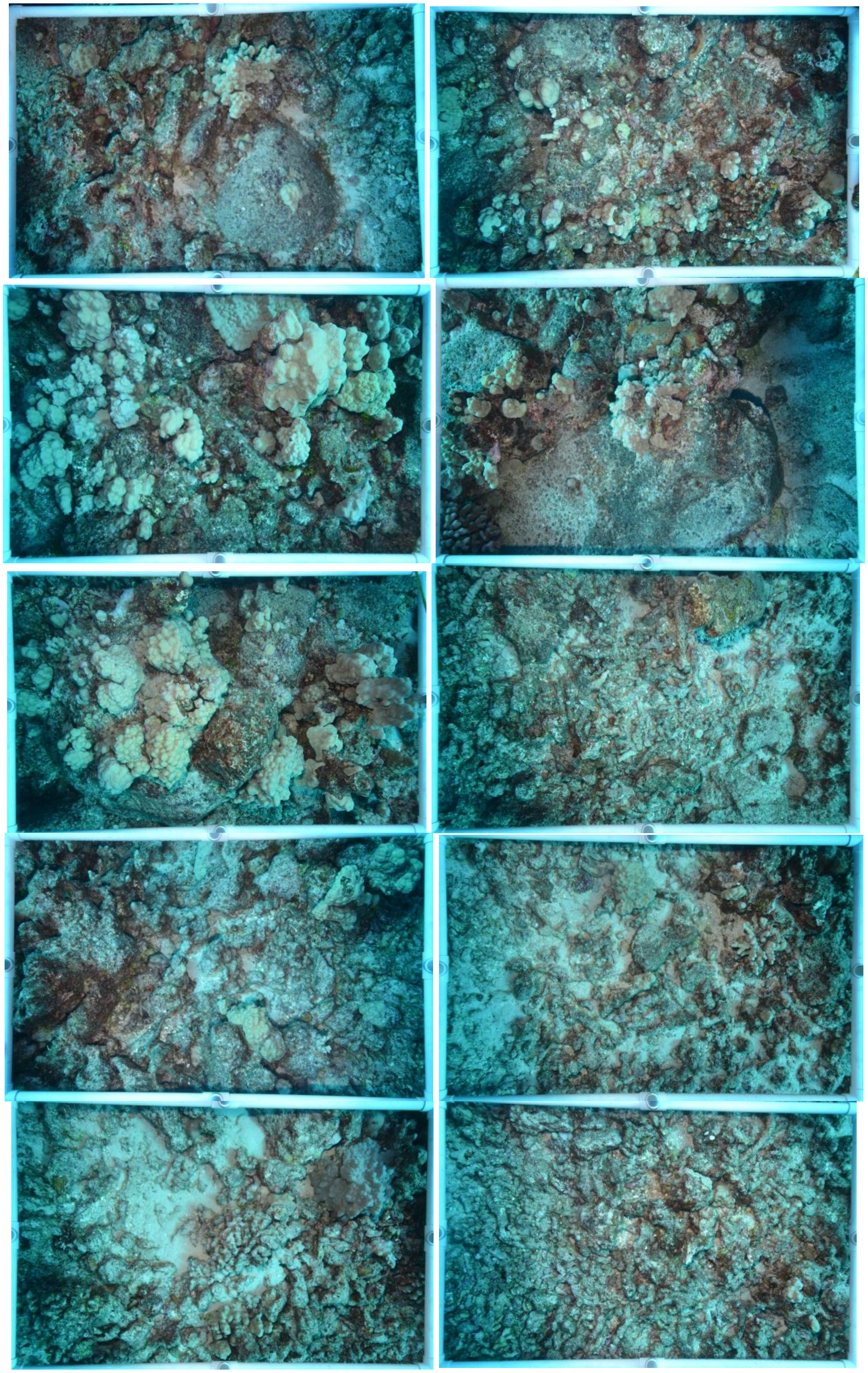
Photoquadrats taken along the 50 ft. transect at Wawaloli



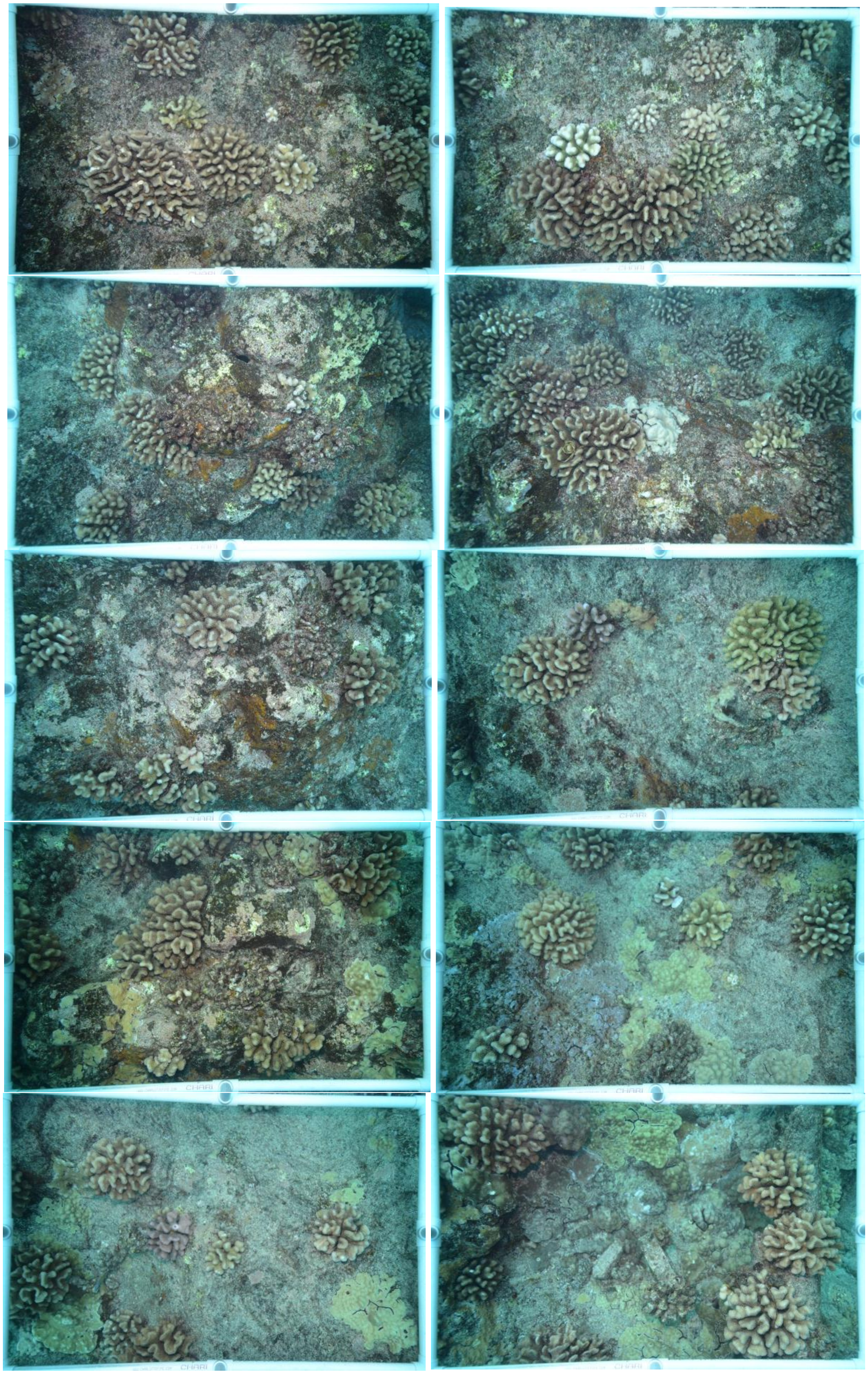
Photoquadrats taken along the 15 ft. transect at 18" Pipe



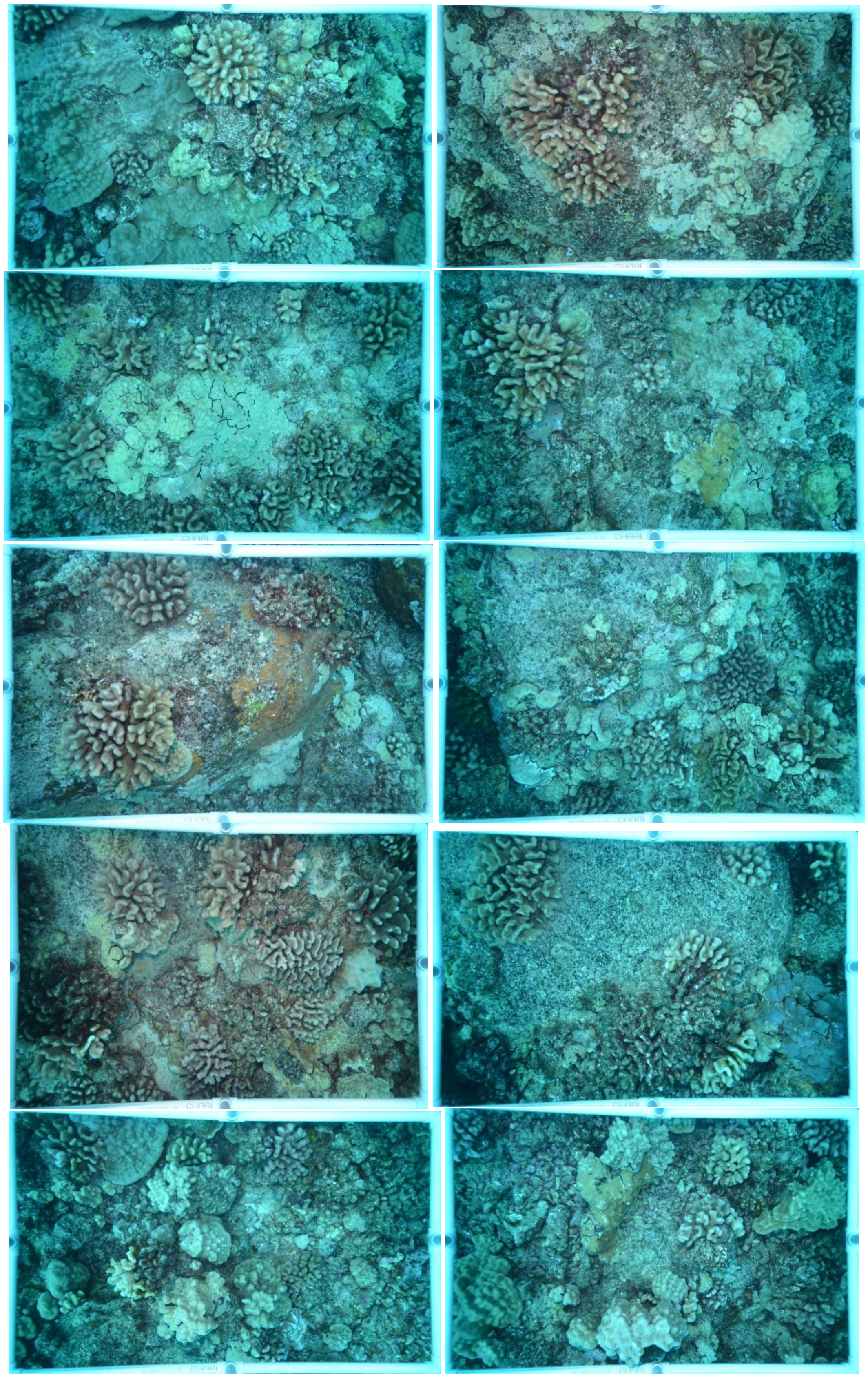
Photoquadrats taken along the 30 ft. transect at 18” Pipe



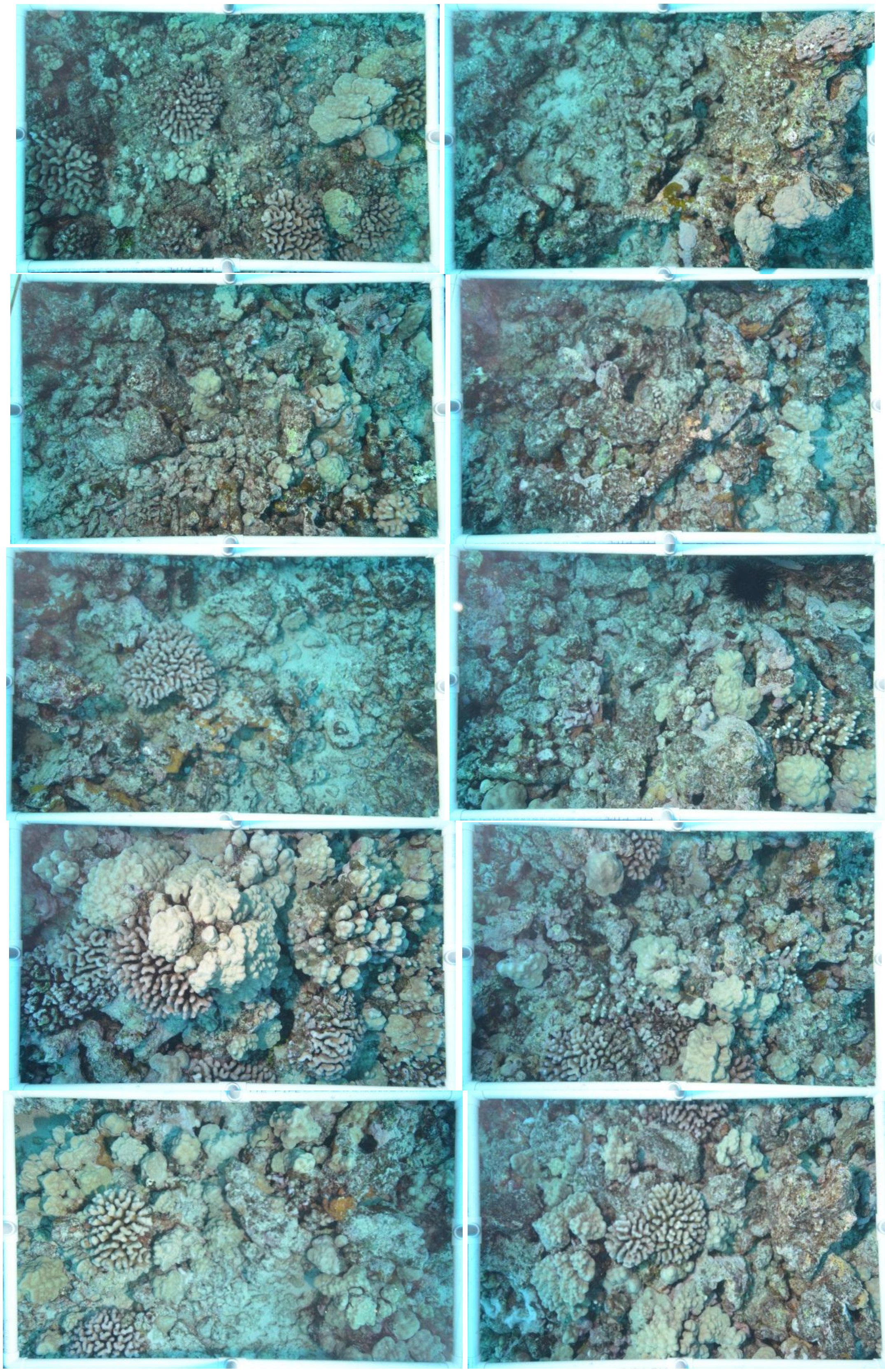
Photoquadrats taken along the 50 ft. transect at 18” Pipe



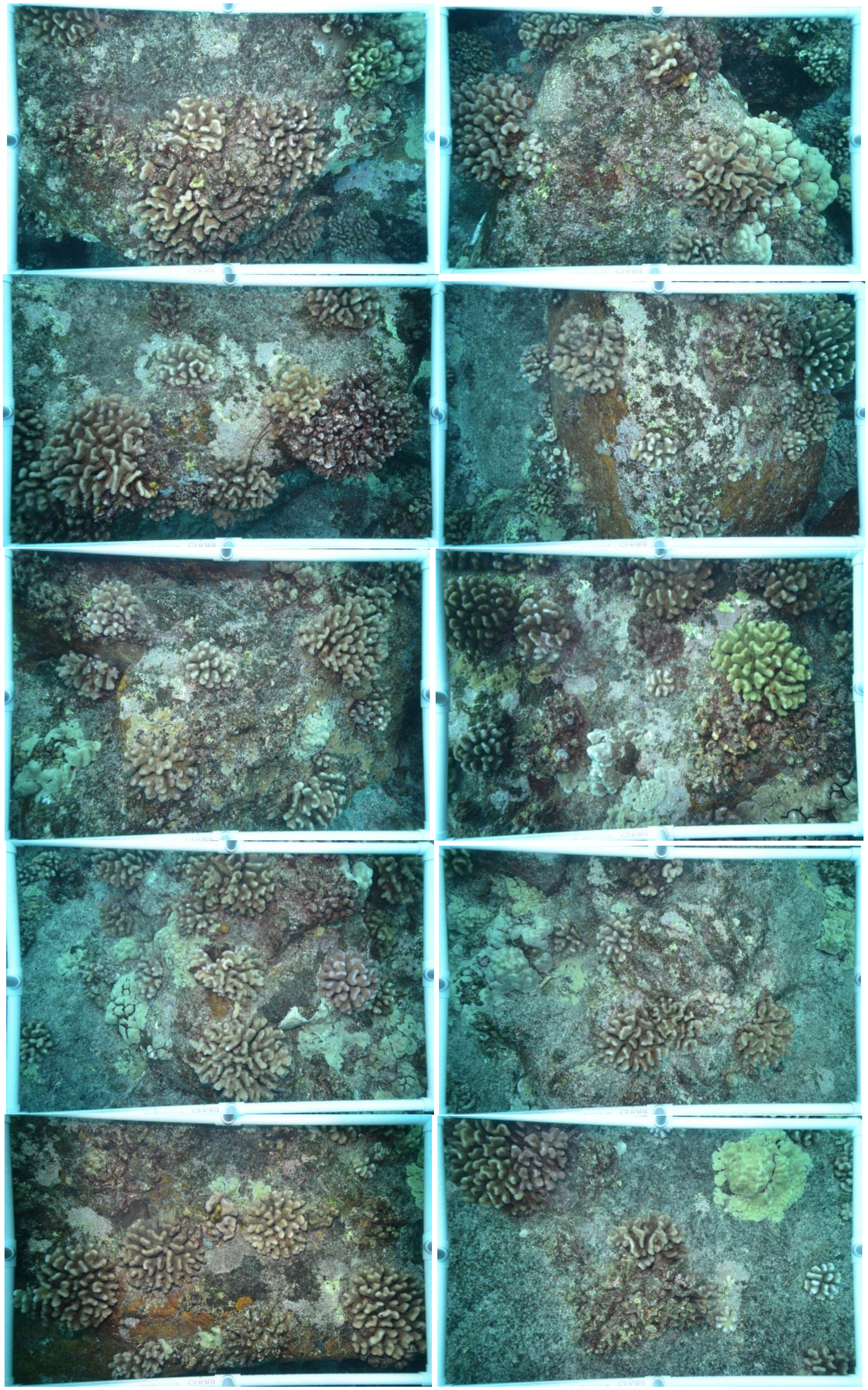
Photoquadrats taken along the 15 ft. transect at 12" Pipe South



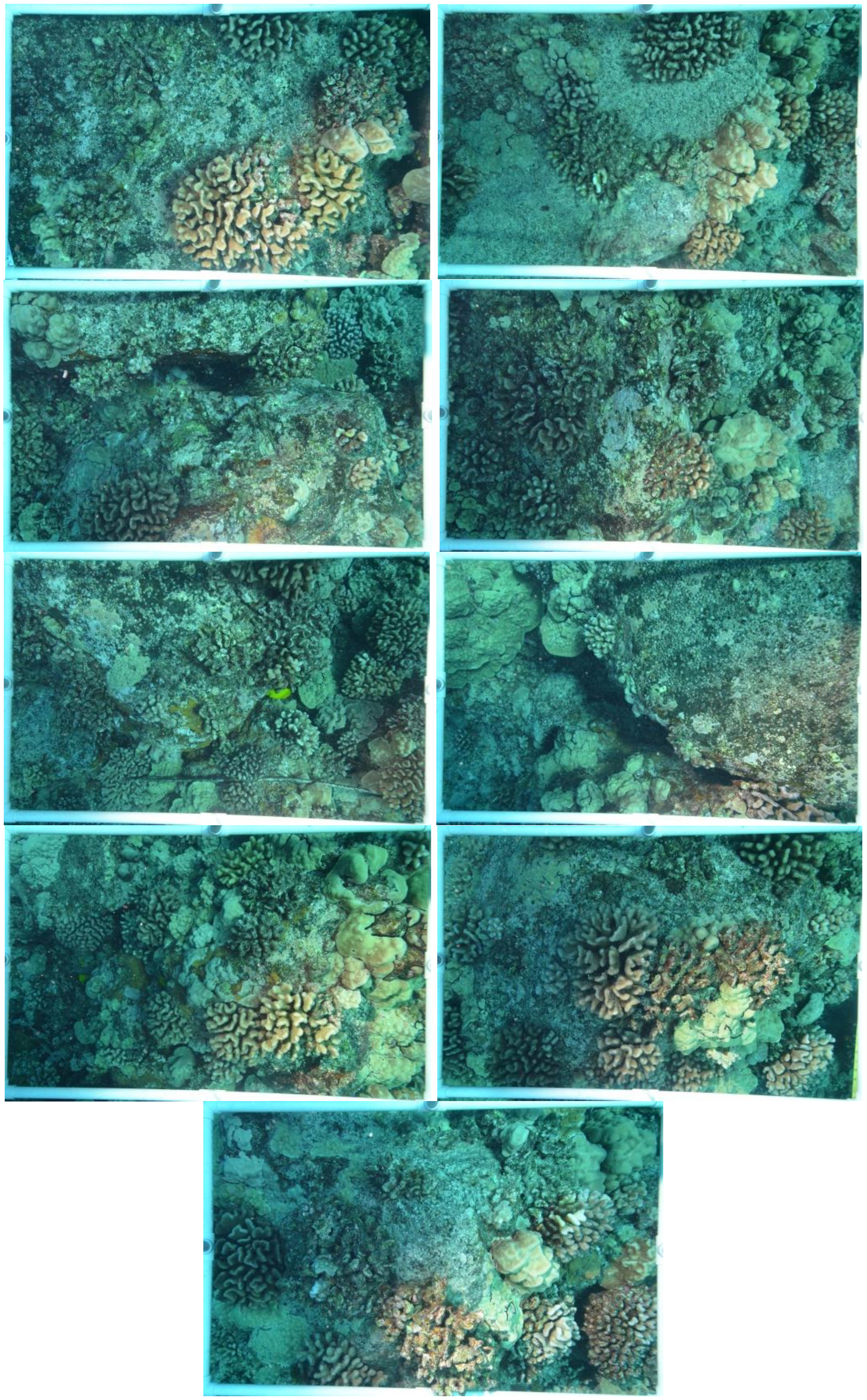
Photoquadrats taken along the 30 ft. transect at 12” Pipe South



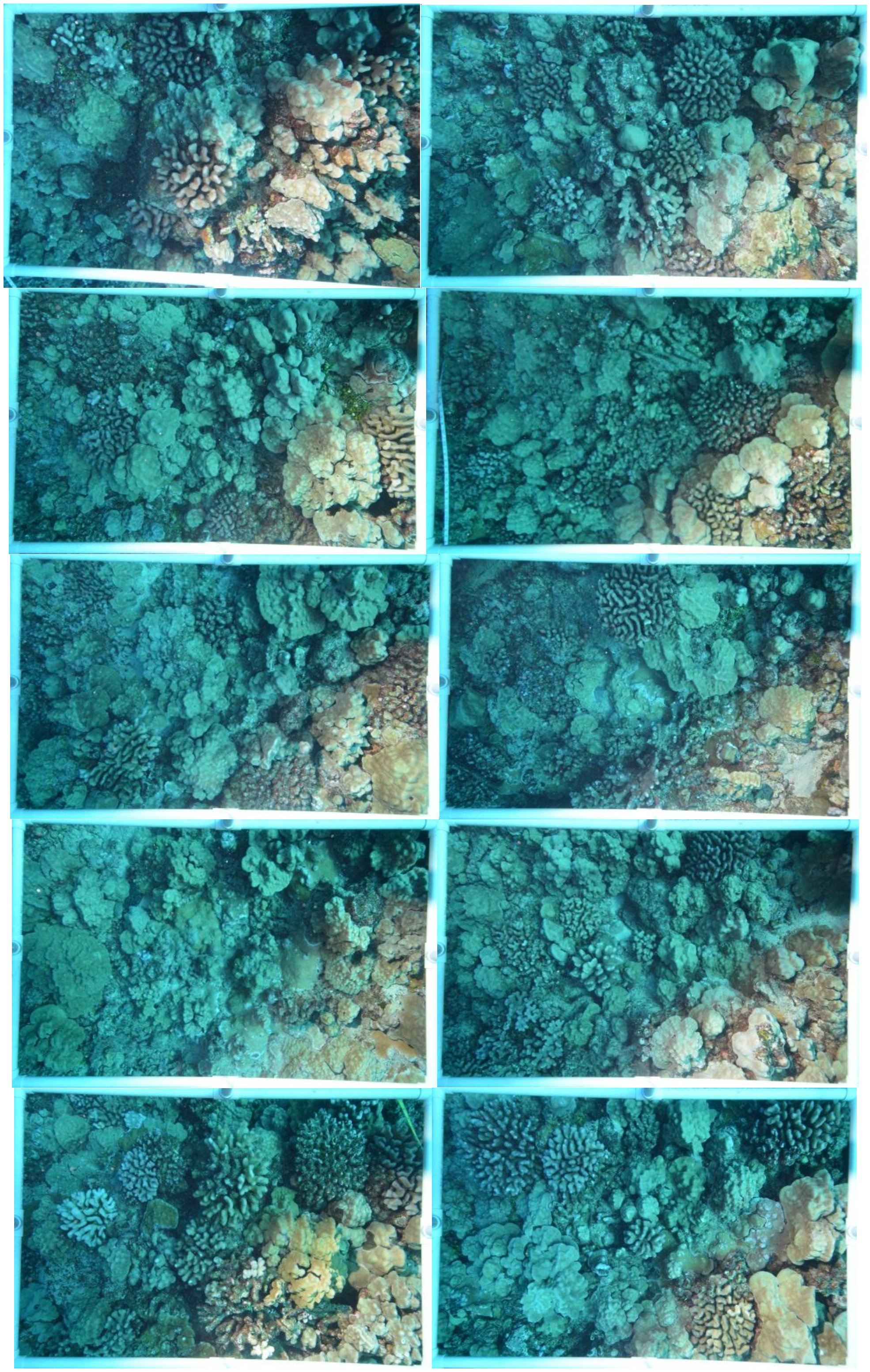
Photoquadrats taken along the 50 ft. transect at 12” Pipe South



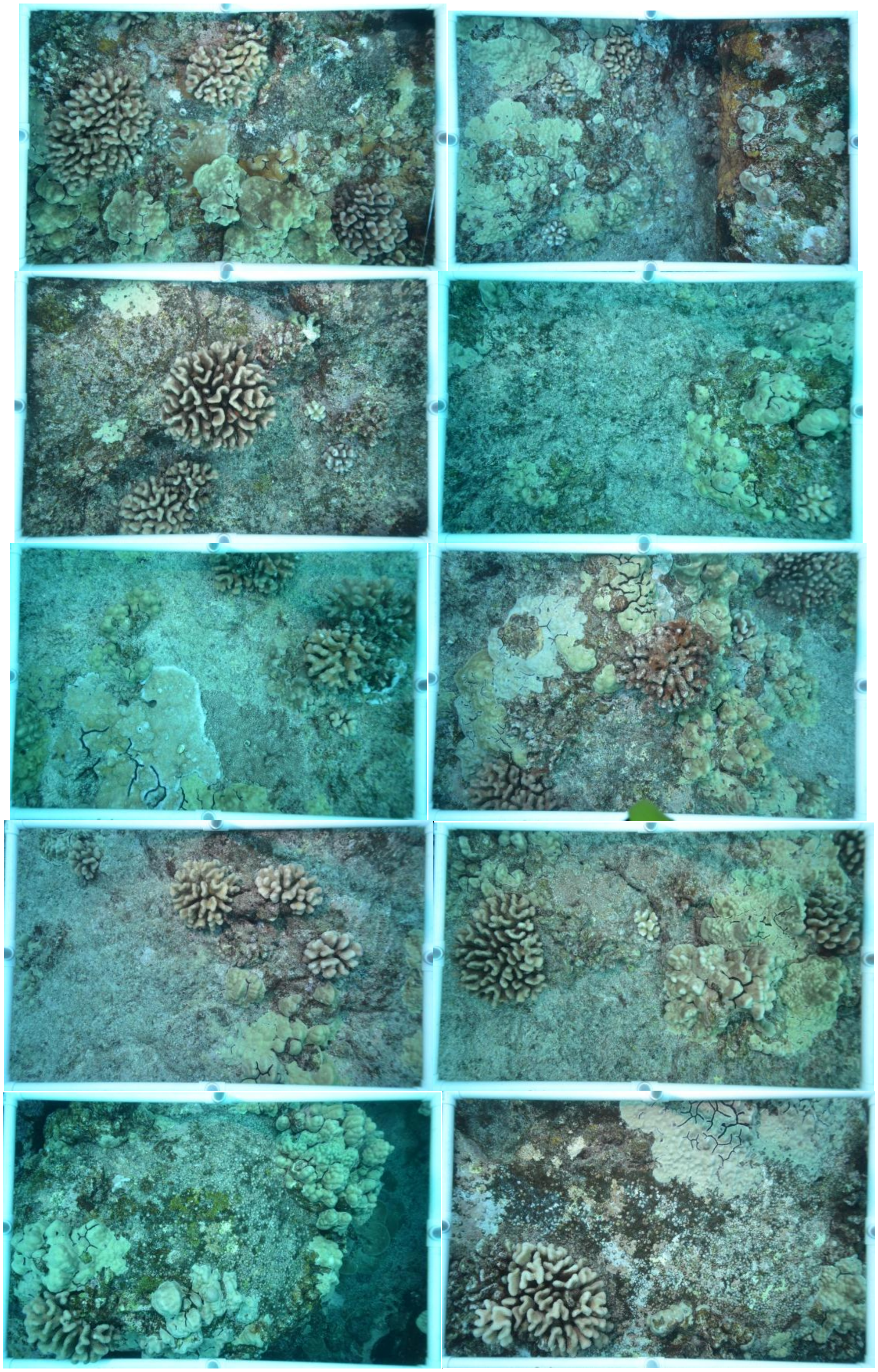
Photoquadrats taken along the 15 ft. transect at 12” Pipe North



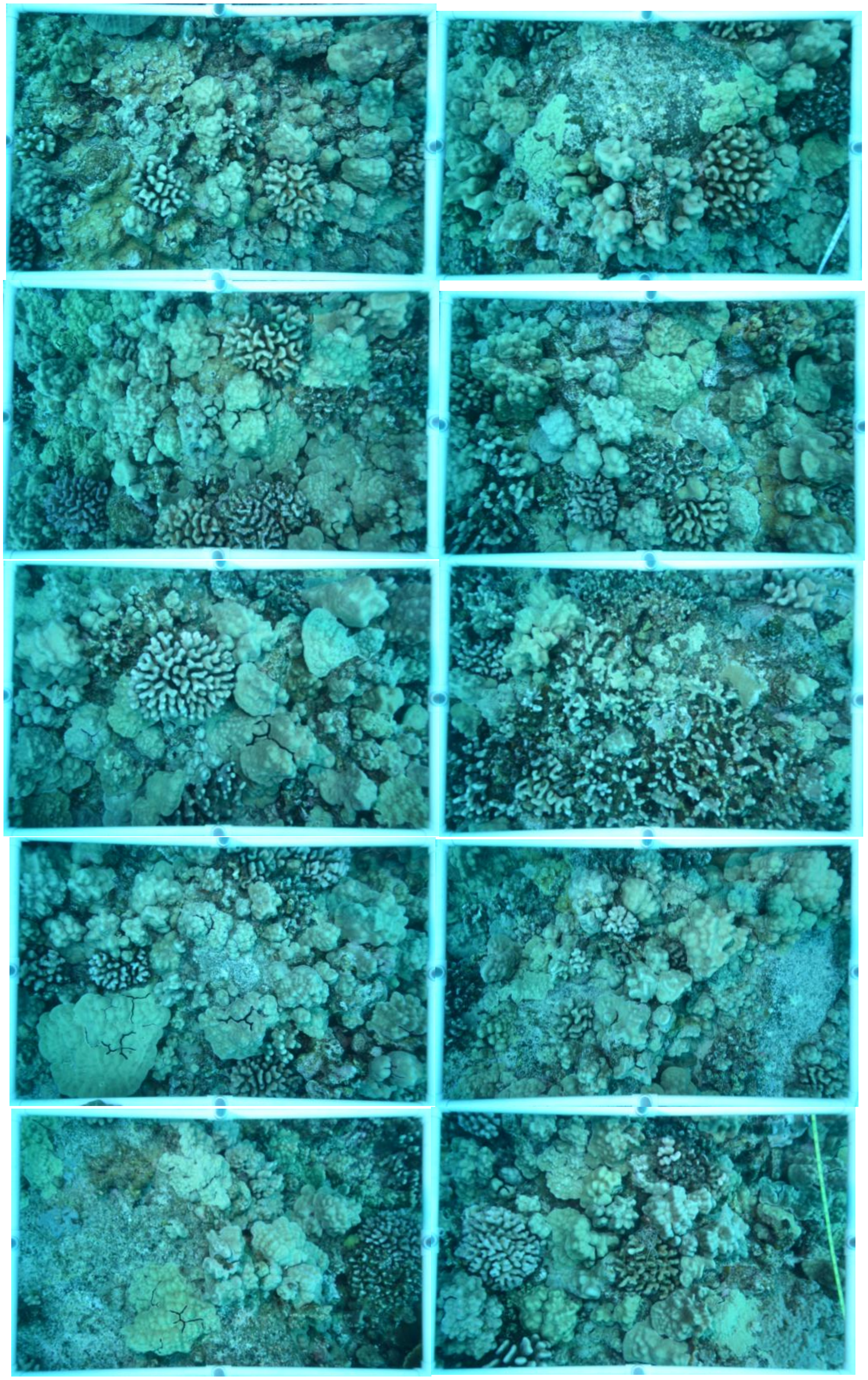
Photoquadrats taken along the 30 ft. transect at 12” Pipe North



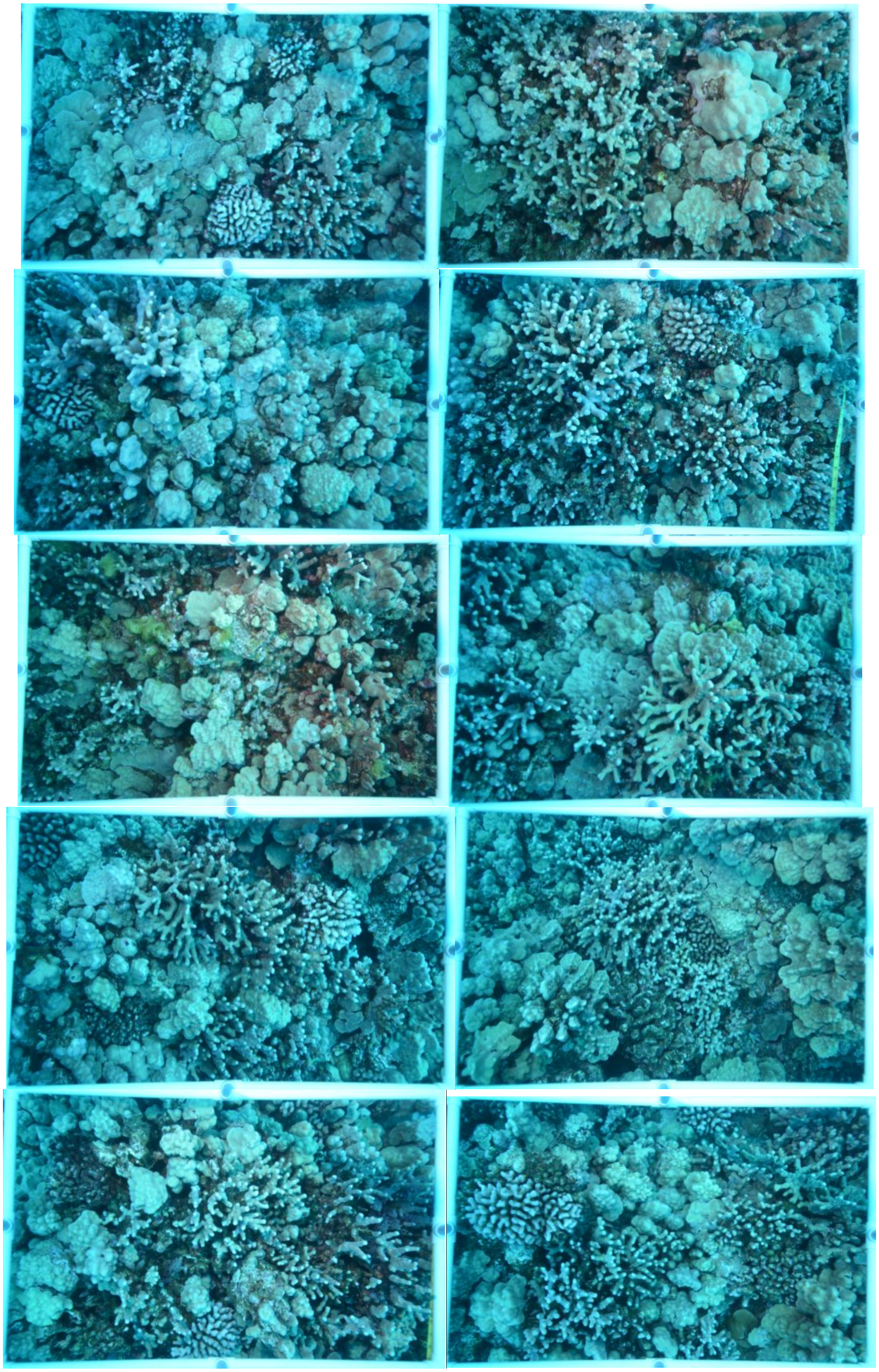
Photoquadrats taken along the 50 ft. transect at 12" Pipe North



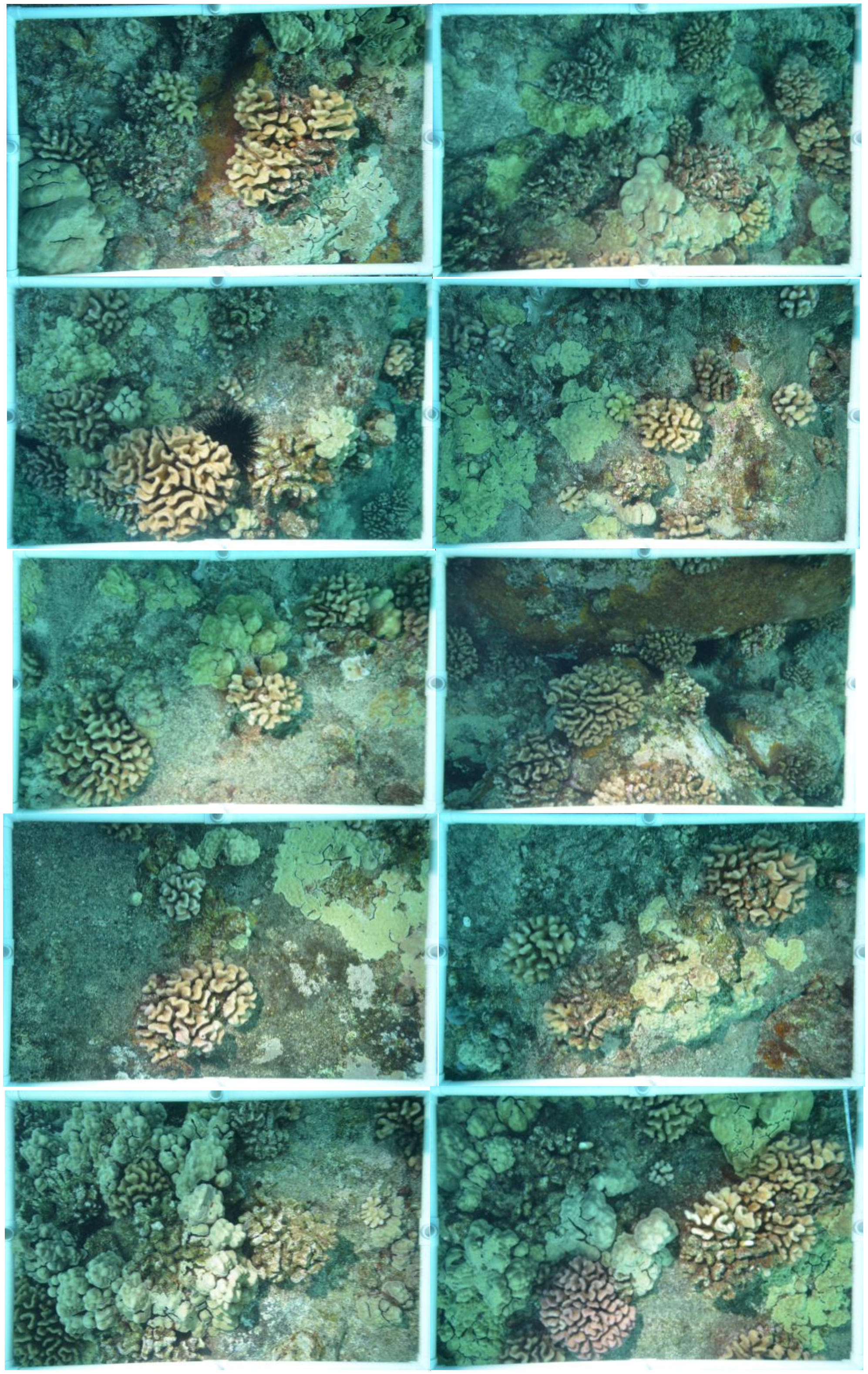
Photoquadrats taken along the 15 ft. transect at NPPE



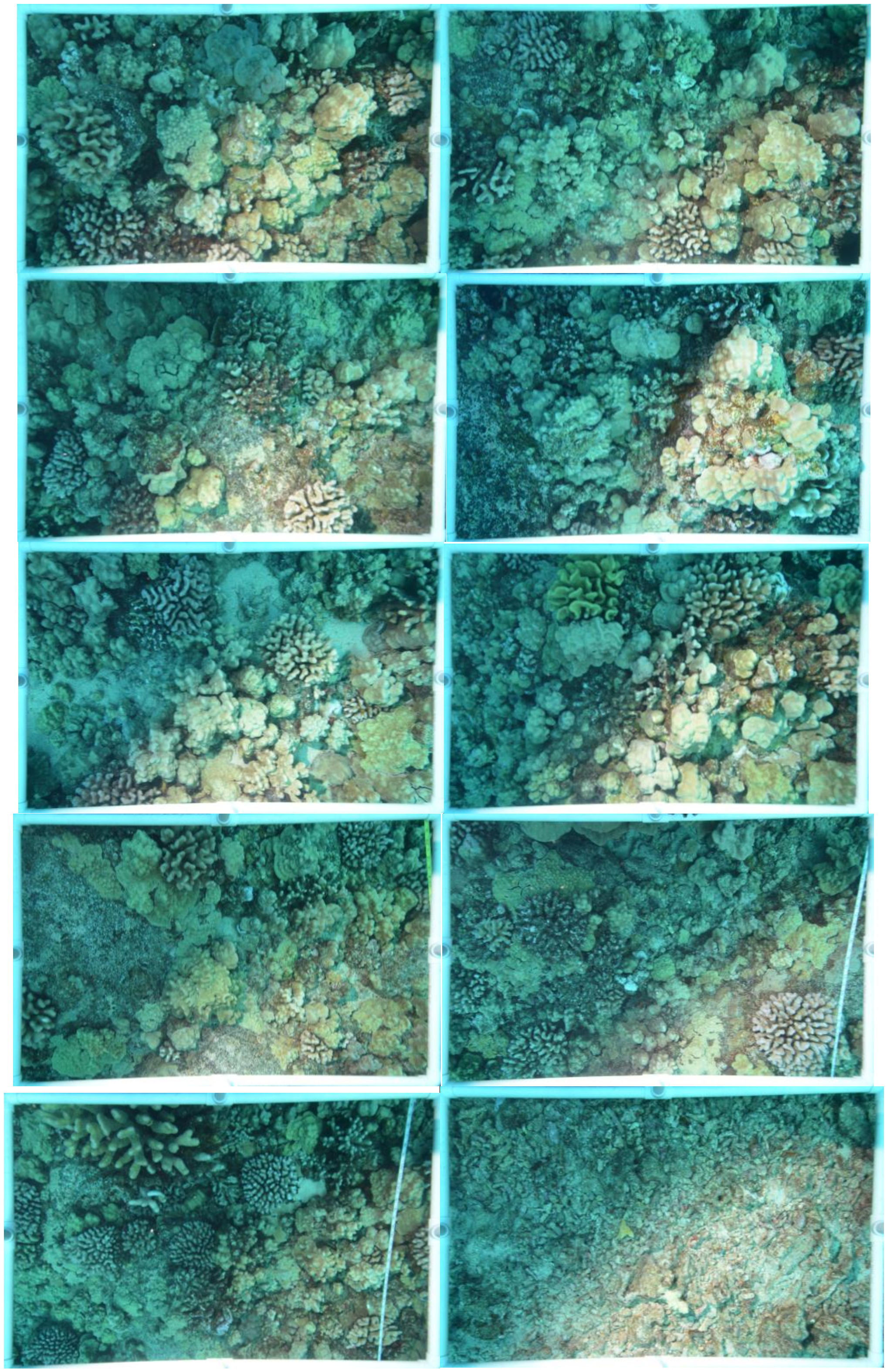
Photoquadrats taken along the 30 ft. transect at NPPE



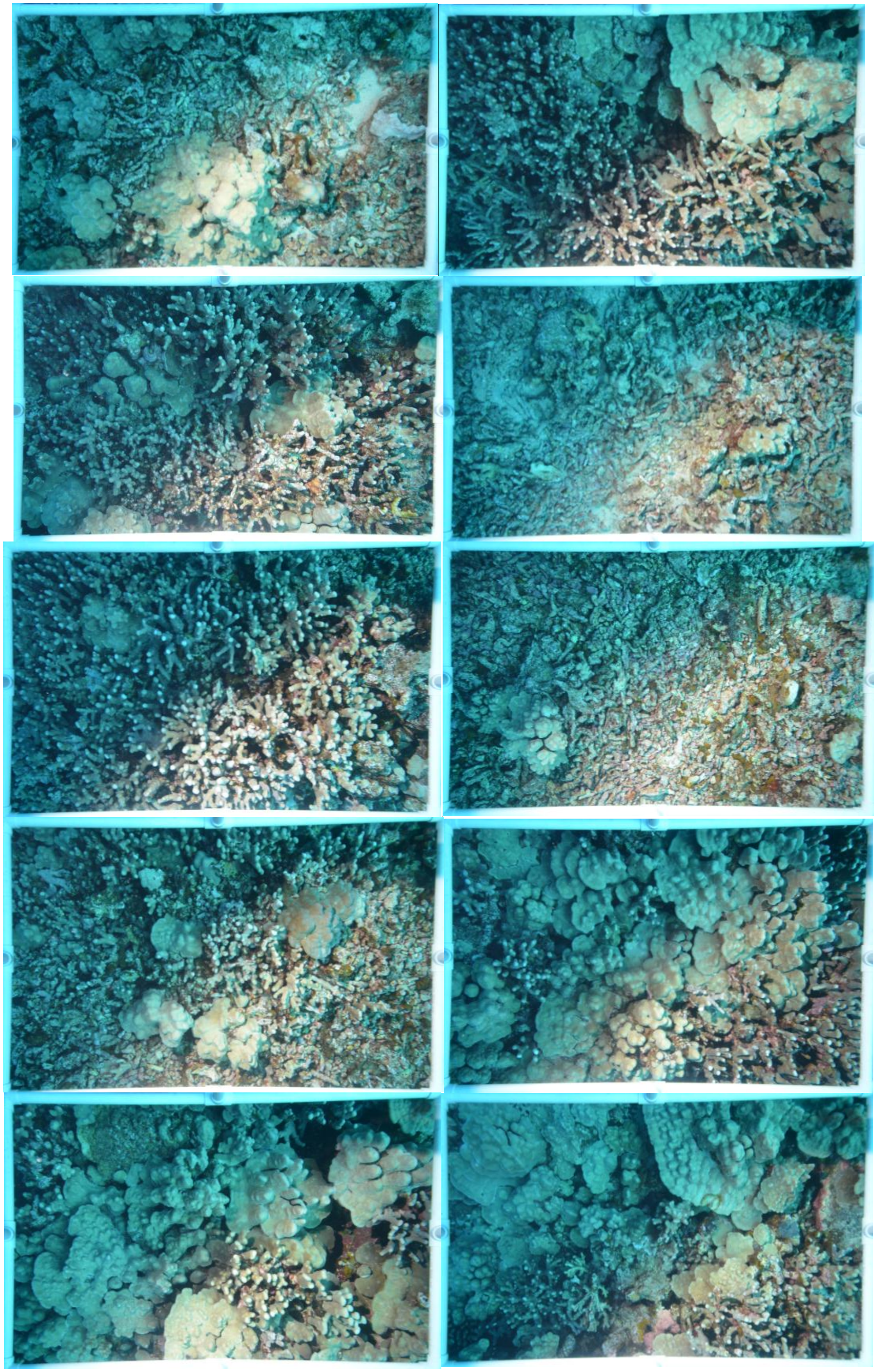
Photoquadrats taken along the 50 ft. transect at NPPE



Photoquadrats taken along the 15 ft. transect at Ho’ona Bay



Photoquadrats taken along the 30 ft. transect at Ho’ona Bay



Photoquadrats taken along the 50 ft. transect at Ho’ona Bay