Kapalāma 1 Container Terminal Restoration Project:

Minimization 2: South Shore Hawaiʻi Coral Reef Nursery Coral Module Outplant Monitoring

Offset 1 & 2: Waikīkī Reef Restoration using Sea Urchin Biocontrol for Invasive Algae

PROGRESS REPORT

Division of Aquatic Resources

Aquatic Invasive Species Team (AIS)

July 2022 – June 2023

CONTENTS

Executive Summary

The Kapalama Container Restoration Project is a mitigation effort to offset the loss of natural resources in Honolulu Harbor associated with the Department of Transportation's (DOT) Kapalama shipping terminal expansion. To mitigate the short- and long-term effects of loss of natural hard substrate, biofouling communities, and coral resources associated with the Kapalama terminal expansion, DOT has transplanted coral colonies to Piers 5 and 6 in the Honolulu Harbor. Additionally, DOT has provided funding for a.) the DAR Hawai'i Coral Restoration Nursery (HCRN) to produce coral modules to mitigate small coral colony loss, b.) the DAR Urchin Hatchery to produce urchins for biocontrol of invasive algae in the Waikīkī Marine Life Conservation District (MLCD), and c.) the DAR Aquatic Invasive Species team (AIS) to outplant hatchery urchins and monitor changes in coral, invasive algae, and bare substrate within the MLCD. The DAR HCRN has outplanted 132 coral modules with a combined 49,290 Ecological Characterization Value (ECV) that the AIS and HCRN teams will continue to monitor. To date, this represents 26% of the ECV to be outplanted under Kapalama 1. The DAR Urchin Hatchery produced 120,830 urchins that were outplanted by the AIS team to the MLCD as of October 2021, exceeding our outplant target of 104,406 urchins. The AIS team also conducted baseline monitoring, subsequent biannual monitoring during outplanting, and further monitoring post-outplanting to track coral, invasive algal, and bare substrate cover. For this reporting period, we provide an update on monitoring progress of outplanted coral modules through June of 2023, monitoring data and maps of coral and invasive algal cover inside the Waikīkī MLCD, and figures of coral and invasive algal cover vs. cumulative urchins outplanted.

MINIMIZATION 2: Hawai'i Coral Restoration Nursery Coral Module Outplant Monitoring

OUTPLANT MONITORING

During this reporting period, the DAR Hawai'i Coral Restoration Nursery (HCRN) has outplanted 52 coral modules worth 16,530 ECV. Overall, HCRN has outplanted 132 modules valued at a combined 49,290 ECV (Table 1), representing 26% of the total ECV (188,276) to be outplanted under this project. Modules are comprised of 10 unique coral species (Table 2) and to date, all outplanted modules have survived. All remaining coral modules to be outplanted from HCRN are in the grow out phase or are ready to be outplanted. The AIS team anticipates that all project modules will be outplanted by the end of 2023 and therefore AIS monitoring under this project would conclude at the end of 2028. Currently, the AIS team is analyzing module photos to determine the percent cover of coral tissue on each module through time. These data will be included in next year's report.

In December 2019, AIS began monitoring coral modules outplanted by HCRN for coral mitigation under the Kapalama Harbor Terminal Coral Offset project (Fig. 1). Outplants were monitored following a set schedule, agreed upon by DAR and the DOT-H (Table 1). In 2020, the COVID-19 pandemic prevented DAR from following the predetermined schedule for ongoing monitoring efforts. Due to severe staffing limitations and a state-wide work-from-home mandate, some gaps in the monitoring schedule occurred. In addition, poor weather and ocean conditions prevented access to the outplant sites on a few occasions during the pandemic. DAR also outplanted smaller cohorts of modules than originally anticipated for logistical reasons.

AIS's monitoring of the coral modules generally began one month after outplanting, followed by quarterly monitoring from the outplant date until one year post outplant. After one year, monitoring occurs biannually for four additional years (Table 1). Modules were monitored using SCUBA and/or snorkel by shore or boat under the auspices of DAR. Due to the pyramid-like shape of most modules, the photos were taken of the top and all four sides to document the condition of outplanted corals. A 50 cm scale bar was placed within the frame of each module photo to provide a size reference to assess coral growth (Fig. 2). Divers also digitally captured the surrounding environment both above and underwater to record in situ conditions.

Table 1: Coral module outplant and monitoring schedule. Outplanted coral modules have a determined Ecological Characterization Value (ECV) that is calculated using the DAR Hawaiian ECV tool (version: Beta8). Checkmarks denote completion of monitoring following a predetermined 5-year schedule.

Outplant Cohort	Outplant Date	Outplant Location	# of Modules	ECV Value	Monitoring Schedule (Months Since Outplant Date)									
					1	3	6	9	12	18	24	30	36	42
1A	5/27/2020	Port Royal	11	5550	✓		✓		✓	✓	✓	✓		
1B	6/7/2019	Port Royal	3	1840			✓		✓			✓	✓	✓
2A	4/19/2021	Sand Island	9	5920	✓	✓	✓		✓	✓	✓			
2B	4/20/2021	Sand Island	2	240	✓	✓	✓		✓	✓	✓			
3	6/22/2021	Sand Island	11	3680	✓		✓		✓	✓	✓			
4	12/28/2021	Sand Island	5	440	✓	✓	✓	✓	✓	✓				
5A	12/14/2021	Airport Reef Runway	1	600	✓	✓	✓	✓	✓					
5B	1/12/2022	Airport Reef Runway	3	1800	✓	✓	✓	✓	✓					
6	5/4/2022	Airport Reef Runway	14	7950	✓	✓	✓	✓	✓					
7	5/12/2022	Sand Island	21	4740	✓	✓	✓	✓	✓					
8	10/6/2022	Airport Reef Runway	6	3150	✓	✓	✓							
9	10/18/2022	Sand Island	21	3620	✓	✓	✓							
10	2/7/2023	Airport Reef Runway	7	4200	✓	✓								
11	2/16/2023	Sand Island	12	1960	✓	✓								
12	4/20/2023	Airport Reef Runway	6	3600	✓									
Totals			**132**	**49,290**										

Table 2: Total number of coral modules outplanted to date by species, module size, and ECV value.

Outplanted Coral Species	# of Modules (15 cm)	# of Modules (22 cm)	# of Modules (32 cm)	# of Modules (42 cm)	# of Modules (1 m)	Total # of Modules	Total ECV
Montipora capitata	0	0	2	40	0	**42**	**24,060**
Montipora flabellata	0	1	0	3	0	**4**	**520**
Montipora patula	0	10	1	20	0	**31**	**3,680**
Pavona duerdeni	0	3	0	0	0	**3**	**600**
Pavona varians	0	5	0	9	4	**18**	**1,730**
Pocillopora grandis	0	0	3	1	0	**4**	**1,120**
Pocillopora meandrina	0	3	0	0	0	**3**	**240**
Porites compressa	0	0	0	1	0	**1**	**640**
Porites evermanni	0	2	1	6	0	**9**	**11,200**
Porites lobata	0	5	0	12	0	**17**	**5,500**
Totals	**0**	**29**	**7**	**92**	**4**	**132**	**49,290**

Figure 1: AIS diver monitoring outplanted coral modules.

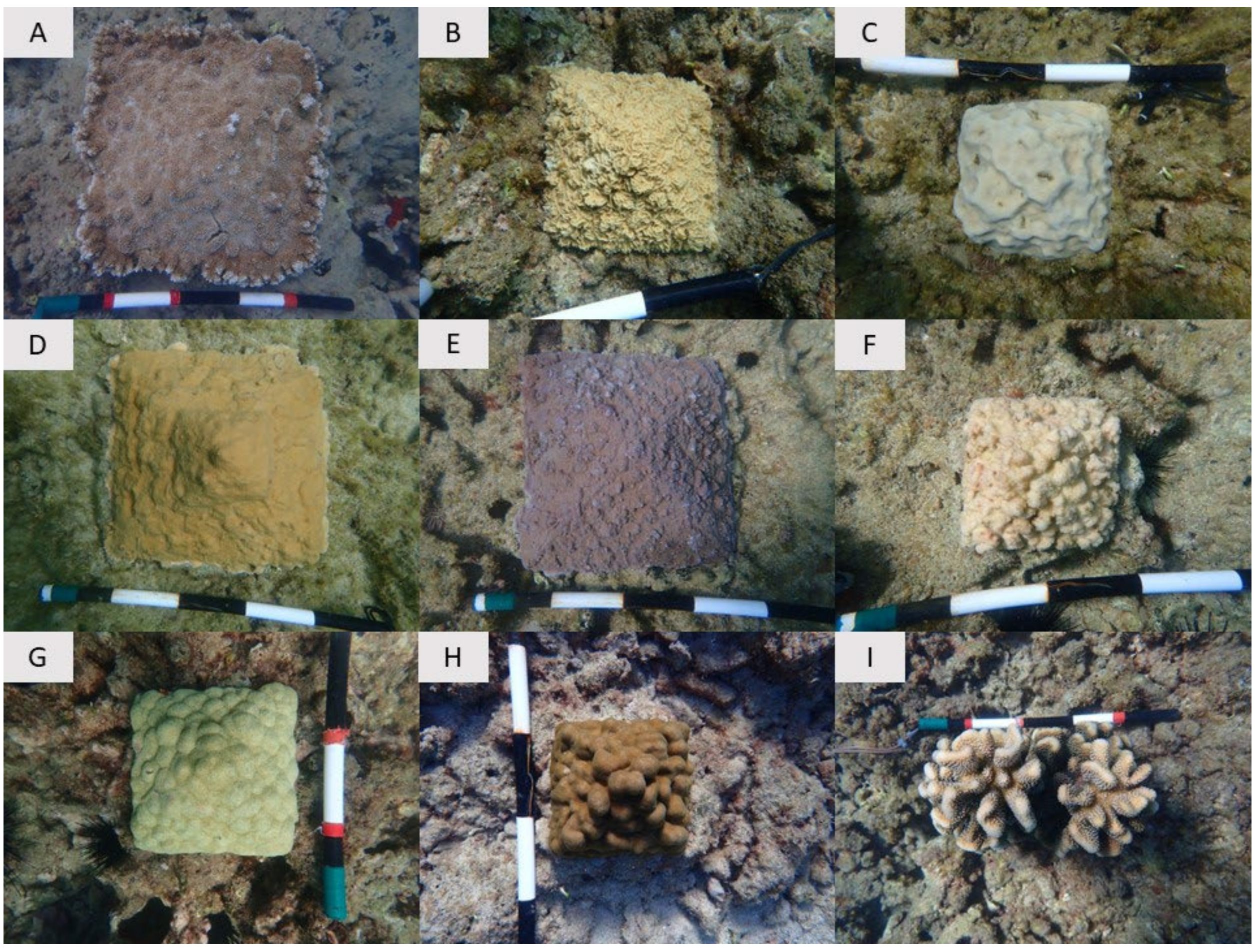

Figure 2: Coral modules outplanted by DAR's Hawai'i Coral Reef Nursery and Aquatic Invasive Species team: (A) *Montipora capitata* (B) *Pavona varians (*C) *Pavona duerdeni* (D) *Montipora patula* (E) *Montipora flabellata* (F) *Pocillopora meandrina* (G) *Porites lobata* and (H) *Porites evermanni* (I) *Pocillopora grandis*.

OFFSET 1 & 2: Waikīkī Reef Restoration using Sea Urchin Biocontrol for Invasive Algae

INTRODUCTION

Aquatic invasive species are defined as non-native species whose introduction and/or spread harms or threatens to harm biological ecosystems, diversity, economies, or human health (CEC, 2003). The introduction of invasive algae to Hawai'i, primarily through aquaculture, has led to phase shifts within Hawaiian coral reef ecosystems (Done 1992). Fast growing invasive algae can overgrow corals, resulting in partial or complete colony mortality, thereby shifting affected reefs from coral to macro-algae dominated ecosystems (Done 1992, Hughes 1994). Removing invasive algae can lead to coral regrowth and recolonization where partial mortality has occurred (Ceccarelli et al. 2018). Algal removal can also increase reef rugosity and restore habitats for various fish, invertebrate, and native algal species (Neilson et al. 2018). The Department of Land and Natural Resources (DLNR) is currently using a biocontrol method of outplanting hatchery-raised native sea urchins (*Tripneustes gratilla*) to reduce invasive algal cover and restore coral reef habitat within the Waikīkī Marine Life Conservation District (MLCD). In Hawaiʻi, *T. gratilla* has been observed to graze on five invasive algal species and has been successfully used as a biocontrol for invasive algae on reefs in Kāneʻohe Bay (Conklin & Smith 2005, Westbrook et al. 2015, Neilson et. al. 2018). *Gracilaria salicornia* and *Acanthophora spicifera* are the two main invasive algal species found in the Waikīkī MLCD (Fig. 3A & Fig. 3B).

Tripneustes gratilla are model organisms that have been successfully reared through aquaculture operations around the world (Dworjanyan and Pirozzi 2007, Pante et al. 2006, Parvez et al. 2018). The DAR Sea Urchin Hatchery at the Ānuenue Fisheries Research Center (AFRC) has successfully reared juvenile *T. gratilla* by spawning wild broodstock and raising their resulting larvae. Resulting juvenile urchins are then raised to sizes suitable for outplanting (15 mm) for invasive algal biocontrol (Fig. 3C). Urchin grazing reduces coral-invasive algal competition for space, light, and nutrients, therefore fostering coral growth and recolonization of previously occupied habitats (Neilson et al. 2018). The DAR Aquatic Invasive Species team (AIS) has outplanted a total of 120,830 hatchery-raised urchins from November 11, 2019 to October 7, 2021 to treat invasive algae in the Waikīkī MLCD. Baseline monitoring was conducted throughout the spring of 2019 to characterize the percent cover of living coral colonies and the two invasive algae *A. spicifera* and *G. salicornia*. Subsequent bi-annual monitoring surveys mapped changes in coral and invasive algal cover over time. This bi-annual monitoring will continue for five years after urchin outplant targets are met (Table 3).

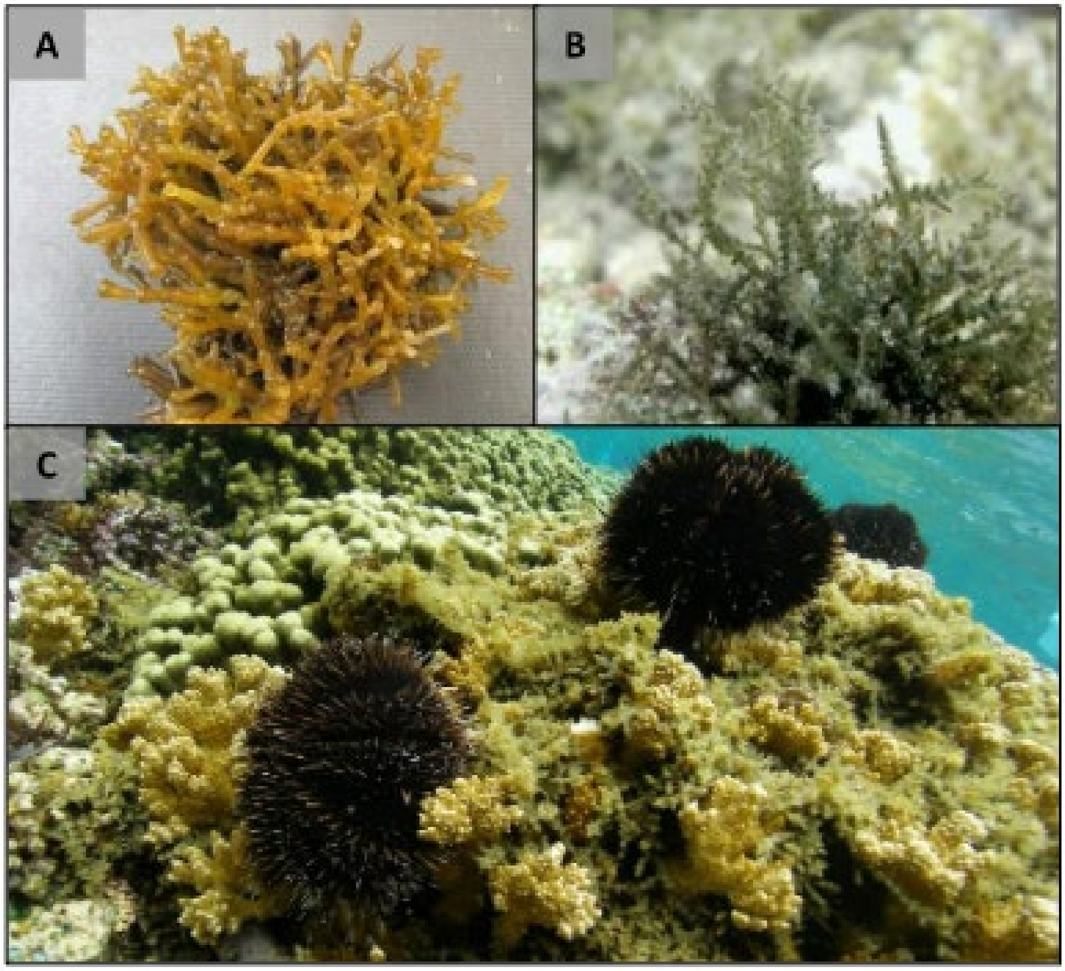

Figure 3: (A) Two species of invasive algae, Gracilaria salicornia and (B) Acanthophora spicifera that are commonly found in the Waikīkī MLCD. (C) Outplanted urchins (*Tripneustes gratilla*) feed on mats of invasive algae.

MANAGEMENT PLAN ACTIONS IMPLEMENTED

A baseline survey was conducted in May 2019 to map coral and invasive algal cover before the introduction of biocontrol methods within the Waikīkī MLCD (Appendix A: Fig 2). The first outplant survey occurred in May 2020 (Appendix A: Fig. S3), one year following the baseline survey, and six months after urchin outplanting began in November 2019 (Tables 3). Outplants and surveys continued from June 2021 to October 2021. From October 2021 to June 2023, bi-annual post-outplant surveys were conducted. A total of 120,830 urchins were raised and released between November 2019 and October 2021 (Table 3), exceeding our outplant target by 16,424 urchins. Reports to DOT are delivered annually for the duration of the project. This is the fourth progress report submitted from the start of the project. The next progress report will cover the period from July 2023 – June 2024.

Table 3: Work plan progress.

Action	Who is responsible	Timeframe	Progress	Accomplishments	Notes
Conduct baseline monitoring surveys.	Monitoring Coordinator, Project Technicians	May 2019	Complete	SNAP assessment of Waikīkī MLCD in May 2019	SNAP assessment for initial proposal conducted in 2017
Outplant native sea urchins to the restoration area.	Project Technicians, DAR Urchin Hatchery	November 2019 - October 2021	Complete	120,830 urchins outplanted	Initial urchin outplanting on 11/14/2019, Completed on 10/7/21
Biannual monitoring of coral and algae	Monitoring Coordinator, Project Technicians	May 2020 – October 2026	In progress	SNAP assessment of Waikīkī MLCD in 6/20, 11/20, 6/21, 11/21, 5/22, 11/22, and 5/23	SNAP assessments will occur biannually in May and November
Annual reporting to DOT and USACE	Monitoring Coordinator, DAR Aquatic Biologist	Annually through end of project	In progress	3rd report submitted 2022	1st report submitted 2020

URCHIN HATCHERY

Beginning in July 2019, the DAR urchin hatchery allocated 50% of its time to produce hatchery-raised collector sea urchins (*T. gratilla*) for the Waikīkī MLCD restoration area (Table 4). As of October 2021, a total of 62,782 liters of phytoplankton have been produced to feed urchin larvae and 3,073.25 Kg of macroalgae have been produced to feed juvenile urchins. To date, a total of 385 wild, adult urchins (Fig. 4) have been spawned in the hatchery to collect gametes for cultured urchins destined for the restoration area. These broodstock yielded 12 million larvae that were moved into tanks for settlement and 149,643 urchin spat moved to the grow-out phase for outplanting (Table 4).

Typically, the hatchery expects approximately 2% survival of competent larvae to outplant based on historical results. The urchins take approximately 5 months from spawning in the hatchery to reach adequate size (~15mm) for outplanting. During the outplant period of this project, half of the urchins produced in the hatchery were released in the Waikīkī MLCD until the outplant target was met.

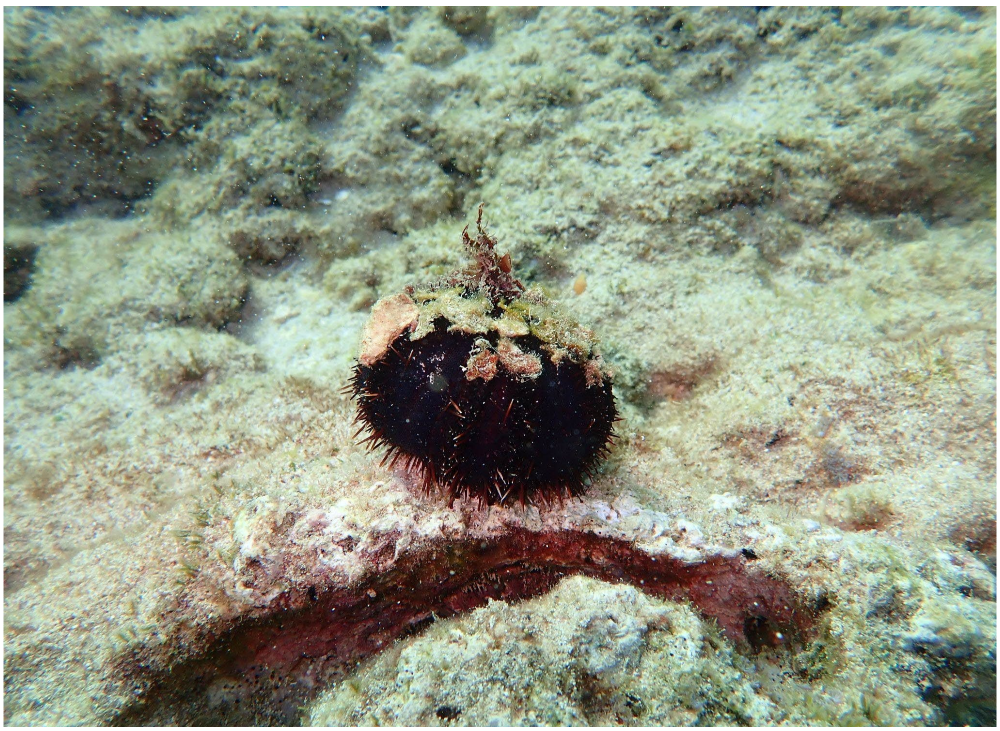

Figure 4: Adult *Tripneustes gratilla* at the Waikīkī MLCD.

Table 4: DAR Urchin Hatchery metrics for July 2019 – October 21, 2021.

	Food Production		Urchin Production			
Date	Phytoplankton produced (L)(for urchin larvae)	Macroalgae produced (Kg) (for urchin juveniles)	Urchins Collected for Spawn	Number of larvae moved into settlement phase (x1000)	Number of spat moved into grow-out phase	Number of hatchery urchins outplanted
Jul-19	3700	62	19	4800	10994	0
Aug-19	3200	71	30	4800	51986	0
Sep-19	2600	81	22	4800	0	0
Oct-19	2400	108	23	4800	20191	0
Nov-19	2200	103	0	0	694	1200
Dec-19	0	80	0	0	1006	0
Jan-20	4163	127	27	4992	0	0
Feb-20	3345	80	30	4954	4019	7000
Mar-20	2845	66	0	0	0	1500
Apr-20	1670	123	30	4800	22969	2400
May-20	4185	111	0	0	0	2850
Jun-20	4100	82	30	5016	17666	5000
Jul-20	4194	100	30	6363	4903	5100
Aug-20	504	116	0	0	2449	1900
Sep-20	4805	94.25	30	6000	0	2700
Oct-20	3179	97	34	6000	206,915	1500
Nov-20	592	86	0	0		1500
Dec-20	73	127	0	0	76,024	0
Jan-21	77	112	0	0	0	10550
Feb-21	72	179	0	0	0	31660
Mar-21	480	182	0	0	0	10550
Apr-21	4440	142	30	6000	0	9000
May-21	448	87	0	0	422,151	1950
Jun-21	450	83	0	0	0	1500
Jul-21	4422	158	25	6000	0	8770
Aug-21	765	101	0	0	149,643	0
Sep-21	560	152	0	0	0	7600
Oct-21	3313	163	25	6000	0	6600
Total	**62,782**	**3073.25**	**385**	**75,325**	**647,818**	**120,830**

On November 14, 2019, the first urchin outplanting of 1,200 hatchery-raised urchins occurred in the MLCD. 7,000 urchins were then outplanted in February 2020 accompanied by a press release that was run by various news outlets. As of October 2021, 120,830 urchins were outplanted to the Waikīkī MLCD, surpassing our outplant target of 104,406 urchins.

URCHIN BIOCONTROL MONITORING AND ANALYSES

An initial baseline survey mapping invasive algal distribution and relative abundance was conducted for the Waikīkī MLCD area on June 26, 2017 to determine the number of urchins needed to manage invasive algae (Appendix A: Fig. S1). Urchin outplant targets were based on the total area where invasive algae was present within the Waikīkī MLCD using the following formula:

Outplant density (6 urchins/m^2) x Area of invasive algae (m^2) = Total # of urchins to be outplanted

Once required urchin outplant numbers were calculated, a rapid pre-outplant assessment, or SNAP survey, was conducted in the Waikīkī MLCD on May 7, 2019. This survey mapped the initial coral and invasive algal distribution and cover (Table 5) before the initiation of urchin biocontrol efforts. However, the area surveyed did not include the area offshore of the Natatorium (Appendix 1: Fig. S2). Therefore, only coral and invasive algal cover distribution north of the Natatorium can be compared with surveys after the pre-outplant survey.

To ensure that the median percent cover of coral and invasive algae are directly comparable amongst all surveys, we reanalyzed these surveys using the pre-outplant area polygon from May 2019 (Table 5). It should be noted that despite using the same area polygon for each survey, the total survey area varied slightly for each survey date. However, these changes are sufficiently small such that all survey results are directly comparable.

This report contains coral and invasive algal median percent cover values (Table 5), distribution maps (Figs. 5, 7, & 9), and median percent cover vs. cumulative urchin outplant plots (Figs. 6, 8, & 10). All median percent cover values and maps were made using the 2019 pre-outplant polygon. The next biannual monitoring is scheduled to be completed in November of 2023.

Table 5: Results of the SNAP Pre-outplant Assessment and Subsequent SNAP Surveys (May 2019 – May 2023).

*Due to swell and staffing restrictions, the area surveyed during 2021 was smaller (excluded offshore area) than all other surveys and therefore that year will not be directly comparable.

Waikīkī MLCD SNAP Assessment Results						
Survey Date	Total Area Surveyed (m2)	Median Coral Cover (%)	Median *Gracilaria salicornia* Cover (%)	Median *Acanthophora spicifera* Cover (%)	Total Median Invasive Algae Cover (%)	Outplanting Stage
May 7, 2019	83,755	0.092	0.82	0.38	1.2	Pre-outplant
May 12, 2020	83,413	0.14	0.67	7.14	7.81	Outplant
Nov. 12, 2020	83,020	0.13	4.72	14.89	19.61	Outplant
June 18, 2021*	72,060	0.05	0.96	12.83	13.79	Outplant
Nov. 17, 2021	84,057	0.12	2.89	8.28	11.17	Post-outplant
May 25, 2022	83,957	0.2	0.46	6.76	7.22	Post-outplant
Nov. 23, 2022	83,697	0.078	1.12	13.97	15.09	Post-outplant
May 31, 2023	83,779	0.097	0.71	6.02	6.73	Post-outplant

Coral

Coral cover was generally low throughout the Waikīkī MLCD during the reporting period (Table 5, Fig. 5). In November 2022, approximately 897 m^2 of habitat had coral present with a median percent cover of 0.078% (Low: 0.02% - High: 0.15%). In May 2023, approximately 985 m^2 of habitat had coral present with a median percent cover of 0.097% (Low: 0.027% - High: 0.18%).

Figure 5: Median percent coral cover in the Waikīkī MLCD restoration area in November 2022 (left) and May 2023 (right).

Median coral cover in the Waikīkī MLCD remained relatively unchanged with urchin outplanting through time (Fig. 6). This is to be expected due to the slow growth rate of corals and its' patchy distribution inside the MLCD (Fig. 5). Although coral populations may take years to over a decade to increase after removal of invasive algae, monitoring results from previous studies have shown statistically significant increases in bare space (e.g. sand, pavement, rubble) for colonization by coral, native algae, and invertebrate species (Conklin & Smith 2005, Neilson et al. 2018).

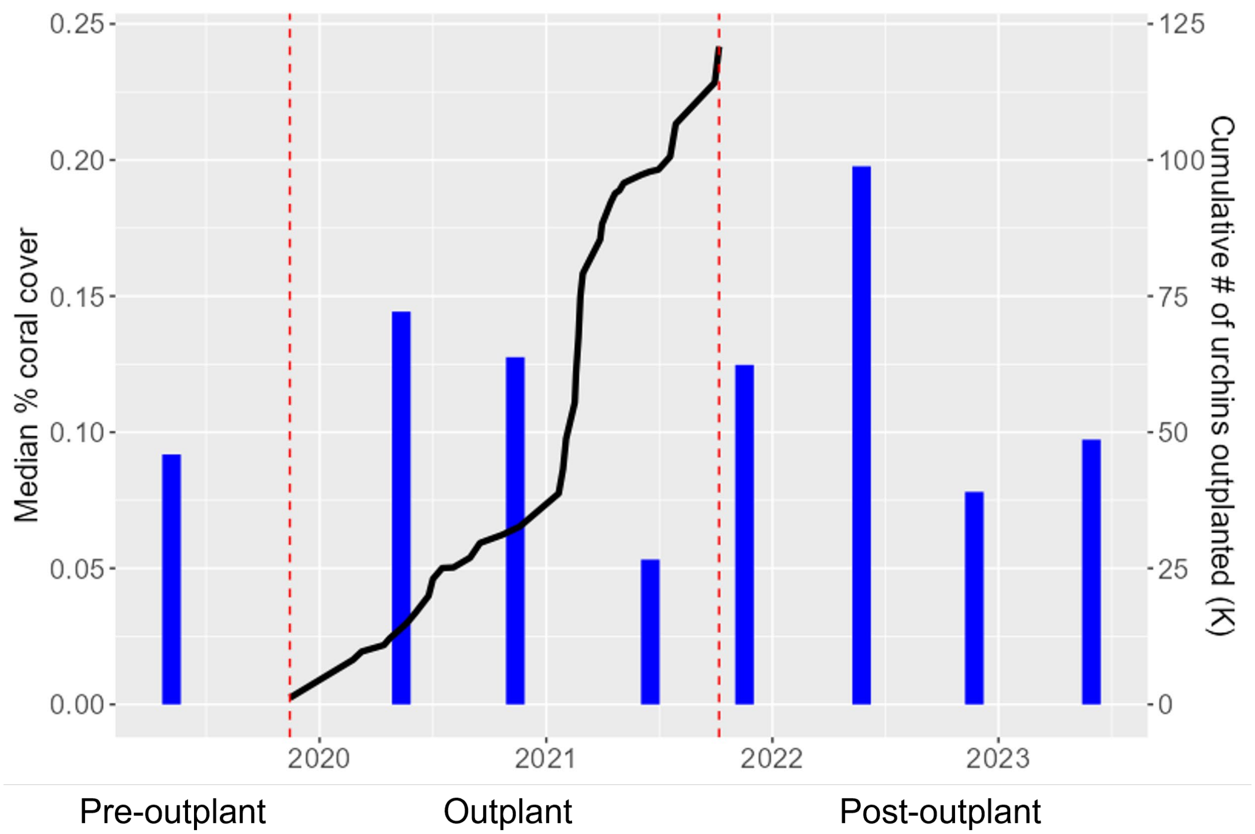

Figure 6: Median percent cover of coral from SNAP Surveys in the Waikīkī MLCD restoration area (left axis) from May 2019 to May 2023 with cumulative number (in thousands) of urchins outplanted (right axis) represented by the black line.

Acanthophora spicifera

Acanthophora spicifera was widely distributed throughout the restoration area during this reporting period (Table 5, Fig. 7). In November 2022, approximately 49,944 m^2 of habitat had *A. spicifera* present with a median percent cover of 13.97% (Low: 7.31% - High: 21.15%). In May 2023, approximately 33,530 m^2 of habitat had *A. spicifera* present with a median percent cover of 6.02% (Low: 2.59% - High: 9.83%). Although *A. spicifera* over did not decline to below 5% median cover, notable changes have occurred during the Kapalama urchin biocontrol project in tandem with urchin outplants to the Waikīkī MLCD (Fig. 8).

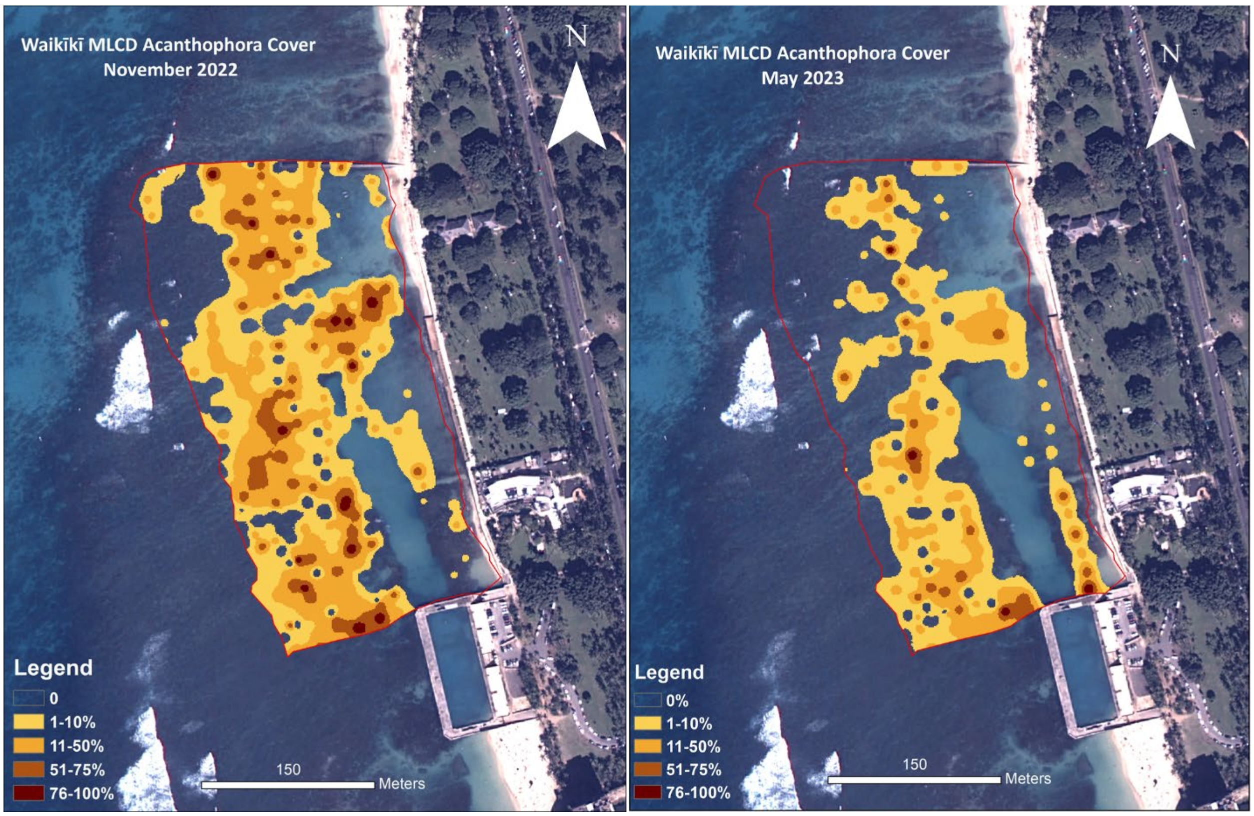

Figure 7: Median percent *Acanthophora spicifera* cover in Waikīkī MLCD restoration area in November 2022 (left) and May 2023 (right).

To compare *A. spicifera* median percent cover values before, during, and after the urchin outplant period, means were calculated for during and after urchin outplants. Mean cover for *A. spicifera* initially grew from 0.38% before outplanting to 11.62% during the outplant period followed by a decline to 8.76% after outplanting (Fig. 8). Cover of *A. spicifera* during the outplant period and in November 2022 may have increased for a couple of reasons. Firstly, the Waikīkī MLCD is adjacent to land with relatively high periodic nutrient fluxes from urban Honolulu into the nearshore environment that can enhance invasive algal growth. Secondly, it is possible that substantial *A. spicifera* increases were attributed to seasonal changes in light availability and other conditions that enhance algal growth. In particular, November 2022 may have reflected a large spring/summer accumulation of *A. spicifera* (Fig. 8). As we continue monitoring, we suspect that the effects of urchin grazing on *A. spicifera* will increase as urchins continue to grow and potentially spawn.

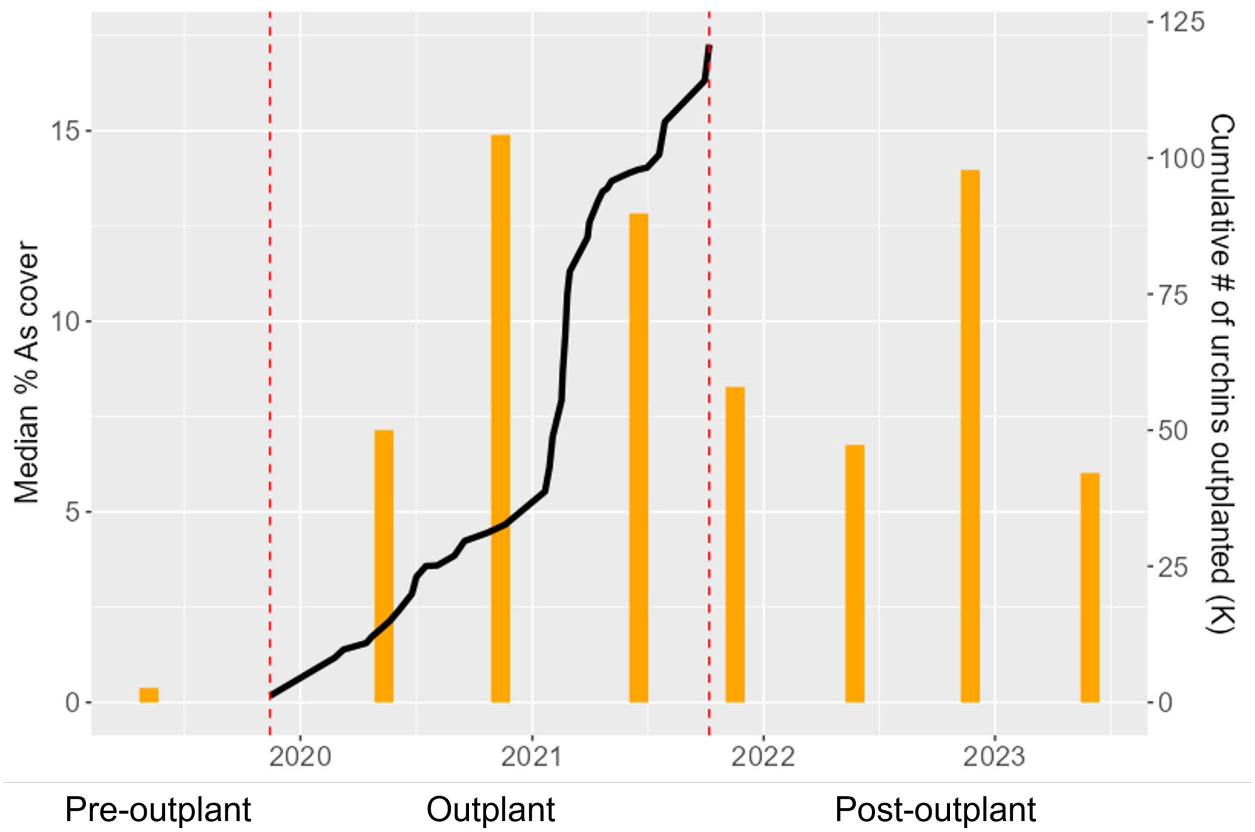

Figure 8: Median percent cover of *Acanthophora spicifera* from SNAP Surveys in the Waikīkī MLCD restoration area (left axis) from May 2019 to May 2023 with cumulative number (in thousands) of urchins outplanted (right axis) represented by the black line.

Gracilaria salicornia

Gracilaria salicornia was relatively widely distributed throughout the restoration area but not nearly to the extent of *Acanthophora spicifera* (Table 5, Fig. 9). In November 2022, approximately 9,443 m^2 of habitat had *G. salicornia* present with a median percent cover of 1.12% (Low: 0.38% - High: 1.97%). In May 2023, approximately 5,128 m^2 of habitat had *G. salicornia* present with a median percent cover of 0.071% (Low: 0.29% - High: 1.18%). Through this reporting period, *G. salicornia* decreased in distribution and cover (Fig. 9).

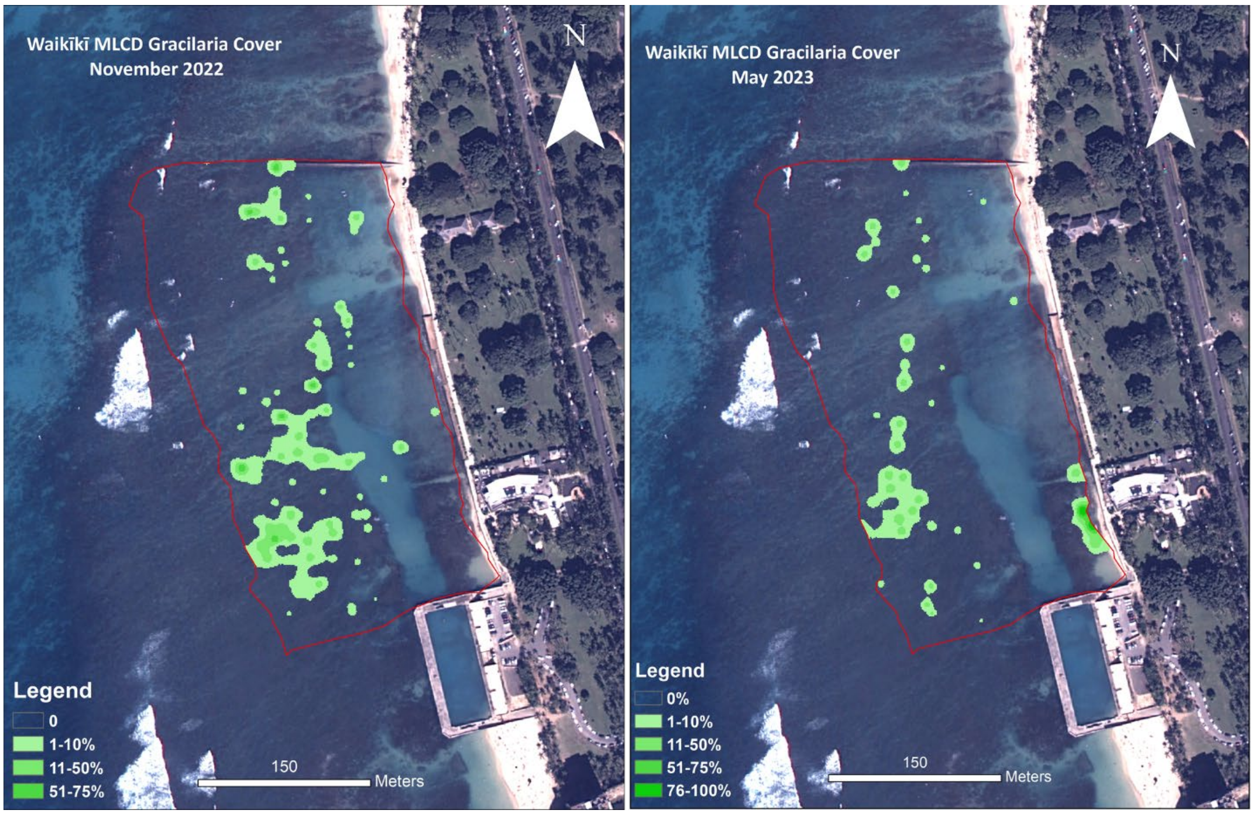

Figure 9: Median percent *Gracilaria salicornia* cover in the Waikīkī MLCD restoration area in November 2022 (left) and May 2023 (right).

Comparing *G. salicornia* median percent cover values before, during, and after the urchin outplant period, means were calculated for during and after urchin outplants. Mean cover of *G. salicornia* initially grew from 0.82% before outplanting to 2.12% during the outplant period followed by a decline to 1.3% after outplanting (Fig. 10). The median cover of *G. salicornia* in the first survey post-outplant was well over twice the cover during the next three surveys which skewed the post-outplant mean. This may have occurred for a couple of reasons. Firstly, the period before the last outplant survey included the majority of urchins released into the Waikīkī MLCD which likely increased urchin grazing on *G. salicornia* (Fig. 10). Secondly, outplant sized (17.5-22.5 mm test diameter) and medium-sized (29.8-43.8 mm test diameter) *T. gratilla* have been found to preferentially graze on *G. salicornia* over *A. spicifera* (Westbrook et al. 2015), which may partially explain why *G. salicornia* cover was reduced drastically at the end of the outplant period and remained low in the post-outplant period compared to *A. spicifera*.

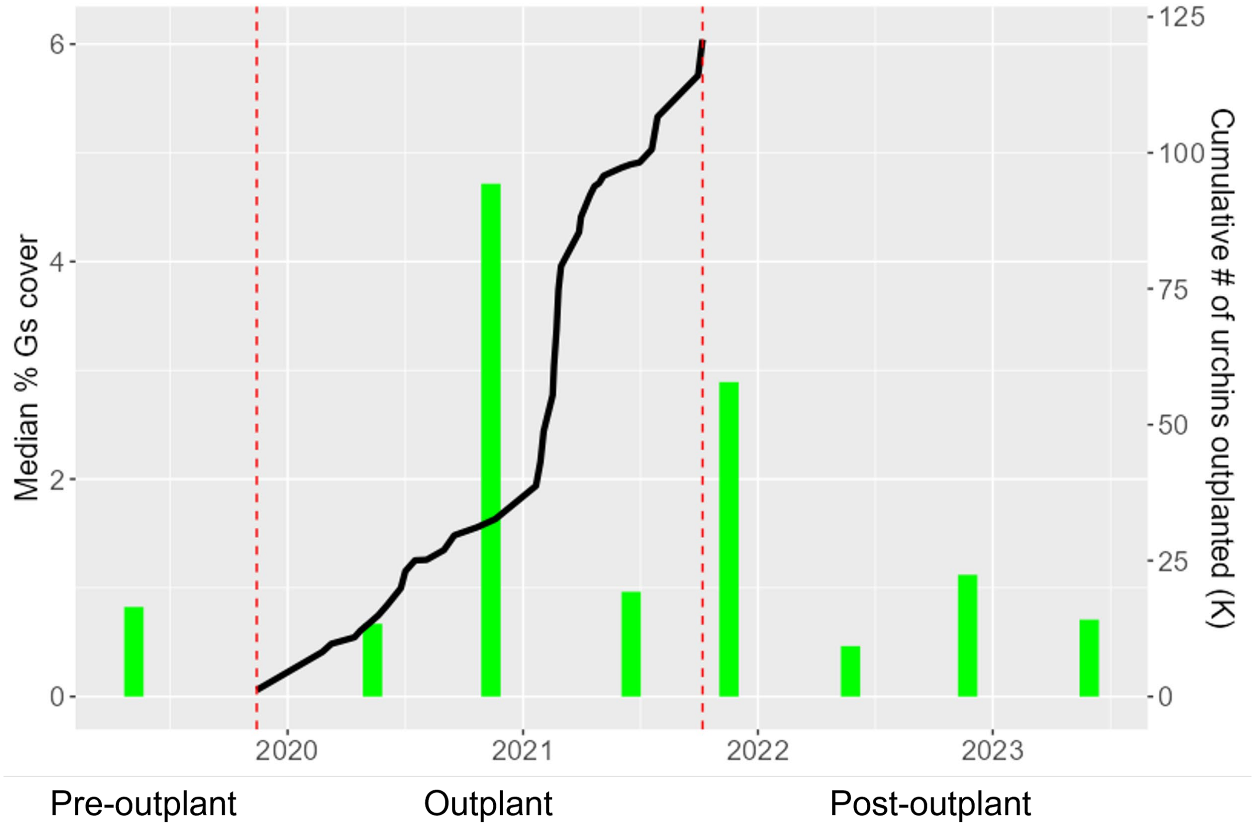

Figure 10: Median percent cover of *Gracilaria salicornia* from SNAP Surveys in the Waikīkī MLCD restoration area (left axis) from May 2019 to May 2023 with cumulative number (in thousands) of urchins outplanted (right axis) represented by the black line.

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APPENDIX A

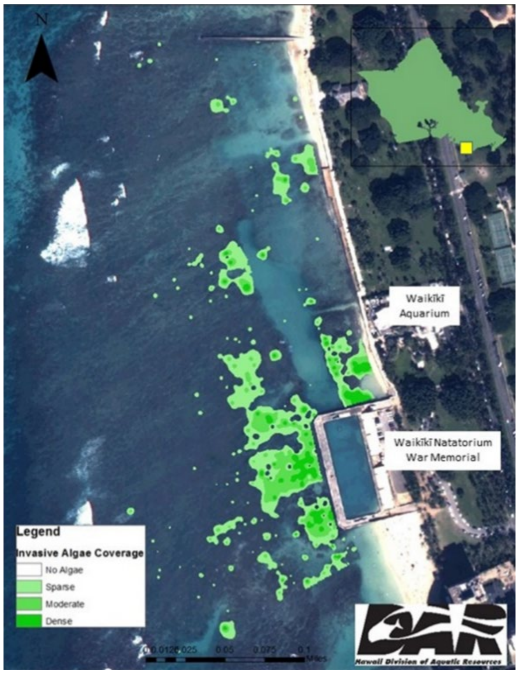

Figure S1: 2017 SNAP Survey that the MOU was based on.

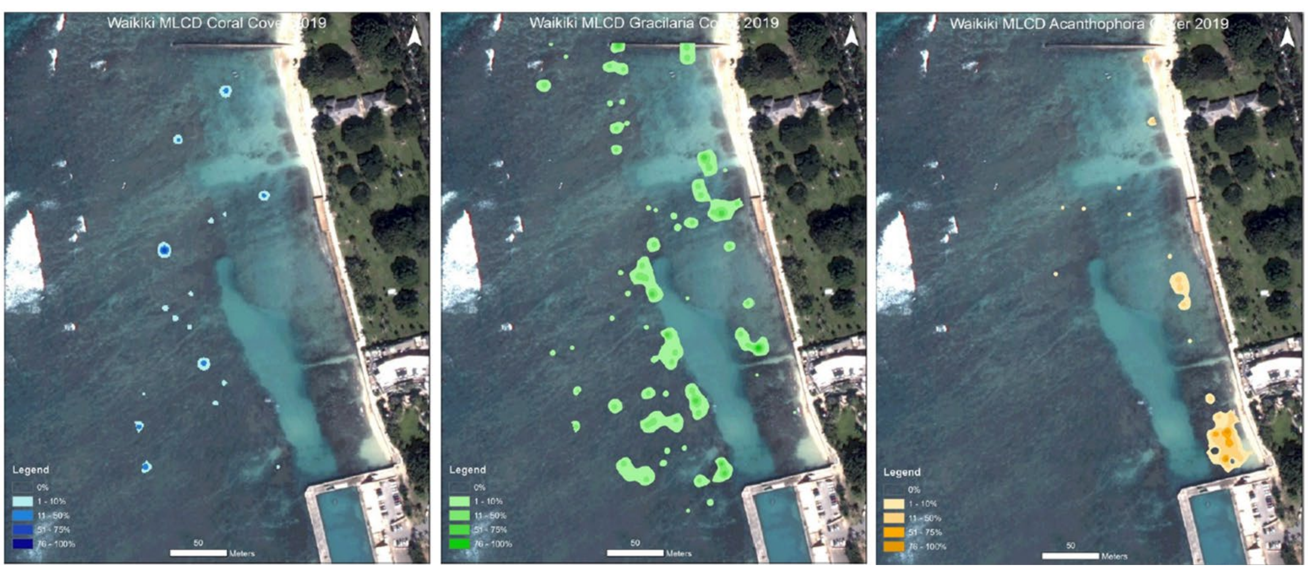

Figure S2: 2019 baseline survey of the restoration area (area in front of the Natatorium not included).

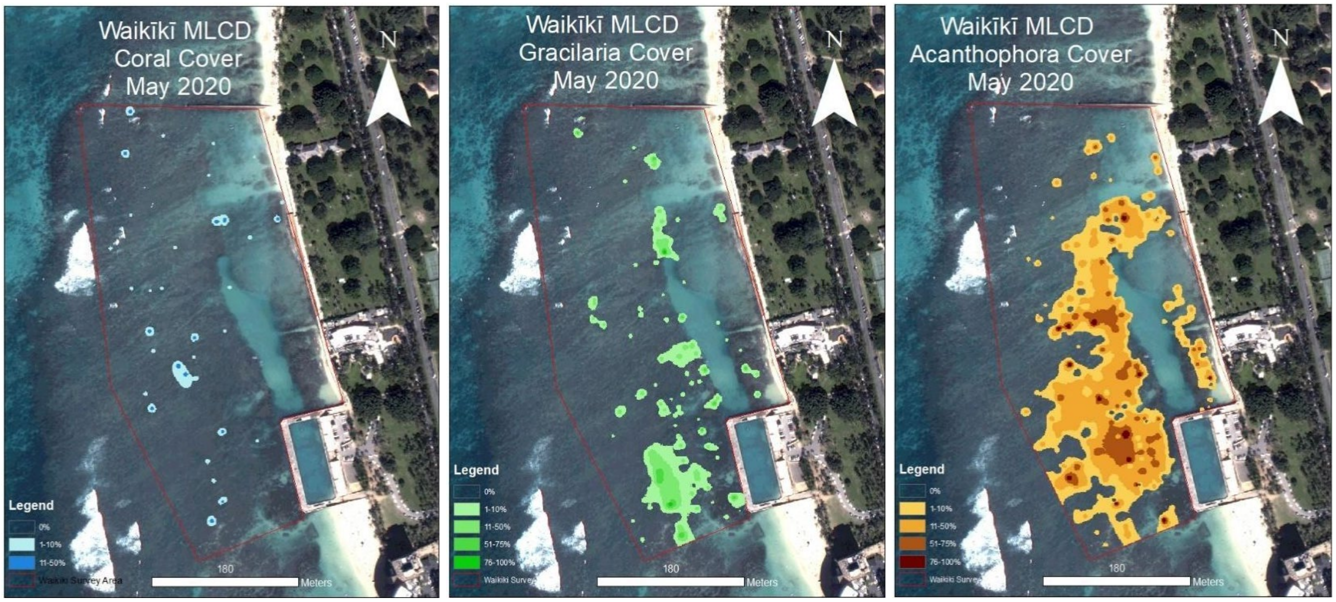

Figure S3: Map of results from May 2020 SNAP surveys.

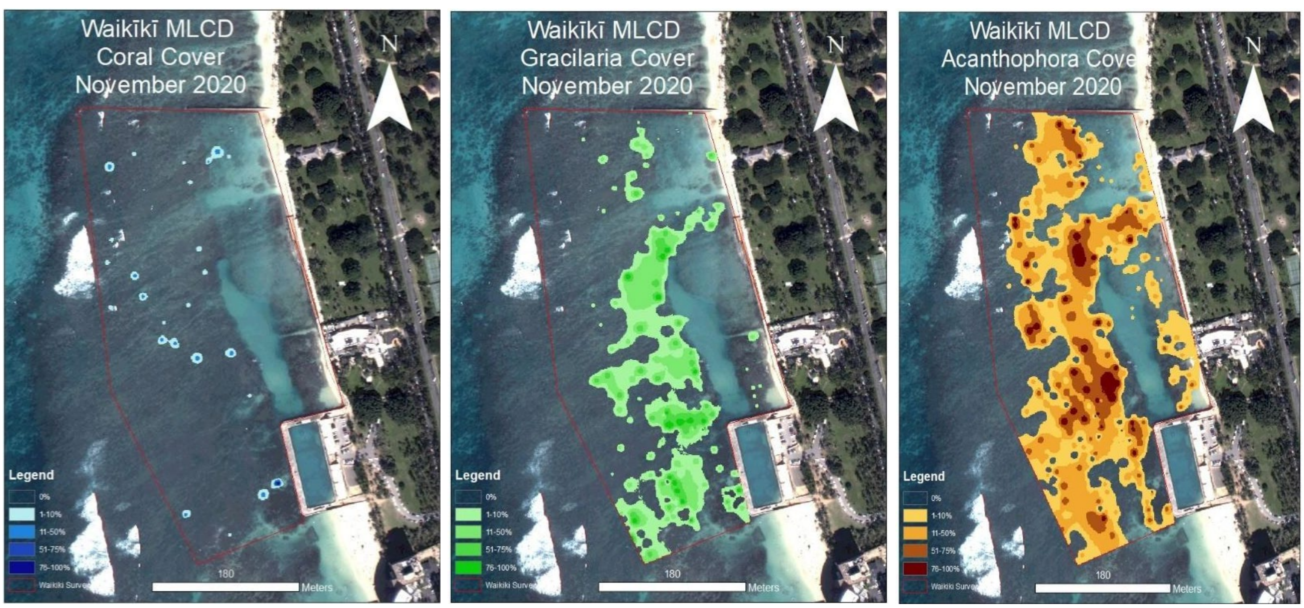

Figure S4: Map of results from November 2020 SNAP surveys.

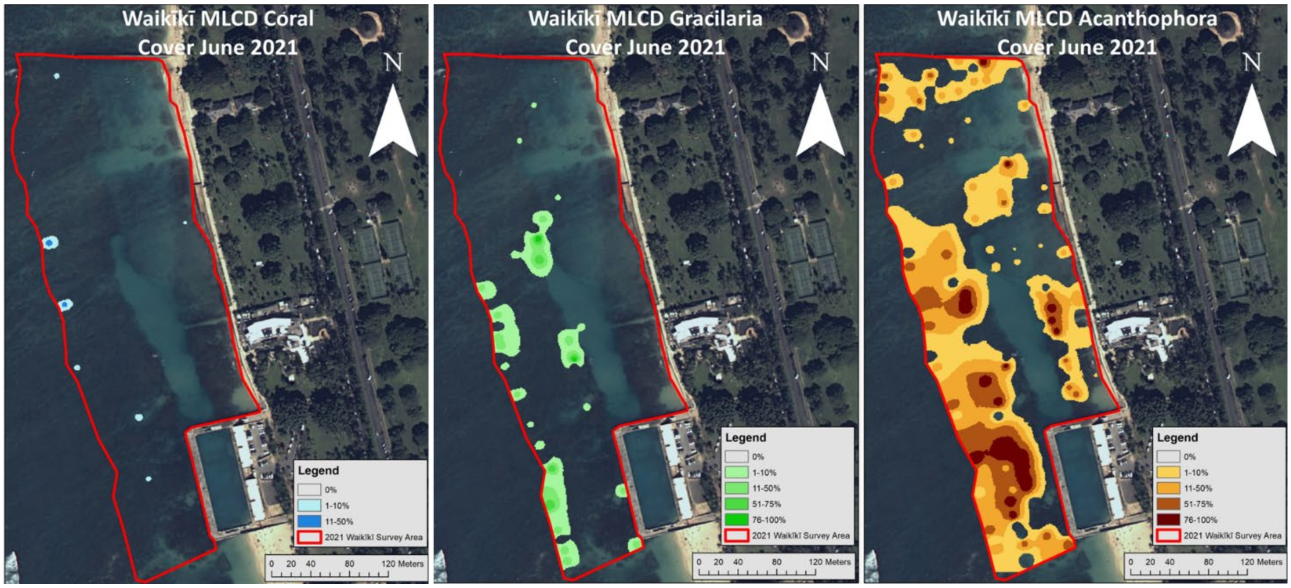

Figure S5: Map of results from June 2021 SNAP surveys.

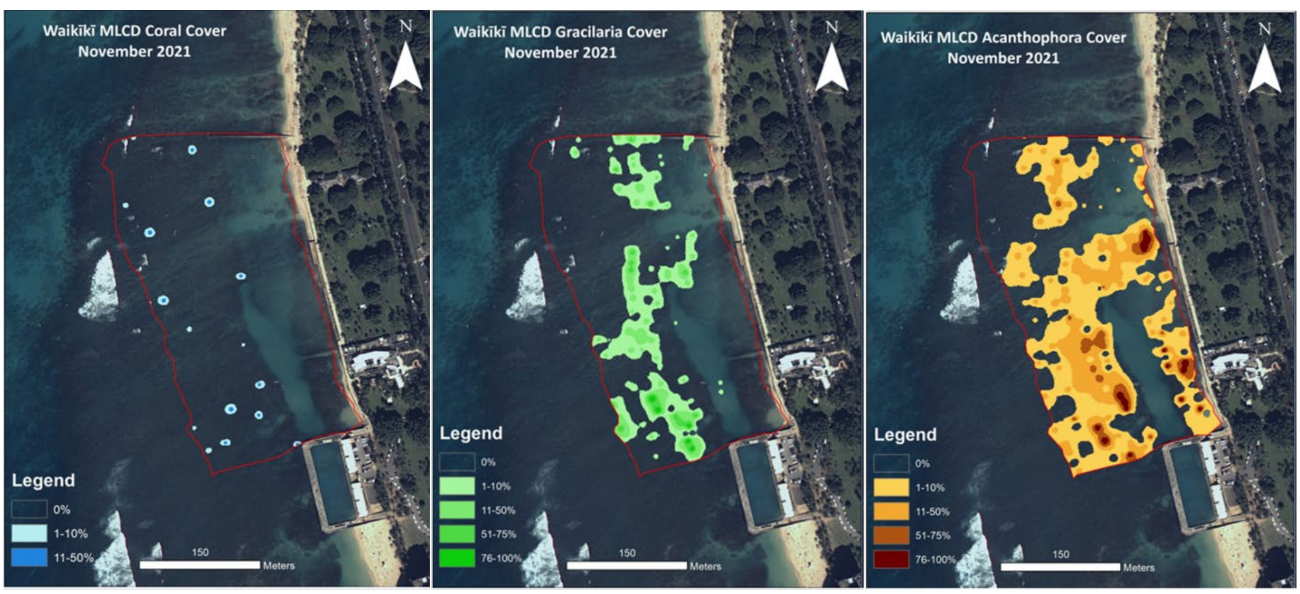

Figure S6: Map of results from November 2021 SNAP surveys.

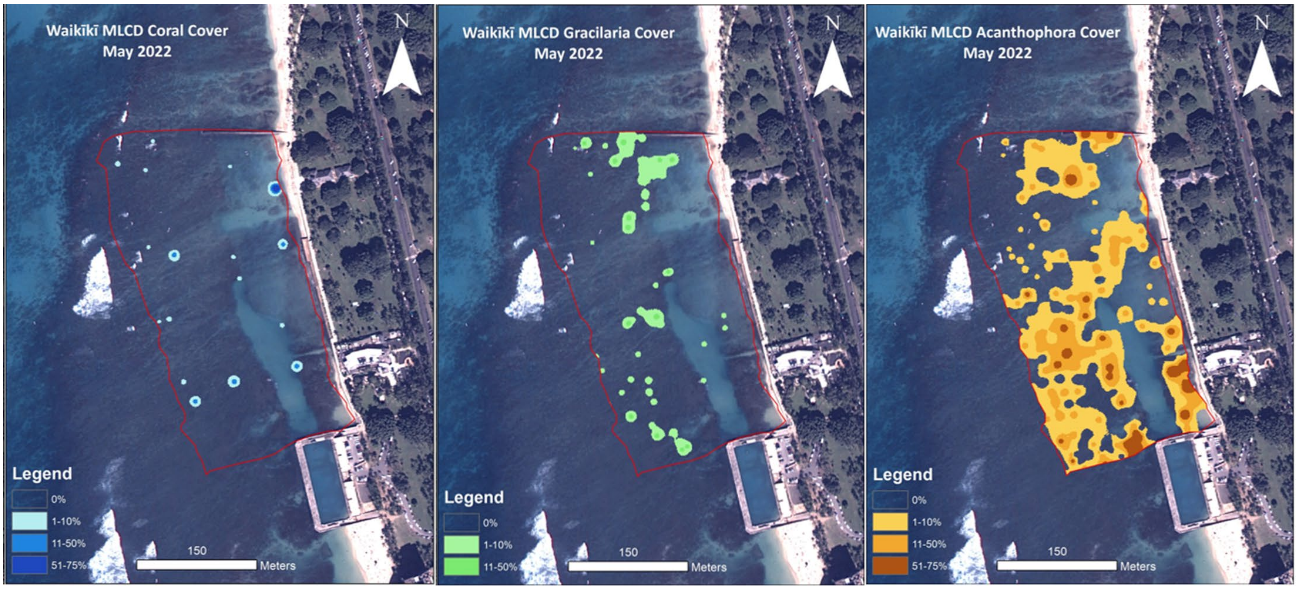

Figure S7: Map of results from May 2022 SNAP surveys.