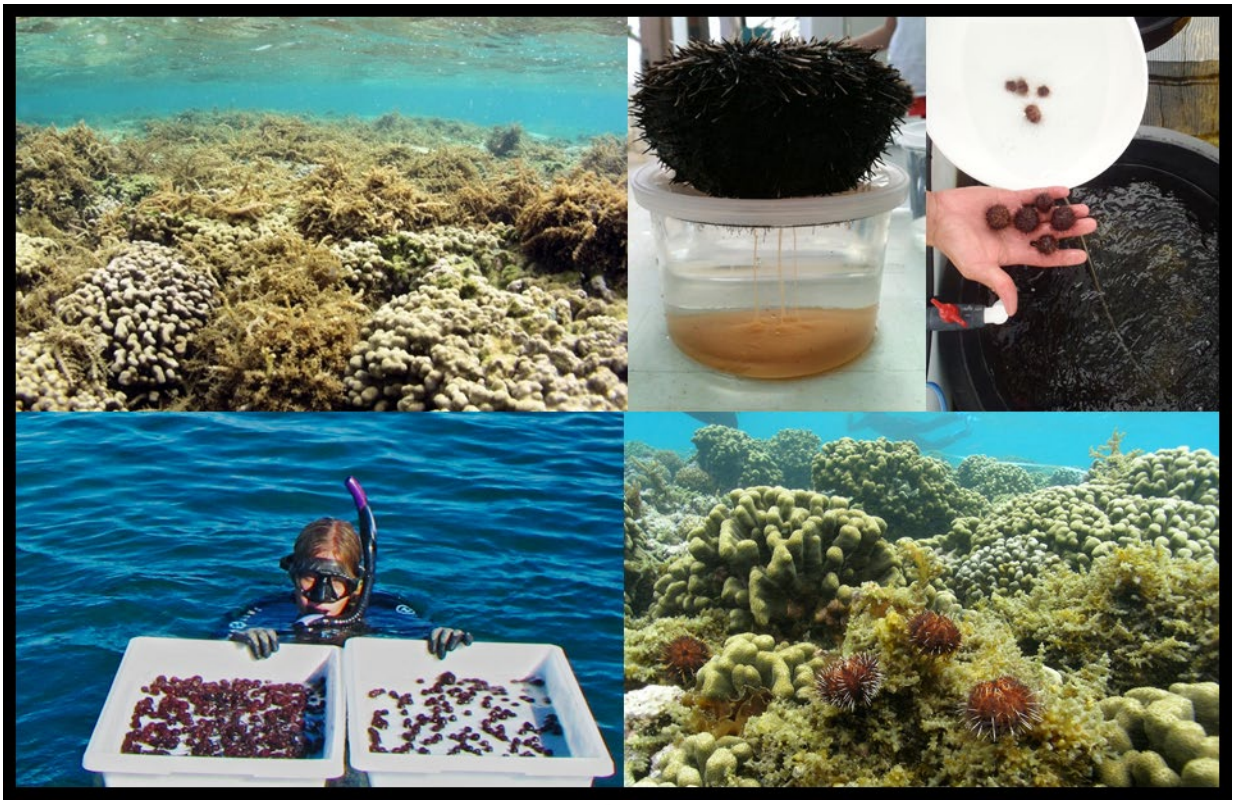
Cape Flattery Settlement Restoration Project: Restoring Reefs in Kāneʻohe Bay



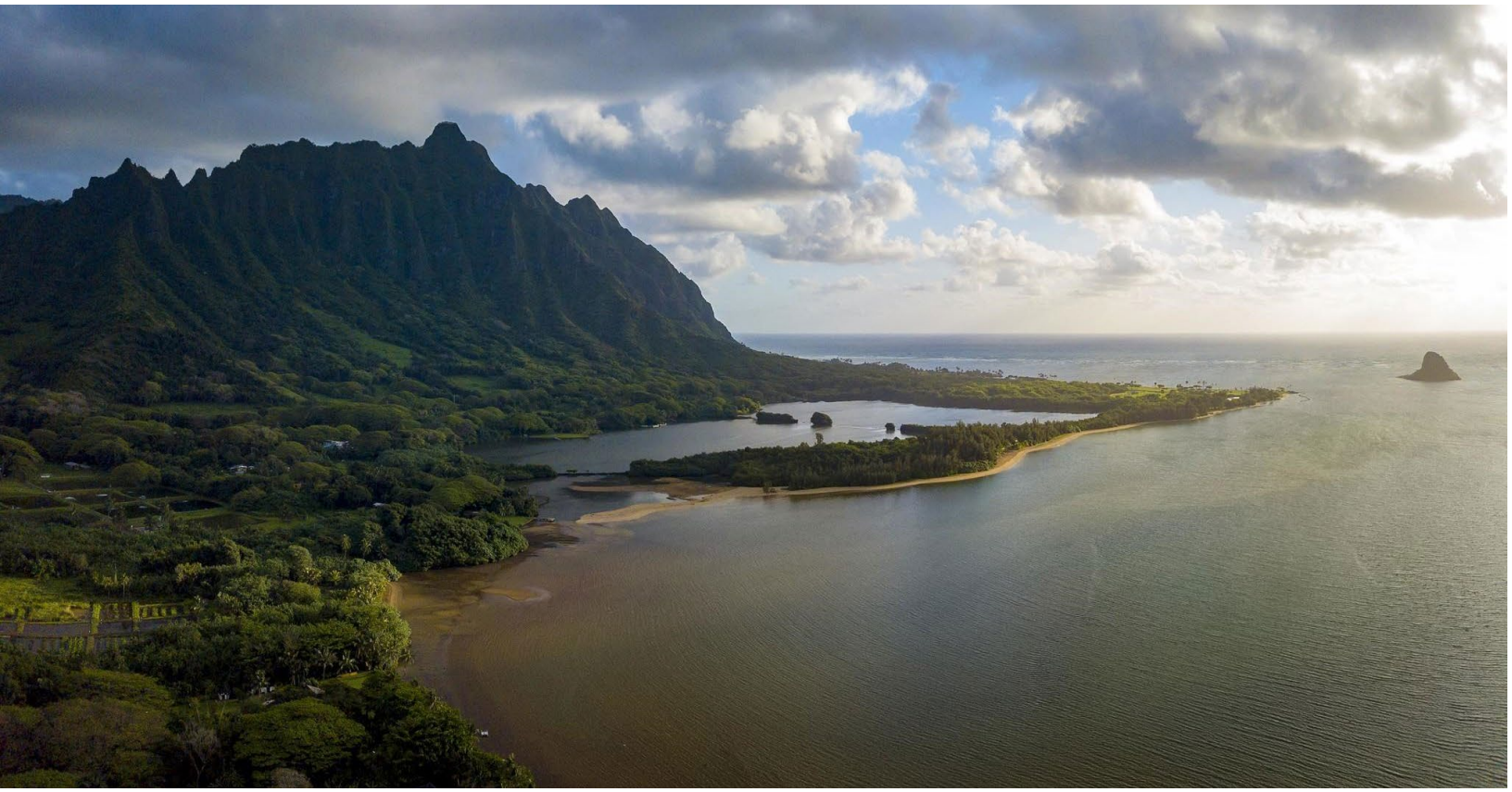
PROGRESS REPORT

DIVISION OF AQUATIC RESOURCES

AQUATIC INVASIVE SPECIES PROGRAM

PROJECT PERIOD: JANUARY 2023 – DECEMBER 2023

Contents



Restoration plan actions implemented

The Division of Aquatic Resources (DAR) continued the Cape Flattery Mitigation project to combat invasive algae in Kāneʻohe Bay during the January- December 2023 reporting period. These activities included annual SNAP surveys and urchin outplanting to manage invasive algal spread for all project reefs. Urchin outplanting has progressed to maintenance stocking of reefs based on annual SNAP surveys to maintain <5% cover of invasive algae (Tables 2 & 3). All priority reefs have been stocked with target numbers of urchins (*Tripneustes gratilla*) since 2018. A summary of Flattery project progress can be found in the work plan in Table 1.

The 2023 annual monitoring of Flattery reefs took place from March 1st to April 17th. SNAP surveys were conducted on all 22 Flattery reefs to map coral, *Eucheuma* spp./*Kappaphycus* spp. (E/K), and *Gracilaria salicornia*/*Acanthophora spicifera* (G/A) distribution and percent cover. SNAP surveys provide relatively fine-scale data to calculate coral and invasive algae median percent cover. These data were then used to forecast urchin outplant targets to manage E/K primarily and G/A secondarily. Going forward, DAR will continue to use SNAP surveys on all 22 Flattery reefs to manage invasive algae effectively in Kāneʻohe Bay.

Table 1: Work plan progress

Action	Who is responsible	Timeframe	Progress	Accomplishments	Notes
Conduct baseline monitoring surveys	Monitoring Coordinator (MC), Project Technicians	March – May 2016	Complete	Priority reef assessment completed 4/2016; Marker 12 assessment completed 5/2016	
Prioritize reef restoration efforts	DAR Aquatic Biologist, Trustees	March 2016 - November 2016	Complete	Initial reef prioritization complete	
Outplant native sea urchins to restoration area	Project Technicians, DAR Urchin Hatchery	April 2016 - end of project	In progress	155,100 urchins were released on treatment reefs in 2023	Initial targets reached for all reefs. Targets updated annually based on survey data.
Annual reporting to the Cape Flattery trustee council	MC, DAR Aquatic Biologist	Annual through end of project	In progress	13th progress report submitted	Reporting frequency changed from biannual to annual at 2020 Flattery Trustees meeting.
Follow-up monitoring of coral and algae conducted annually	Monitoring Coordinator, Project Technicians	March through end of project	In progress	Annual monitoring for restoration reefs completed in April 2023	All 22 project reefs will be monitored using SNAP methodology as agreed upon by AIS and DAR admin.
Urchin outplants	MC, Project Technicians	August 2018-end of project	In progress	Urchins added to previously stocked reefs as needed and available	
Reef reprioritization	DAR Aquatic Biologist, MC, and Trustees	January 2017-end of project	In progress	New prioritization tool incorporating reef area, coral, E/K, and G/A cover created by MC	Reefs are re-prioritized based on annual algae surveys

Approach

Restore and protect coral reef habitat through urchin bioremediation

Ānuenue Fisheries Research Center (AFRC) Urchin Hatchery production

During the 2023 reporting period, Flattery staff conducted 5 urchin spawning events, resulting in the spawning of 149 wild urchins with additional urchins spawned from resident AFRC broodstock. 24,754 liters of phytoplankton were produced to feed urchin larvae, and 3,443 kg of macroalgae were produced to feed juvenile urchins. In total, 25,465,000 larvae were produced and moved into tanks for the settlement and grow-out phases during this reporting period. Of those, 167,395 grew to transplantation size (~10mm) and were released onto priority reefs (Table 2).

***Table 2**: Monthly hatchery production and total urchins outplanted.*

DATE		FOOD		URCHINS		
		Phytoplankton produced (L) for urchin larvae	Macroalgae produced (kg) for urchin juveniles	Urchins collected for spawn	Number of larvae moved into settlement/grow-out phase (x1000)	Number of hatchery urchins outplanted
2023	Jan	3,590	129	31	6,343	1,000
	Feb	1,160	544	0	0	23,600
	Mar	75	229	0	0	27,800
	Apr	4,481	272	31	3,813	22,400
	May	727	499	0	0	22,800
	Jun	4,160	274	30	4,504	23,200
	Jul	280	272	0	0	13,600
	Aug	4,305	218	30	4,483	7,900
	Sep	150	286	0	0	4,600
	Oct	4,955	290	27	6,322	3,600
	Nov	796	161	0	0	4,095
	Dec	66	269	0	0	12,800
Totals		**24,754**	**3,443**	**149**	**25,465**	**167,395**

Deploying hatchery-raised urchins

In total, 167,395 urchins were outplanted onto project reefs during this reporting period (Table 3). Urchin outplant targets for all reefs will be reached in the spring of 2024. Additional maintenance outplanting occurred on reefs that had algae present at greater than 5% cover. Refer to Table 3 for urchin release data over the course of the project, including the number and destination of the urchins. Target maintenance number of urchins is based on 2 urchins/m^2 of E/K.

***Table 3**: Log of urchin outplants including outplant location, total number of urchins released, and area treated..*

Date Released	Reef Number	Urchins Released	Area treated (m^2)
1/20/2023	16, 40	1000	500
2/15/2023	M12	13600	6800
2/24/2023	P1	10000	5000
3/3/2023	P1	5400	2700
3/16/2023	M12	11200	5600
3/30/2023	M12	11200	5600
4/13/2023	24, 28, 30, M12, P3	11200	5600
4/28/2023	P1	11200	5600
5/12/2023	M12	12000	6000
5/25/2023	P1	10800	5400
6/1/2023	14	5000	2500
6/15/2023	41	11200	5600
6/30/2023	15	7000	3500
7/13/2023	14	7600	3800
7/27/2023	P1	6000	3000
8/10/2023	14	4400	2200
8/24/2023	9	3500	1750
9/14/2023	15	2200	1100
9/28/2023	9	2400	1200
10/11/2023	24	1800	900
10/26/2023	29, 31	1800	900
11/9/2023	16	1095	548
11/22/2023	P5	3000	1500
12/7/2023	43	4000	2000
12/28/2023	38, P5	8800	4400
Totals		**167,395**	**83,698**

Annually monitor treatment reefs in Kāneʻohe Bay

Conduct annual monitoring of Flattery treatment reefs

Annual surveys were conducted on Flattery project reefs shown in Figure 1 that range in size from 1,968 m^2 to 250,350 m^2 (Table 4). Monitoring began on March 3, 2023 and consisted of SNAP surveys of all 22 project reefs (Table 4). SNAP survey data categorized coral and invasive algae percent cover into 5 cover bins: (0: 0%, 1: 1-10%, 2: 11-50%, 3: 51-75%, 4: 76-100%). In the past, DAR used a combination of SNAP and E/K presence/absence surveys to reduce time spent monitoring in Kāneʻohe Bay. As of 2022, DAR will monitor all reefs using SNAP methodology annually to provide higher resolution data to manage invasive algae in Kāneʻohe Bay. For a more detailed description of SNAP survey methodology, refer to Appendix B.

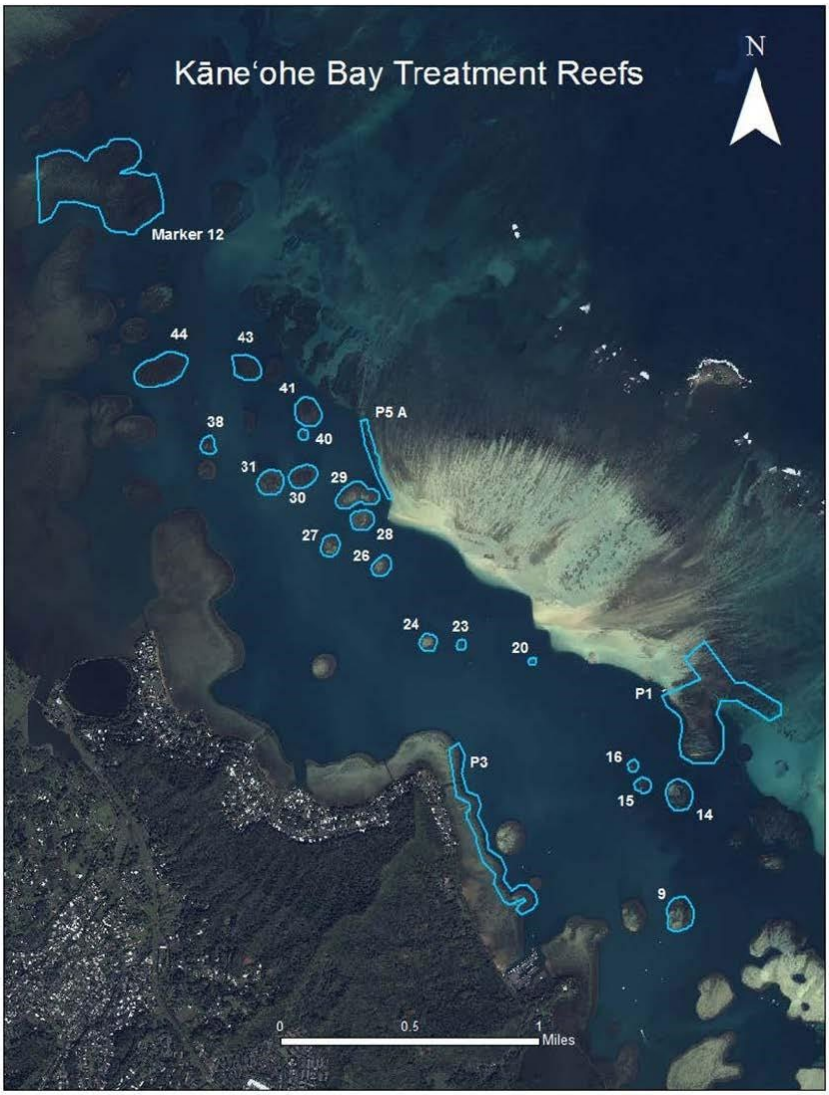


Figure 1: Treatment reefs for the Flattery project in Kāneʻohe Bay

Map survey data and calculate median percent cover

Coral and invasive algae distribution were mapped using the inverse distance weighting (IDW) tool in ArcGIS to visualize the distribution of coral and invasive algae on Flattery project reefs. The IDW tool calculates weighted average cover values (from SNAP surveys) around a given GPS point based on surrounding data points. IDW maps for each SNAP reef can be found in Appendix A. Percent cover was then calculated based on the area of each cover bin (1-4) for coral and invasive algae on each reef (Table 4). Due to the large size of bins used to simplify monitoring (e.g. 1: 1-10%, 2: 11-50%, 3: 51-75% etc.), the middle value was assumed for each bin to calculate median percent cover. For a more detailed description of ArcGIS interpolations and percent cover calculations, refer to Appendix B.

***Table 4**: Reef characteristics and SNAP survey progress for 2022 and 2023 priority reefs. Note that the table also includes presence/absence data for 2021 where only Eucheuma/Kappaphycus total area was quantified.*

Reef Marker	2022 SNAP Survey				2023 SNAP Survey				2023 Urchin Outplant Numbers	
	Area Surveyed (m^2)	Total Coral area (m^2)	Total *Eucheuma/ Kappaphycus* area (m^2)	Total *Gracilaria/ Acanthophora* area (m^2)	Area Surveyed (m^2)	Total Coral area (m^2)	Total *Eucheuma/ Kappaphycus* area (m^2)	Total *Gracilaria/ Acanthophora* area (m^2)	Target number of urchins for maintenance stocking ($2/m^2$)	Total number of urchins outplanted from Jan – Dec 2023
M12	250,238	172,047	3,133	58,591	250350	178134	3302	48674	6,604	57,800
9	27,620	25,361	825	2,107	27651	23530	2273	2523	4,546	5,900
14	21,759	21,759	4,309	5,409	25820	22259	7363	3335	14,726	17,000
15	7,660	7,583	2,820	0	7660	7564	3780	0	7,560	9,200
16	3,475	3,475	20	0	3465	3465	411	30	822	1,095
20	1,970	1,970	309	0	1968	1929	241	2	482	0
23	3,378	3,156	1,280	0	3378	2502	2617	0	5,234	0
30	19,482	18,199	540	0	19474	13785	341	0	682	0
40	3,179	3,016	475	0	3177	2424	589	109	1,178	0
41	23,994	20,270	3,436	676	24007	16344	8441	795	16,882	11,200
P1	207,867	152,711	8,143	33453	207997	131046	20665	32191	41,330	43,200
P3	54,181	44,023	21	2652	54192	32722	257	4555	514	0
P5	19,863	13,545	2,375	5191	19863	12580	4437	2574	8,874	9,000
24	8,548	7,127	48	0	8548	6355	784	0	1,568	1,800
26	13,053	12,347	1,857	699	13057	8190	4943	3776	9,886	0
27	13,426	11,516	667	1086	13420	7983	1266	2660	2,532	0

28	14,675	10,748	62	6842	14669	8775	170	7257	340	0
29	30,305	28,663	164	5033	30302	22870	204	8421	408	408
31	21,903	20,426	134	665	21908	16626	657	894	1,314	1,392
38	8,020	6,605	1,428	1699	8025	6098	1159	1216	2,318	2,800
43	22,467	22,103	2,150	21	22463	22143	2388	0	4,776	4,000
44	48,317	44,699	1,406	150	48330	42779	1864	758	3,728	0
TOTALS	**825,380**	**651,349**	**35,602**	**124,274**	**829,724**	**590,103**	**68,152**	**119,770**	**136,304**	**164,795**

Analyze survey data and compare to previous years

In the following three sections of this report, both total reef area (m^2) and median % cover are reported for coral and both categories of invasive algae. Total area provides context for how many square meters of a given reef have coral or invasive algae present. Median percent cover represents the relative density of coral or invasive algae for a given reef. These median cover values are used to determine if project reefs are below the management threshold of 5% median cover of invasive algae.

Coral

Coral distributions were variable amongst Flattery project reefs. In 2023, total coral area on Flattery reefs ranged from 1,929 m^2 to 178,134 m^2 (Fig. 3). The large difference in the areal extent of reef M12 vs. all other reefs surveyed explains the large range in coral area observed (Table 4). The median percent cover of coral was calculated based on the median value of each percent cover bin over the entire reef area. Median cover among reefs varied from 12% (P3) to 86.6% (R16) in 2023 (Fig. 4) with a mean of 34.39%.

Due to the nature of SNAP surveys, the area of each reef monitored varies slightly from year to year. However, the change in area is minimal and therefore it is reasonable to compare median percent cover values between years. Median coral cover has remained relatively stable (Fig. 4). Additionally, DAR changed the monitoring method of six reefs (24, 28, 31, 38, 43, and 44) from using SNAP surveys to presence/absence surveys for 2020 and 2021 due to a low ratio of *Kappaphycus/Eucheuma* cover to coral cover. As a result, coral area and cover estimates were not calculated for these years (Figs. 3 & 4). Twelve additional reefs (on top of the original ten reefs) were surveyed since 2016 (Reefs: P1, P3, P5, 24, 26, 27, 28, 29, 31, 38, 43 and 44) except for in 2021 and 2022. All 22 reefs (Table 4) are surveyed annually since 2022 using the SNAP methodology.

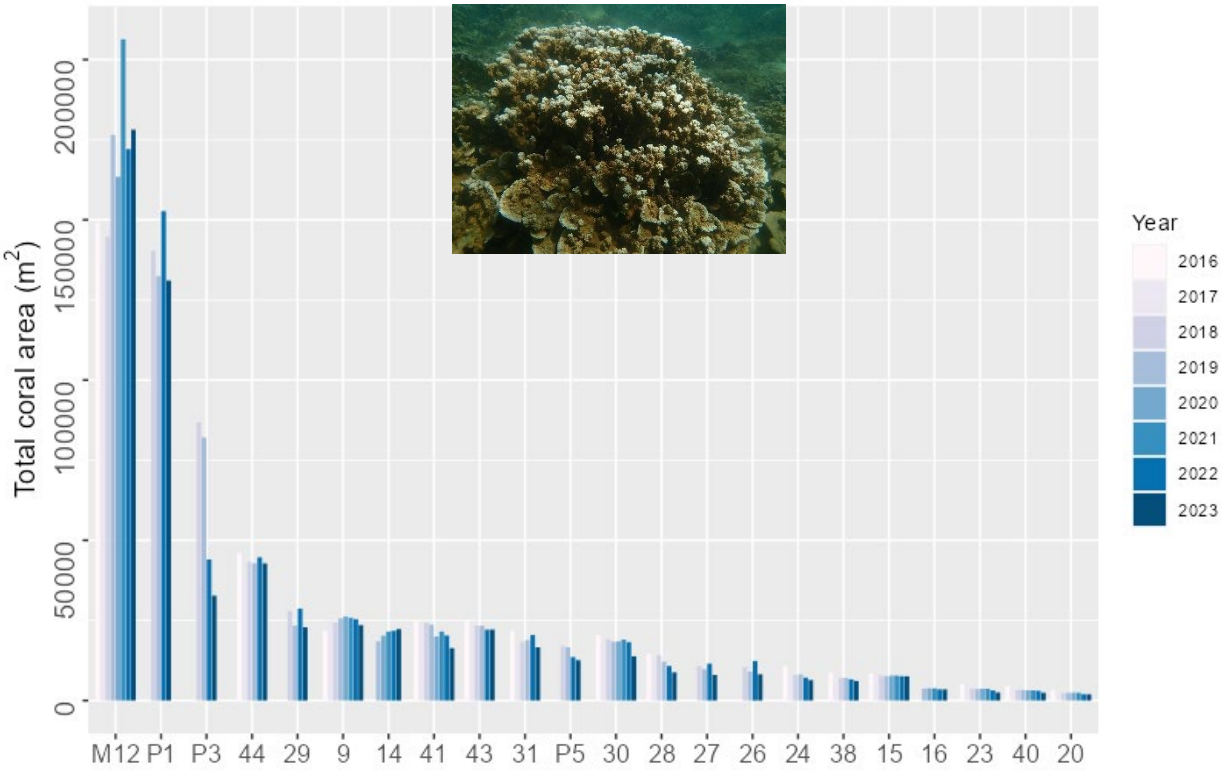


Figure 3: Total coral area (m^2) by reef. Reefs are displayed based on descending reef area. Note that presence/absence reefs (P1, P3, P5, 24, 26, 27, 28, 29, 31, 38, 43 and 44) do not have coral data for the years 2020 and 2021.

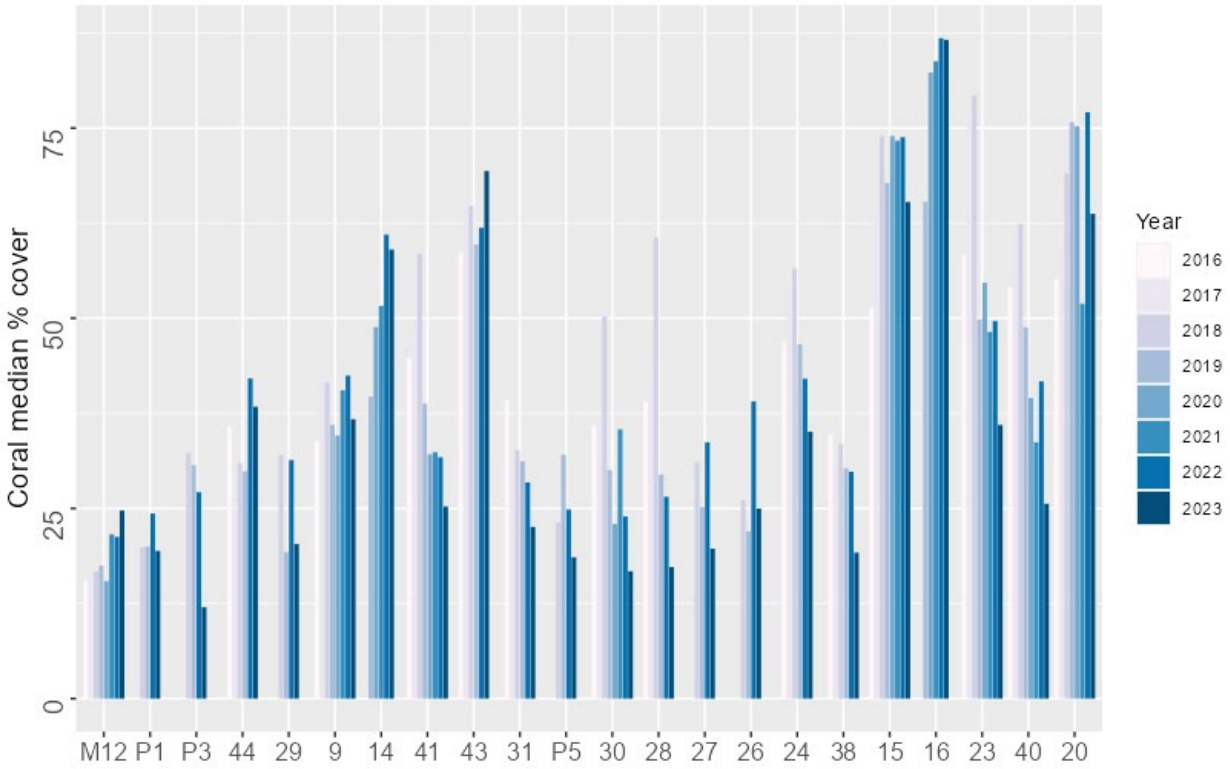


Figure 4: Median percent cover of coral by reef. Reefs are displayed based on descending reef area. Note that presence/absence reefs (P1, P3, P5, 24, 26, 27, 28, 29, 31, 38, 43 and 44) do not have coral data for the years 2020 and 2021.

Kappaphycus/Eucheuma

During all survey years, *Eucheuma* spp./*Kappaphycus* spp. (E/K) area was quantified using SNAP or presence/absence (P/A) methodology (2020 and 2021). Of the 22 reefs that were surveyed, E/K area decreased on three reefs (20, 30, and 38) and increased on all other 19 managed reefs (Fig. 5) from 2022 to 2023. Reef median algal cover was calculated to determine if E/K cover was below the 5% management goal in years where SNAP surveys were conducted (2016-2019 and 2022 onward). In 2023, reefs 14, 15, 23, and 26 all had median E/K cover values above the 5% management threshold (Fig. 6). High algal cover can be found in smaller areas across individual reefs and generally is not evenly distributed. The increase in areal extent of E/K and prevalence of managed reefs exceeding the 5% management goal, it appears that there is an increase in E/K that is occurring Bay wide. The AIS team is restarting the Super Sucker (underwater algae vacuum) in 2024 to reduce nuisance level E/K where loose, dense algae is present (14, 15, 23, 26) followed by urchin biocontrol. All Flattery project reefs are treated by outplanting 2 urchins/m^2 of E/K.

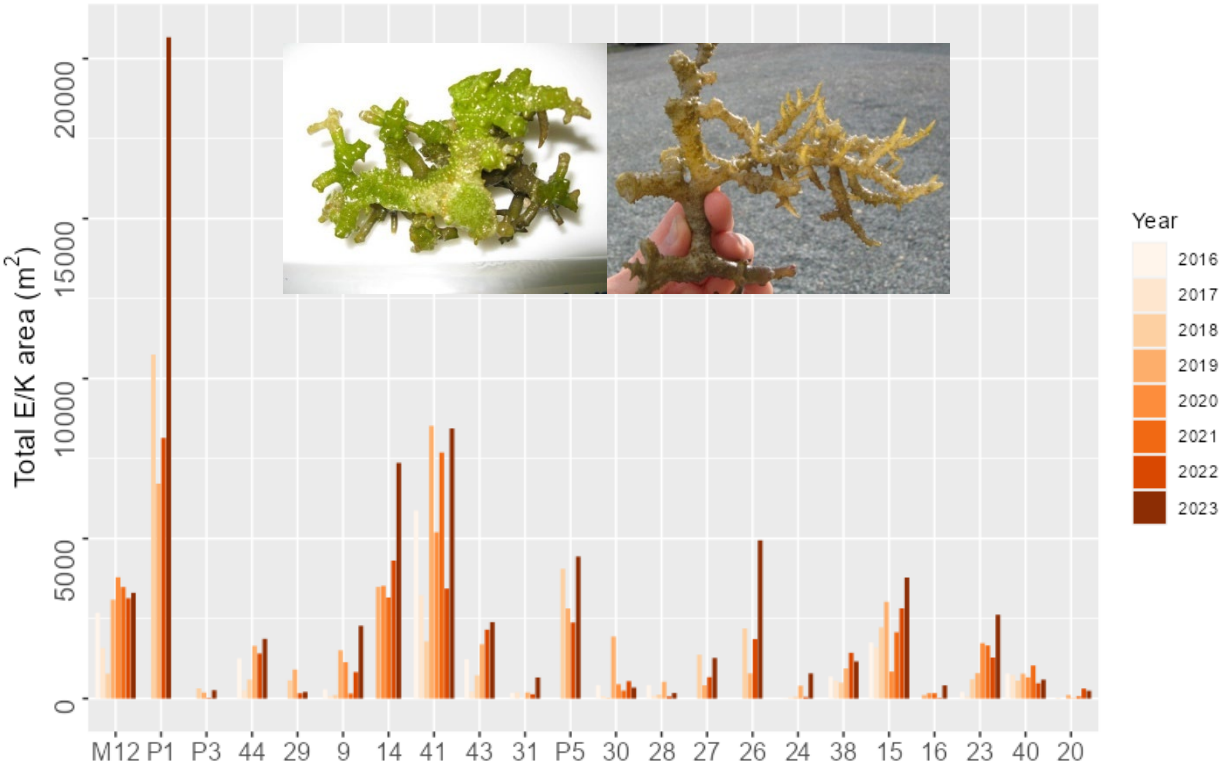


Figure 5: Total *Eucheuma/Kappaphycus* area (m^2) by reef. Reefs are displayed based on descending reef area.

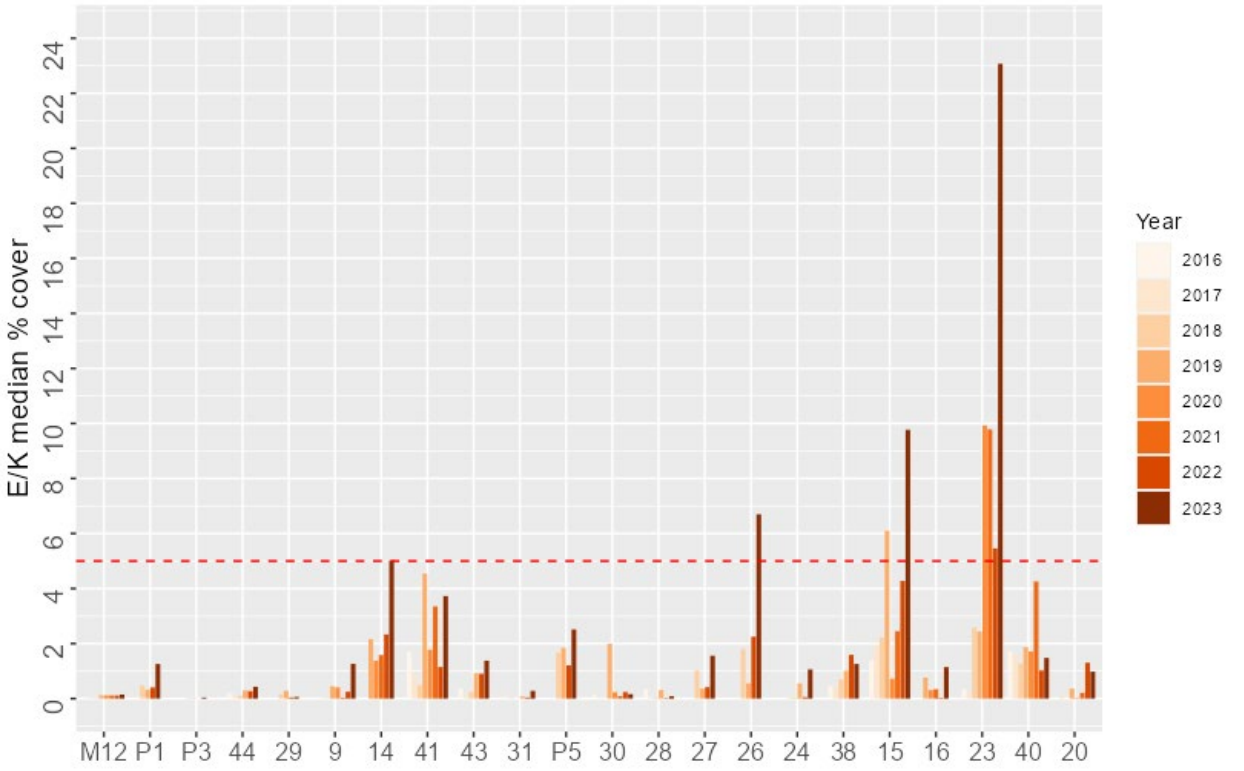


Figure 6: Median percent cover of *Eucheuma/Kappaphycus* by reef. Red dashed line represents the 5% management target. Reefs are displayed based on descending reef area. Note that presence/absence reefs (P1, P3, P5, 24, 26, 27, 28, 29, 31, 38, 43 and 44) do not have G/A data for the years 2020 and 2021.

Gracilaria/Acanthophora

Graciliaria salicornia and *Acanthophora spicifera* (G/A) were secondarily targeted for urchin biocontrol on Flattery reefs. G/A is a factor in prioritizing reefs for urchin outplanting (Appendix C), but is not used to set outplant targets like E/K. This is because E/K is an incipient invasive species capable of spread within the Bay and potentially to other parts of O'ahu. From 2022 to 2023, G/A area decreased or was 0 on ten reefs (M12, 14, 15, 23, 30, P1, P5, 38, and 43) while area increased on the other twelve managed reefs (Fig. 7). At present, only two reefs where G/A area increased (26 and 28) had median G/A cover values exceeding the management threshold of 5% (Fig. 8). Presence/absence (P/A) surveys do not quantify G/A area or cover, as data is only collected for E/K during these surveys. This is why G/A data is not presented for 2020 and 2021 when P/A surveys were conducted (Figs. 7 & 8). Going forward, SNAP surveys will be conducted for all project reefs to determine G/A area and coverage on these reefs annually instead of once every three years. In addition, the Super Sucker will be used to treat nuisance levels of G/A where practical.

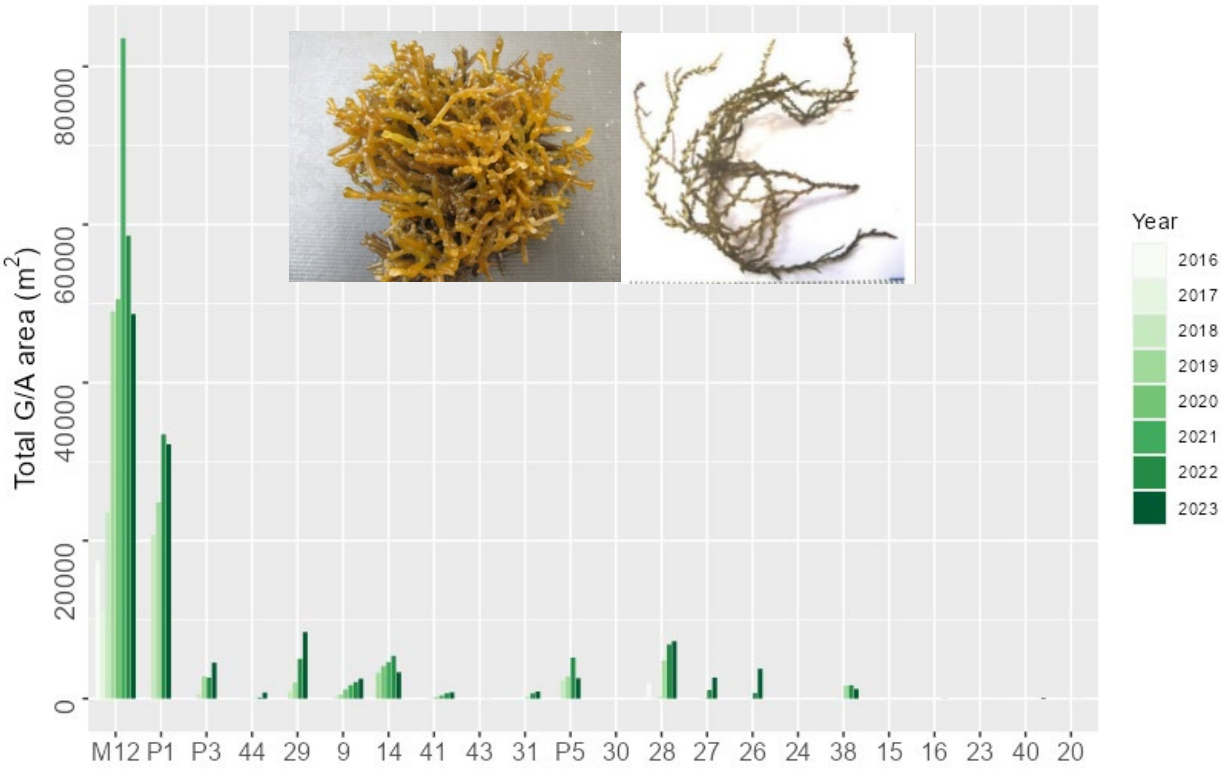


Figure 7: Total *Gracilaria/Acanthophora* area (m^2) by reef. Reefs are displayed based on descending reef area. Note that presence/absence reefs do not have G/A data for the years 2020 and 2021.

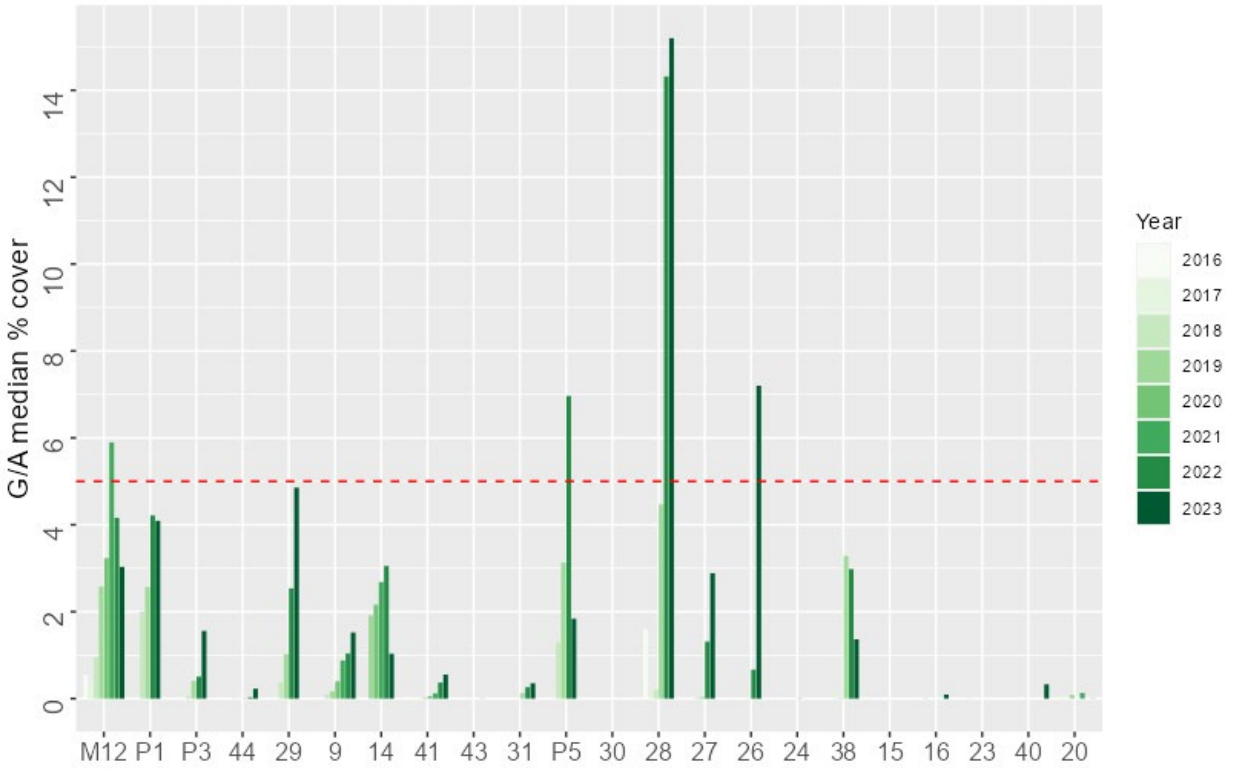


Figure 8: Median percent cover of *Gracilaria/Acanthophora* by reef. Reefs are displayed based on descending reef area. Red dashed line represents the 5% management target. Note that presence/absence reefs do not have G/A data for the years 2020 and 2021.

Flattery reef reprioritization tool and other activities

Flattery project reefs are reprioritized annually for urchin biocontrol based on SNAP survey data. This is important, particularly in years where urchin outplant targets of 2 urchins/m^2 of *Eucheuma/Kappaphycus* (E/K) are not able to be met due to limited urchin hatchery production. Previously, prioritization of reefs was done by quantifying the relative percent cover of E/K or the total area where E/K was present divided by the total area of a given reef. These values could be calculated for all project reefs monitored using SNAP or presence/absence survey methodology. Reefs were then ranked in descending order based on the calculated relative percent cover of E/K.

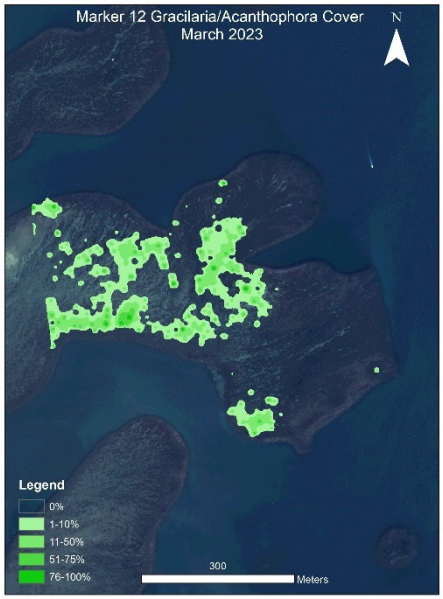
In 2022, the AIS team developed a new tool to improve how we reprioritize reefs for management. This tool allows the AIS team to objectively rank Flattery reefs for management based on several factors. Firstly, the tool uses higher resolution SNAP data to quantify E/K median percent cover data, improving upon past prioritization based on a relative measure of E/K through lower resolution presence/absence surveys. This change will allow us to prioritize reefs more precisely and to locate where E/K is growing on project reefs to manage invasive algae more effectively. Secondly, the tool factors in coral cover and reef size for reprioritization. This addition allows the AIS team's reprioritization to consider the extent that invasive algae threaten coral resources. Lastly, the tool incorporates *Gracilaria/Acanthophora* (G/A) median percent cover. While G/A are not incipient targeted species like E/K, G/A still does overgrow corals on some project reefs. Therefore, we created a reprioritization tool that factors in coral, E/K, and G/A cover, as well as reef area to rank and prioritize reefs for urchin biocontrol.

After the 2022 SNAP surveys of all 22 Flattery project reefs, the HCRI Monitoring Coordinator created a tool to score these reefs using SNAP data. This tool first scores the 4 categories (coral, E/K, and G/A cover as well as reef area) for each reef and then scales those scores based on management priorities. Once scaled, these scores of each category are summed to get a total score for each reef that can rank and prioritize reefs in descending order for urchin biocontrol. This reprioritization tool will be used each year to reprioritize all 22 project reefs. For a detailed description of how this reprioritization tool works, refer to Appendix C.

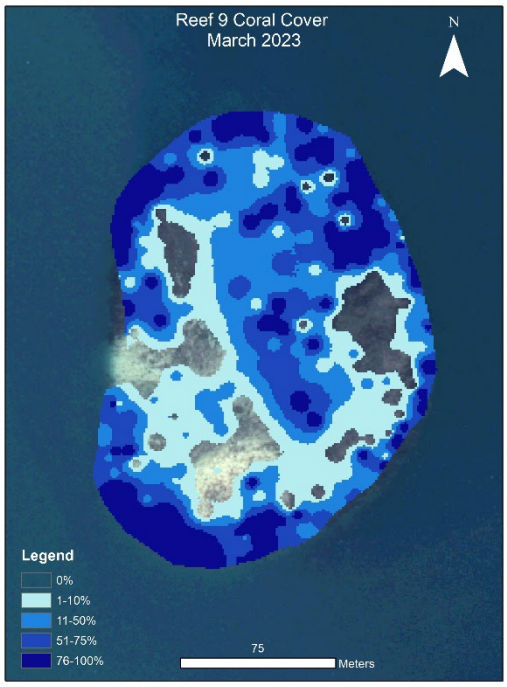
In 2023, the AIS team began the process of restarting the Super Sucker program. During the 2023 SNAP surveys, AIS staff observed nuisance levels of E/K on several reefs in central Kāneʻohe Bay. After consulting with DAR Administrators and the Flattery Trustee Board, the AIS team began the process of renovating the Super Sucker. Repairs to the main barge platform were performed to clean and repaint the hull, service the engines, fix the algae sorting table, and rewire the electrical for the GPS and marine radio. New trash pumps, algae bags, hoses, and other associated materials for Super Sucker operation were purchased to replace old equipment. Following acquisition of the needed materials, the AIS team successfully conducted a full system test at AFRC. The goal for the AIS team is to initiate use of the Super Sucker following the 2024 SNAP surveys to inform which reefs to prioritize for treatment. Once E/K has been treated on project reefs with over 5% median cover, G/A will be targeted secondarily for removal.

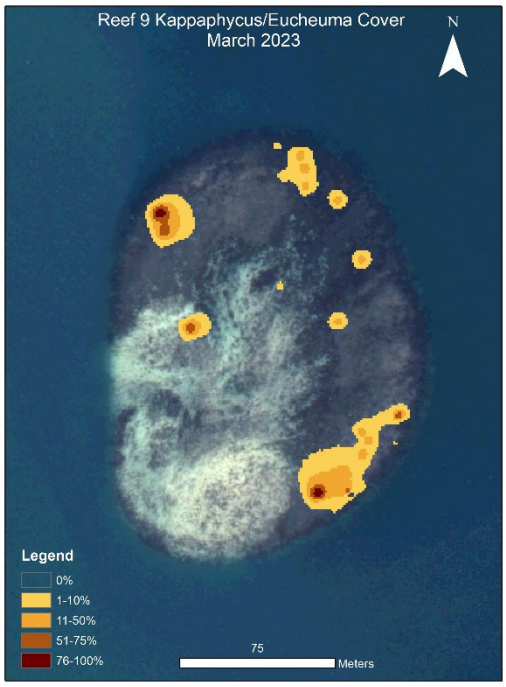
Appendix A: SNAP Reef Maps 2023

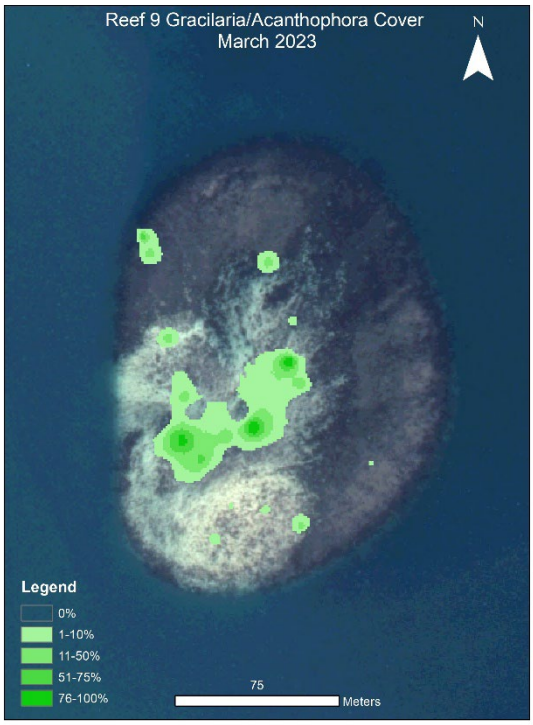
Marker 12



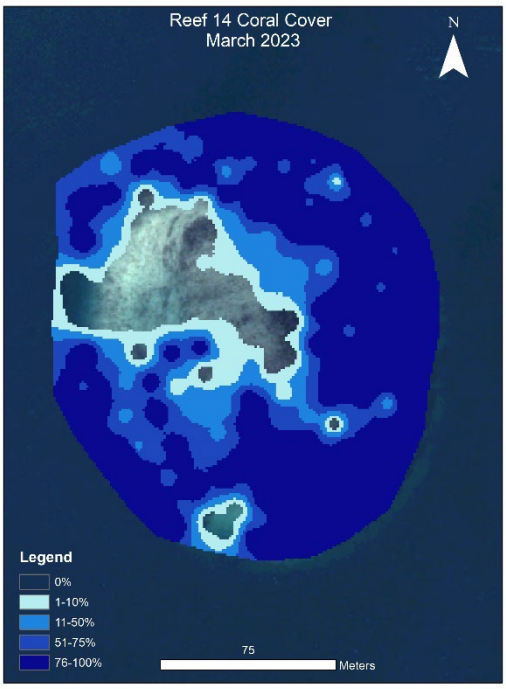
Reef 9

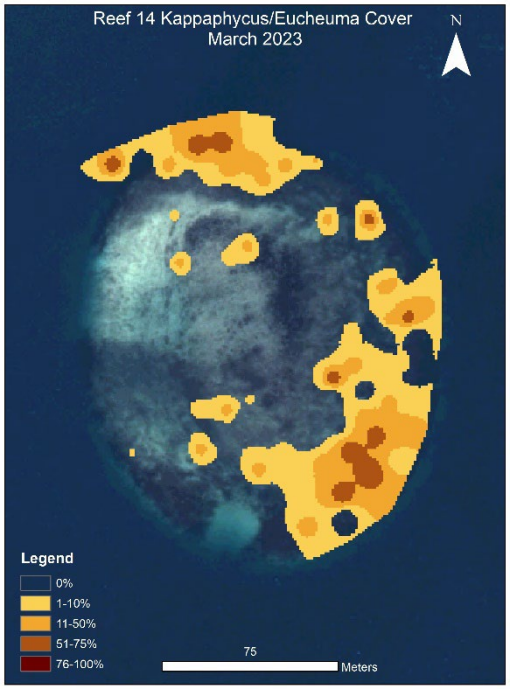

Reef 9 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters

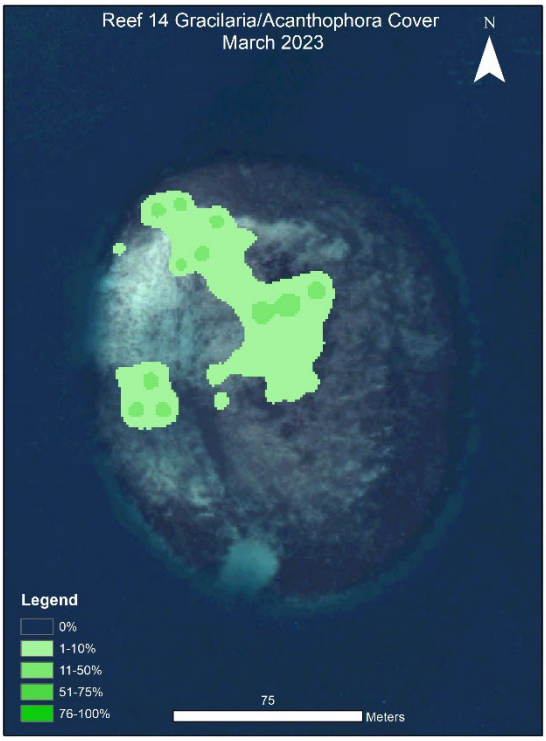

Reef 9 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters


Reef 9 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters

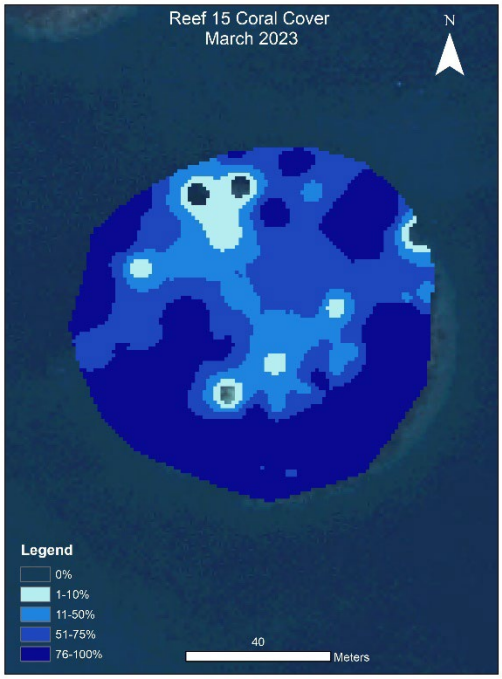
Reef 14

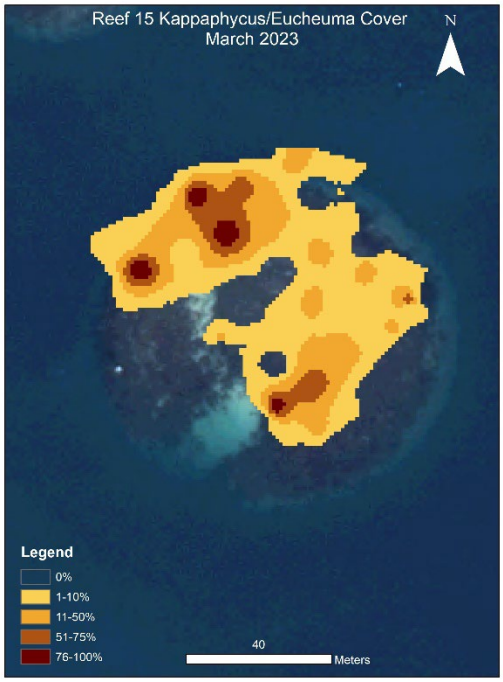

Reef 14 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters


Reef 14 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters


Reef 14 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters

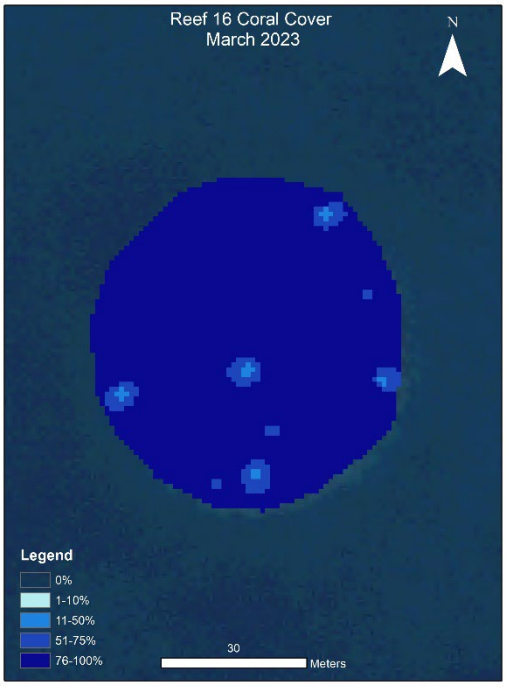
Reef 15

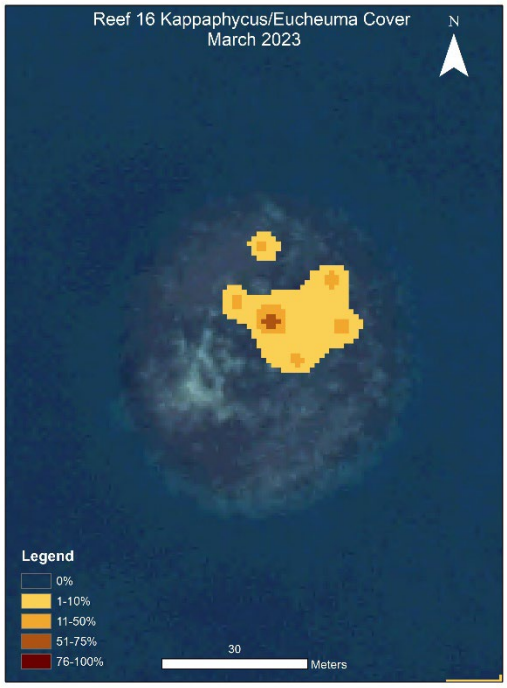

Reef 15 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters

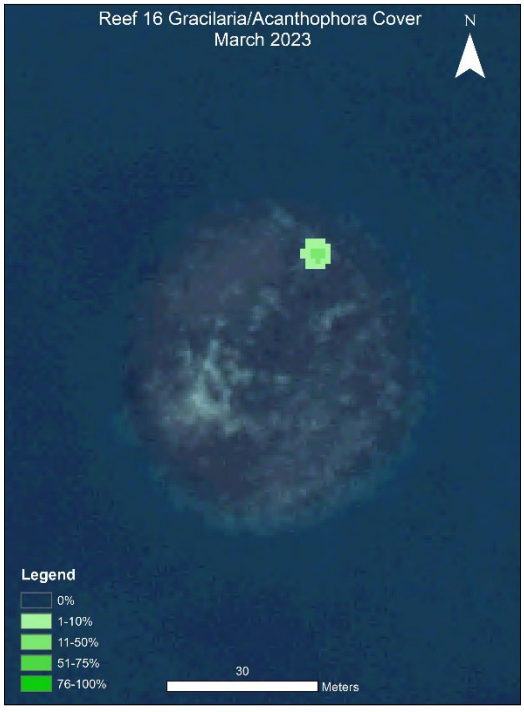

Reef 15 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters


Reef 15 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters

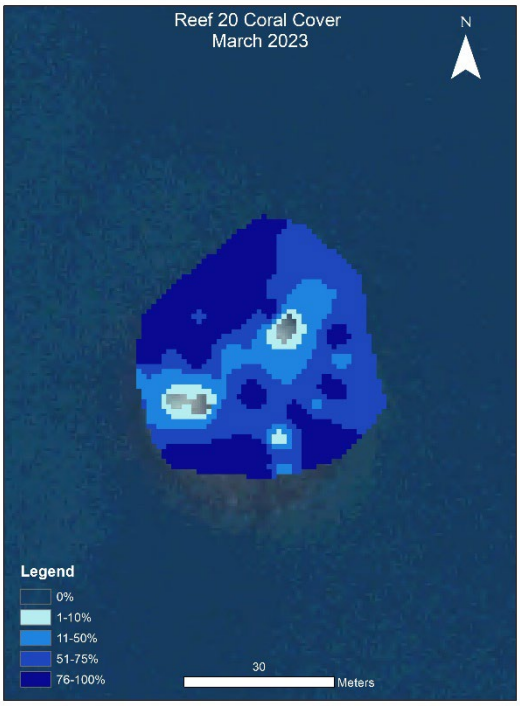
Reef 16

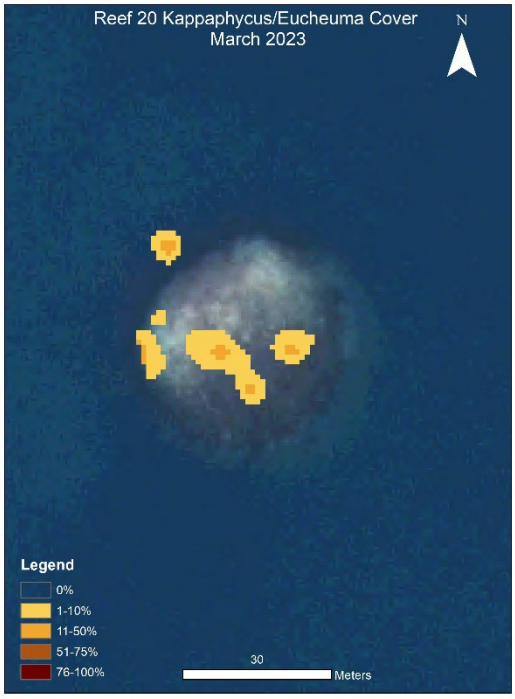

Reef 16 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters


Reef 16 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters


Reef 16 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters

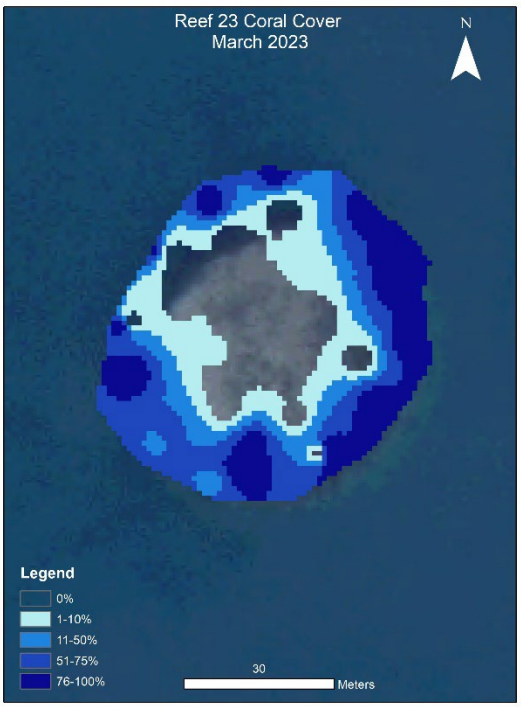
Reef 20

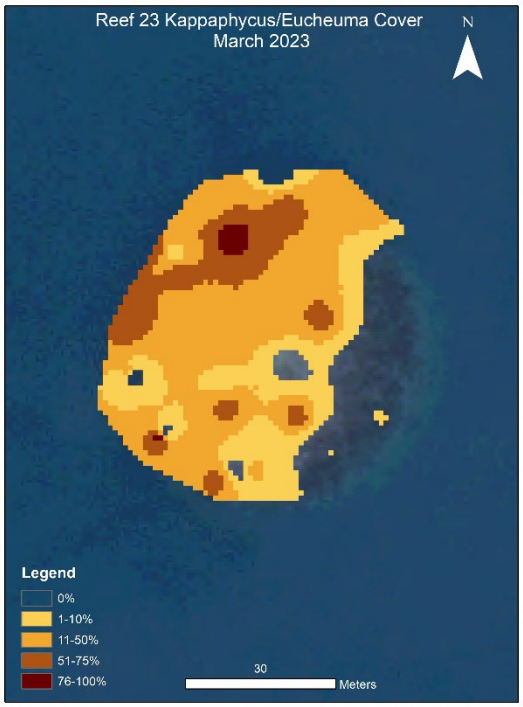

Reef 20 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters

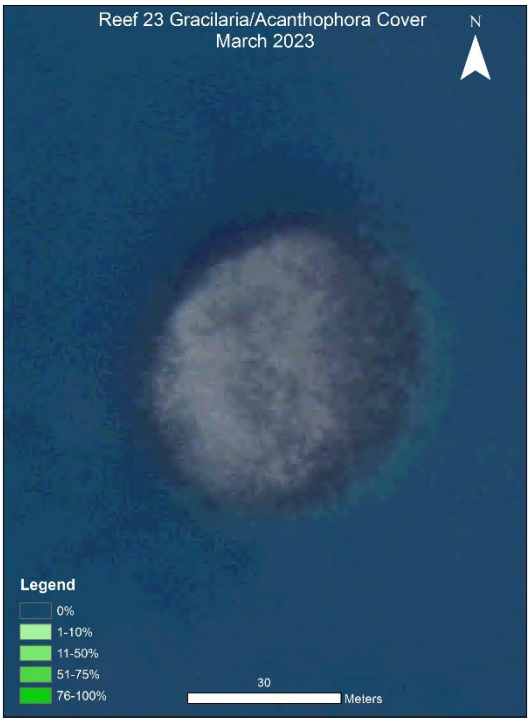

Reef 20 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters


Reef 20 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters

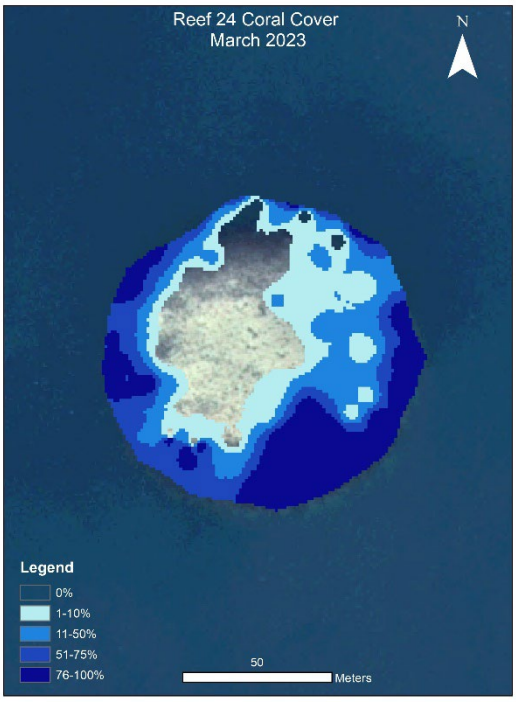
Reef 23

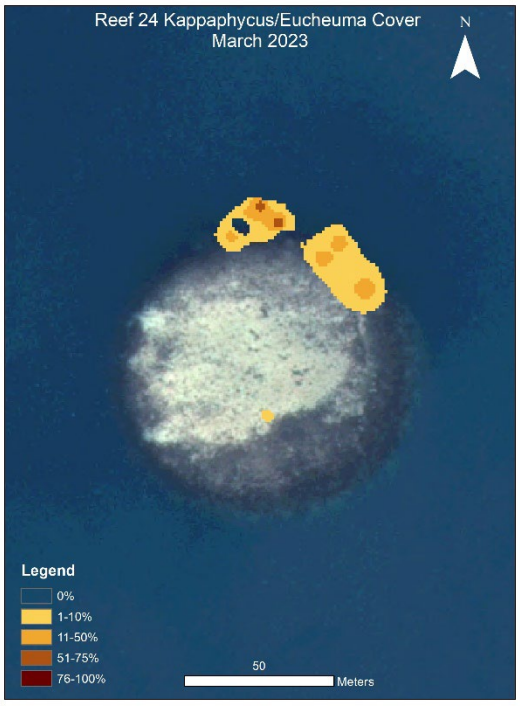

Reef 23 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters

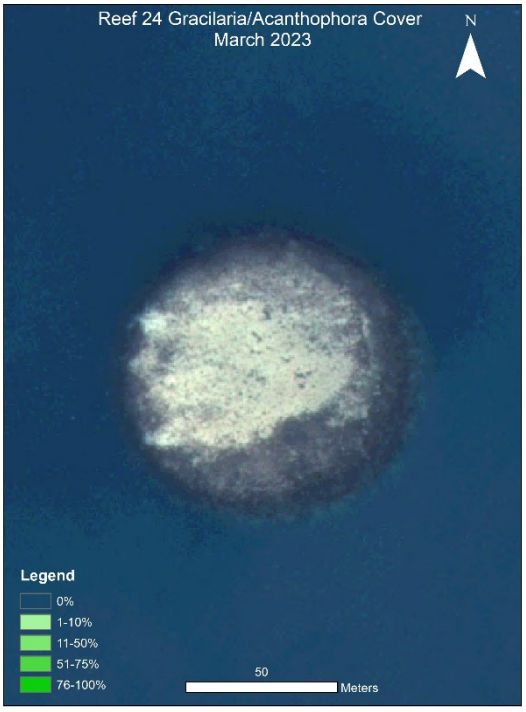

Reef 23 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters


Reef 23 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters

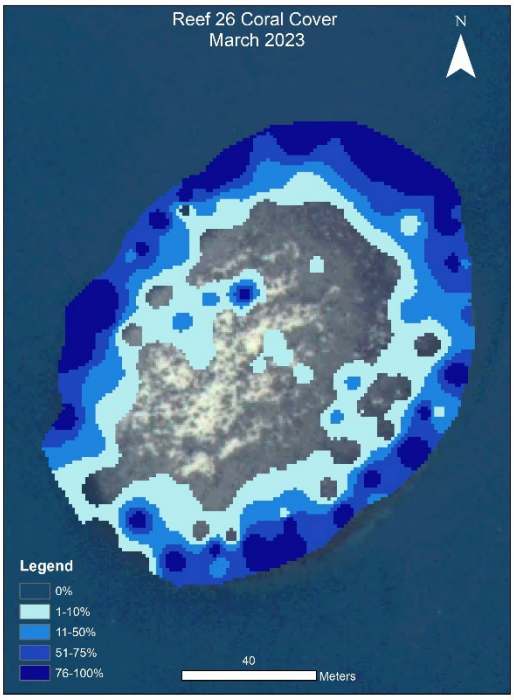
Reef 24

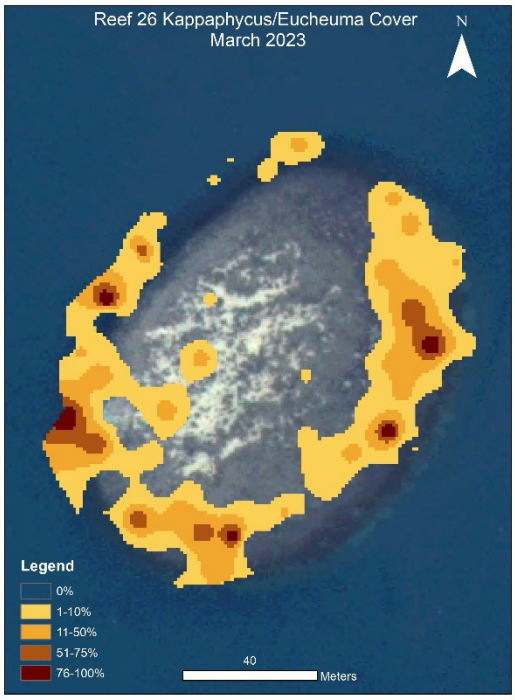

Reef 24 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
50
Meters


Reef 24 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
50
Meters


Reef 24 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
50
Meters

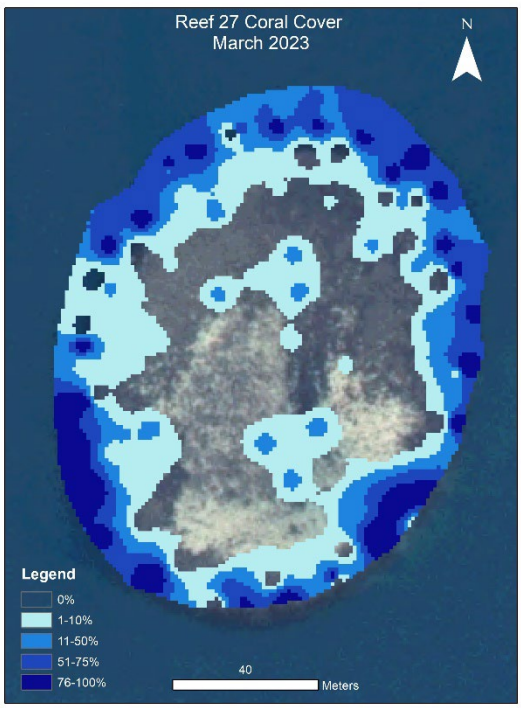
Reef 26

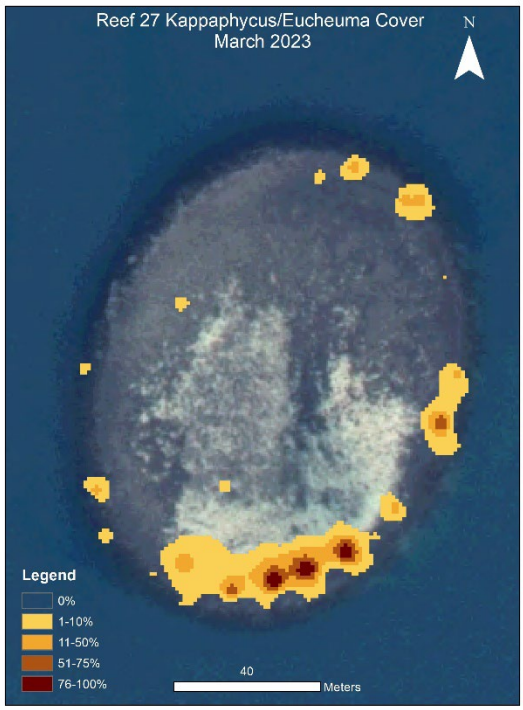

Reef 26 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters


Reef 26 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters


Reef 26 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters

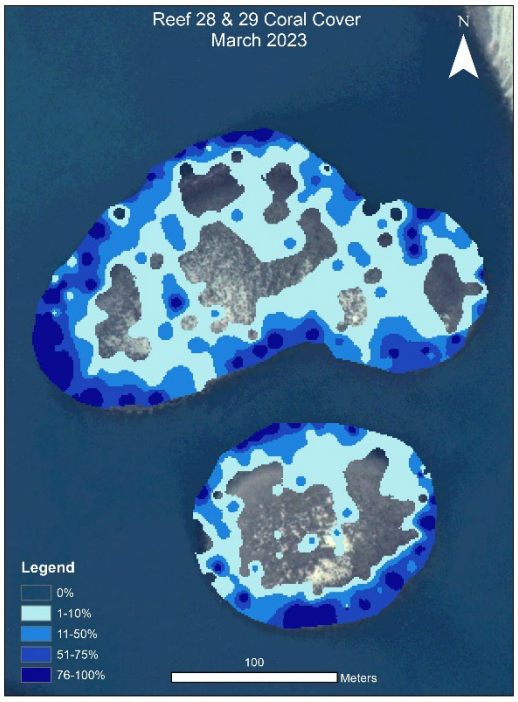
Reef 27


Reef 27 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters


Reef 27 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters


Reef 27 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
40
Meters

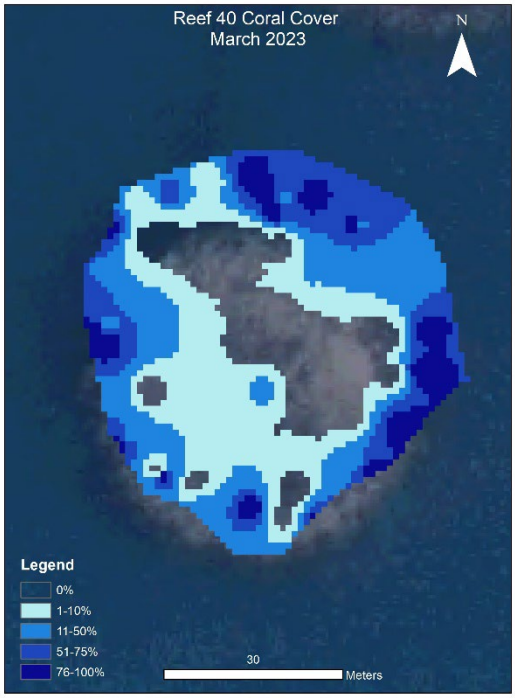
Reef 28 & 29

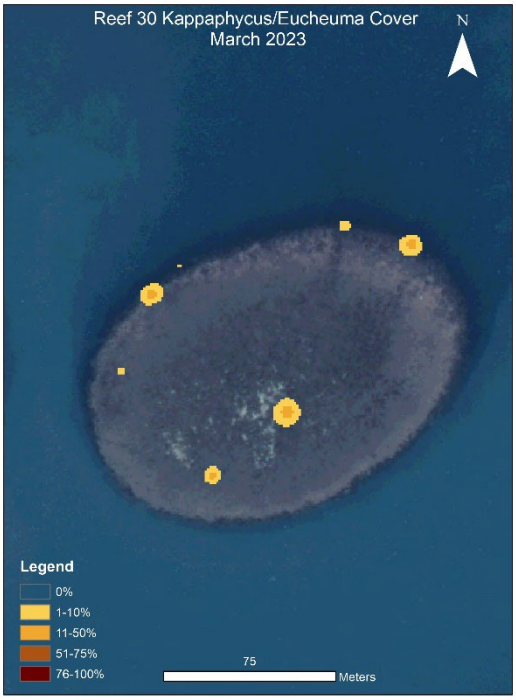

Reef 28 & 29 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
100
Meters


Reef 28 & 29 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
100
Meters


Reef 28 & 29 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
100
Meters

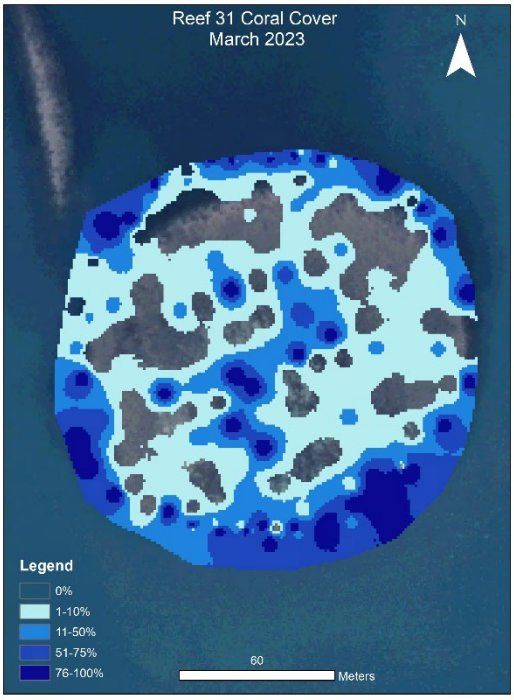
Reef 30

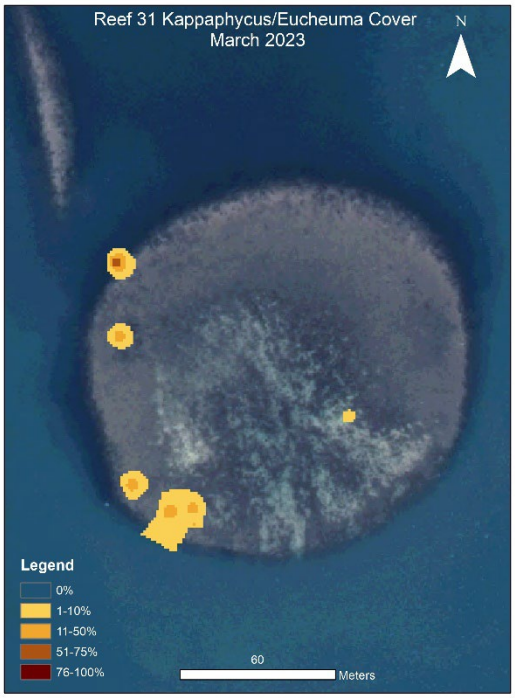

Reef 40 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters


Reef 30 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters


Reef 30 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters

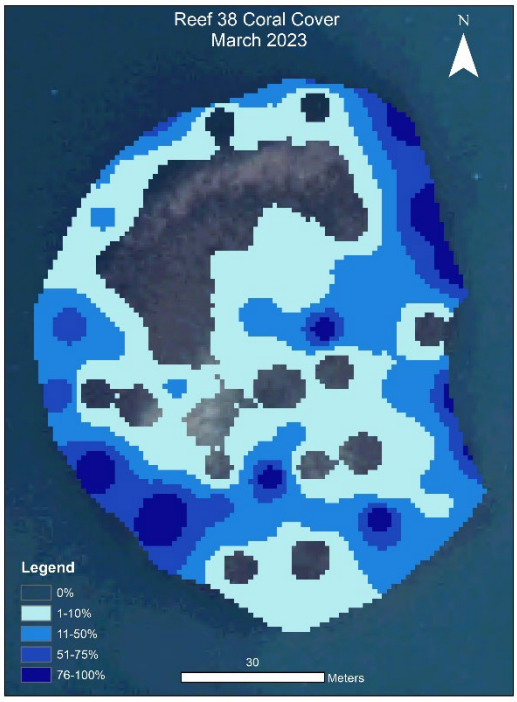
Reef 31

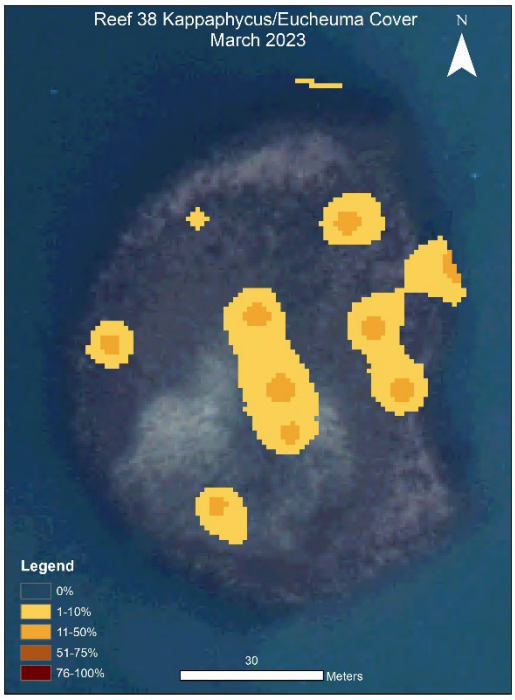

Reef 31 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
60
Meters


Reef 31 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
60
Meters


Reef 31 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
60
Meters

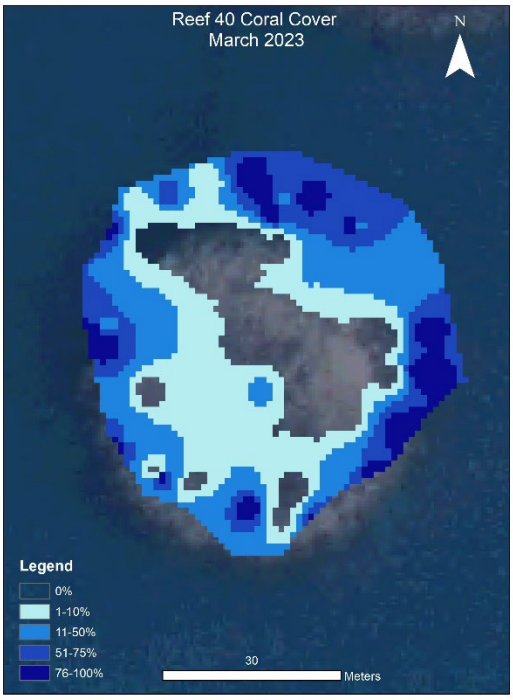
Reef 38

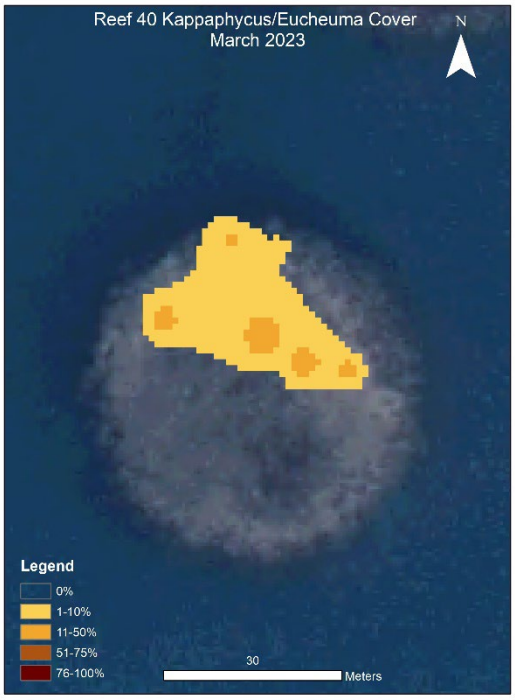

Reef 38 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters


Reef 38 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters


Reef 38 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters

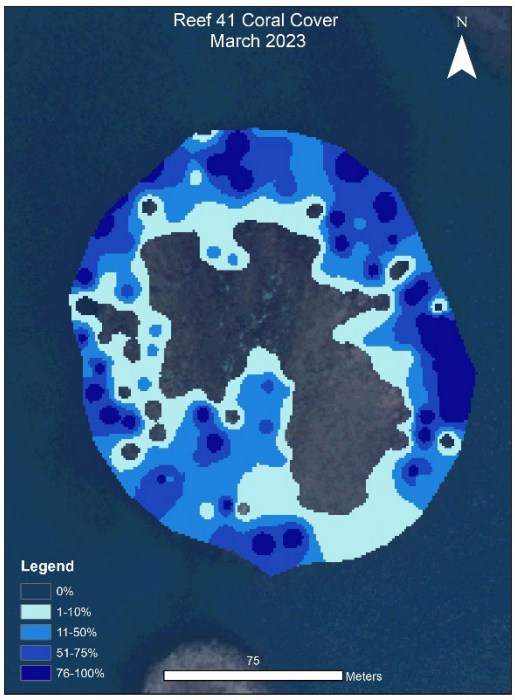
Reef 40

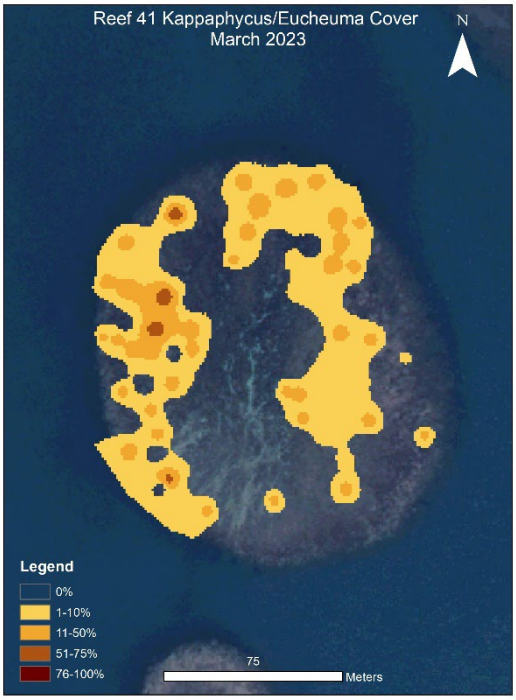

Reef 40 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters

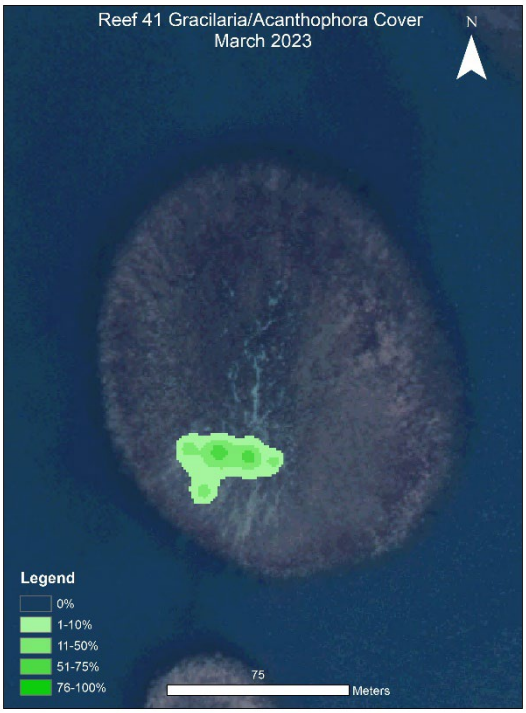

Reef 40 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters


Reef 40 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
30
Meters

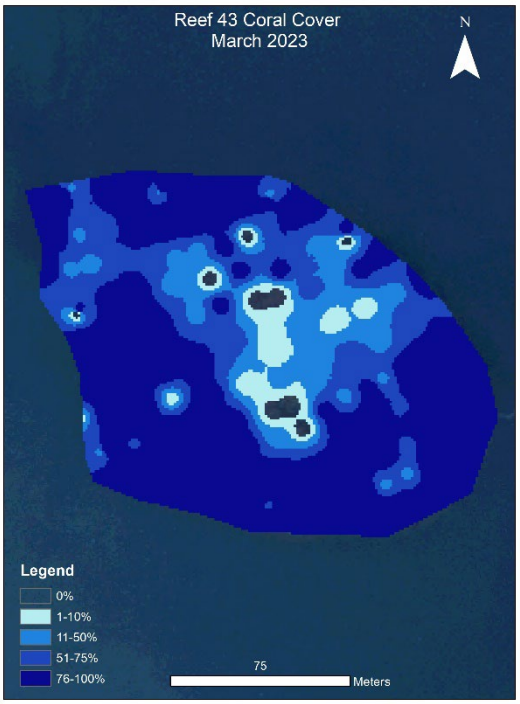
Reef 41


Reef 41 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters


Reef 41 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters


Reef 41 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters

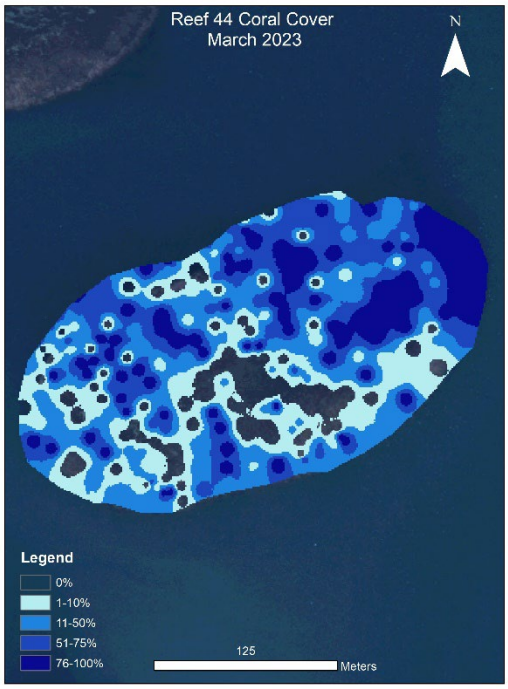
Reef 43

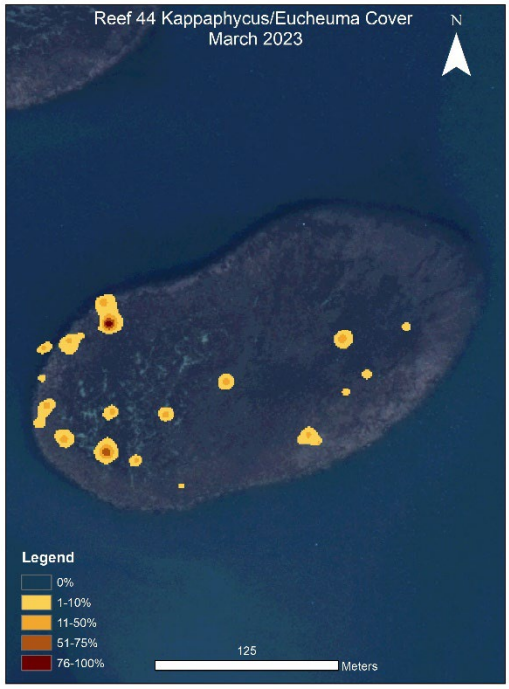

Reef 43 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters


Reef 43 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters


Reef 43 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
75
Meters

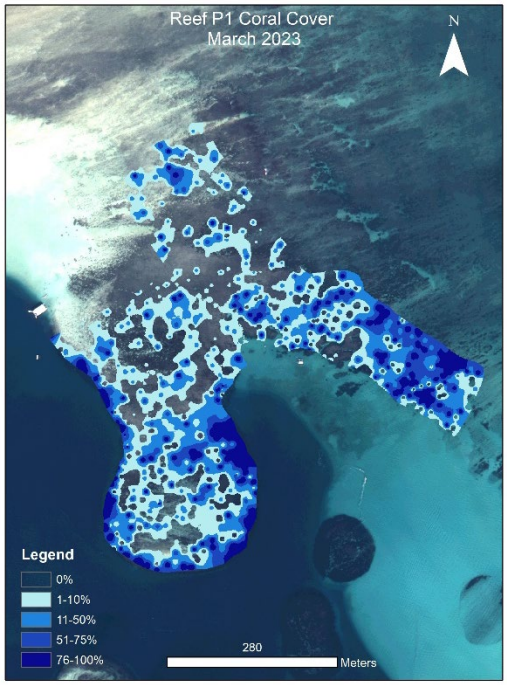
Reef 44

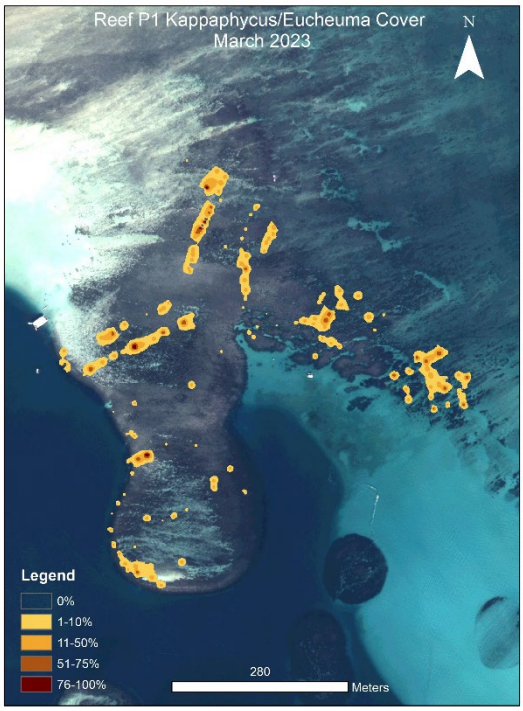

Reef 44 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
125
Meters


Reef 44 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
125
Meters


Reef 44 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
125
Meters

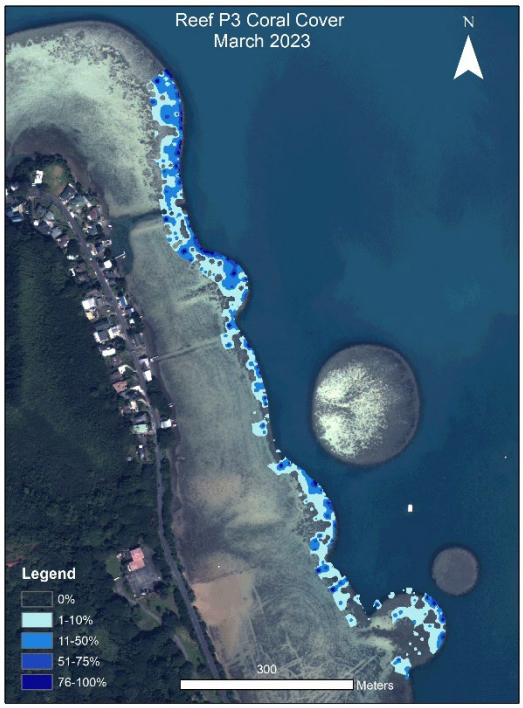
Reef P1


Reef P1 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
280
Meters


Reef P1 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
280
Meters


Reef P1 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
280
Meters

Reef P3


Reef P3 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
300
Meters


Reef P3 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
300
Meters


Reef P3 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
300
Meters

Reef P5


Reef P5 Coral Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
150


Reef P5 Kappaphycus/Eucheuma Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
150


Reef P5 Gracilaria/Acanthophora Cover
March 2023
N
Legend
0%
1-10%
11-50%
51-75%
76-100%
150

Appendix B: Monitoring Plan

DEPARTMENT OF LAND AND NATURAL RESOURCES (DLNR)
DIVISION OF AQUATIC RESOURCES (DAR)

Cape Flattery Settlement Restoration Project: Restoring Reefs in Kāneʻohe Bay

Monitoring Plan

Aquatic Invasive Species Team

Division of Aquatic Resources

Updated: Dec 2022

Contents

Project Funding

This monitoring plan is part of restoration work outlined in the settlement to offset the impacts to coral damaged by the Cape Flattery ship grounding event.

Goals and Restoration Objectives

Goals

1. To aid in the regrowth and colonization of coral colonies and other native coral reef organisms on select reef areas in Kāne'ohe Bay
2. To protect unaffected coral reef habitat in Kāne'ohe Bay

Original restoration objectives

1. Clear and maintain over 25 acres of invasive algae to levels less than 5% cover
2. Protect against the spread of invasive algae to unaffected reef areas

Project Site Description

Restoration area

Primary restoration goals have since been expanded and from managing 25 acres of invasive algae to approximately 232 acres of reef affected by invasive algae. Flattery restoration efforts are currently focused on 19 distinct reefs and 3 fringing reefs within Kāne'ohe Bay, O'ahu totaling 938,438 m^2 (232 acres) of reef area (Fig. 1). Reefs in Kāne'ohe Bay have abundant coral reef habitat composed of a diverse array of coral species including: *Montipora capitata, Montipora patula, Montipora flabellata, Porites compressa, Porites lobata, Pocillopora damicornis, Pocillopora meandrina, Lobactis scutaria,* and *Pavona varians.* These corals compete for space with four species of invasive algae (*Eucheuma* spp., *Kappaphycus* spp., *Gracilaria salicornia, and Acanthophora spicifera*) that can overgrow and kill coral colonies. *Eucheuma* spp. and *Kappaphycus* spp. (E/K) are the primary target of Flattery restoration efforts in Kāne'ohe Bay and are hereafter referred to "invasive algae".

Figure 1. Flattery restoration area in Kāne'ohe Bay.

Restoration site selection

The area known as Marker 12 is the priority site as deemed by the project trustees. This reef's high coral cover, high density of invasive algae, proximity to unaffected coral reefs, and importance as a break for reducing the northern spread of invasive algae[1,2] made it a clear choice as the main restoration site. Additionally, the northern area of Kāneʻohe Bay is of particular interest for restoration efforts because there are ongoing restoration activities in central Kāneʻohe Bay to prevent spread of the algae outside of the Bay.

Outside of Marker 12, small patch reefs are preferred for restoration because they require far less urchins to meet management targets, particularly when urchin supply from the hatchery is limited. Eleven reefs were initially selected for restoration based on their size, percent cover of live coral, and percent cover of invasive algae as determined in 2014 baseline assessments[3]. Patch reefs 20, 23, 24, 28, 30, 31, 38, 40, 41, 43, and 44 were identified as ecologically suitable restoration sites due to the threat of invasive algae to coral resources. Reducing invasive algal cover allows corals to regrow where partial mortality has occurred and allows for potential recolonization of previously occupied habitats. An additional eleven reefs (reefs 9, 14, 15, 16, 26, 27, 29, and 3 fringing reef areas) were added after invasive algal cover on the initial 12 reefs were reduced to below 5% cover bringing the total to 22 managed reefs. Additional reefs may be added as restoration progresses.

Restoration methods

The Flattery restoration strategy was altered following a dramatic reduction in the invasive algae cover in Kāneʻohe Bay in 2015 – 2016. This shift triggered a revision of our restoration methods, monitoring metrics, and location of the restoration activities. Previously, our work plan was exclusive to Marker 12 using a combination of the Super Sucker, an underwater vacuum used to remove invasive algae from the reef (Appendix 1), and biocontrol using native sea urchins (*Tripneustes gratilla*). Currently, the Super Sucker is an inefficient management tool due to relatively low algal cover and its patchy distribution. Therefore, current management efforts focus solely on urchin biocontrol to maintain invasive algae in its current state. The project was expanded to additional reef locations to maintain the restoration acreage goal and take advantage of the low algal cover. If the algal cover increases to the point where the Super Sucker is deemed necessary to prevent significant coral overgrowth; we will restart using this management tool.

DLNR invasive algae biocontrol is supported by aquaculture of native Hawaiʻian collector urchins at the DAR Urchin Hatchery. Broodstock urchins are collected from the wild and spawned to produce larvae

[1] Rodgers S and Cox E. 1999. The distribution of the introduced rhodophytes *Kappaphycus alvarizii, Kappaphycus striatum* and *Gracilaria salicornia* in relation to various physical and biological factors in Kāneʻohe Bay, Oʻahu, Hawai'i. Pacific Science 53: 232-241.

[2] Conklin E and Smith C. 2005. Abundance and spread of the invasive red algae, *Kappaphycus spp*, in Kāneʻohe Bay, Hawai'i and an experimental assessment of management options. Biological Invasions 7: 1029-1039.

[3] University of Hawaiʻi, Social Science Research Institute (SSRI). 2014. SNAP-Assessment Report. Prepared for Department of Land and Natural Resources, Division of Aquatic Resources. Honolulu, HI: Neilson, B., G. Gewecke, B. Stubbs, K. Tejchma.

that can then settle and be raised to outplant size (~15mm test diameter). Previously established biocontrol procedures are followed in the collection, culture, and release of sea-urchins to minimize the risk of disease transmission within the hatchery. Urchins are then outplanted to managed reefs where invasive algal cover is relatively high as determined by annual SNAP surveys. Outplanted urchins are effective in grazing invasive algae to prevent regrowth over time, particularly in habitats where invasive algae grow between coral fingers and in reef crevices.

Monitoring Plan and Methods

Management plan actions implemented

A management plan tracker is used to document the accomplishment of milestones outlined in the *Reef Restoration Work Plan for Kāneʻohe Bay, Oʻahu*. Progress will be tracked in a table (Table 1) that indicates the team member responsible for each action, the timeframe for the action, progress that has been made, associated specific accomplishments, and notes.

Table 1. Sample management plan tracker for the Reef Restoration Work Plan for Kāneʻohe Bay, Oʻahu

Action	Who is responsible	Timeframe	Progress	Accomplishments	Notes
Conduct baseline monitoring surveys.					
Prioritize reef restoration efforts					
Outplant native sea urchins to restoration area.					
Bi-annual reporting to the Cape Flattery trustee council					
Follow-up monitoring of coral and algae conducted annually					
Maintenance of outplanted urchins					
Identification of and continuation on future priority reefs					

Coral and invasive algal cover

The project characterizes changes in coral and invasive algal cover on managed reefs in Kāne'ohe Bay using SNAP surveys (methods detailed below). Metrics for changes in benthic habitat are percent cover, density, and distribution of coral and invasive algae.

SNAP and presence/absence assessments

Maps of coral and invasive algal cover are created annually by conducting a snapshot, or SNAP survey for each reef. These maps are used to pinpoint hotspots of invasive algae that coincide with high coral cover to target for urchin biocontrol. The SNAP assessments from 2020-2021 were conducted annually on ten treatment reefs (Reefs 9, 14, 15, 16, 20, 23, 30, 40, 41, and Marker 12). The reefs were selected based on 2019 survey data comparing interpolated coral cover w/ interpolated algae cover as well as spatial distribution of reefs throughout the bay (Fig. 2). Prior to 2022, surveys on the remaining restoration reefs were abbreviated, only noting presence/absence of algae (Appendix 2). From 2022 onwards, all 22 managed reefs will be surveyed using the SNAP survey methodology because it a.) provides higher resolution data for invasive algal cover and distribution through time and b.) is not time prohibitive as was previously determined.

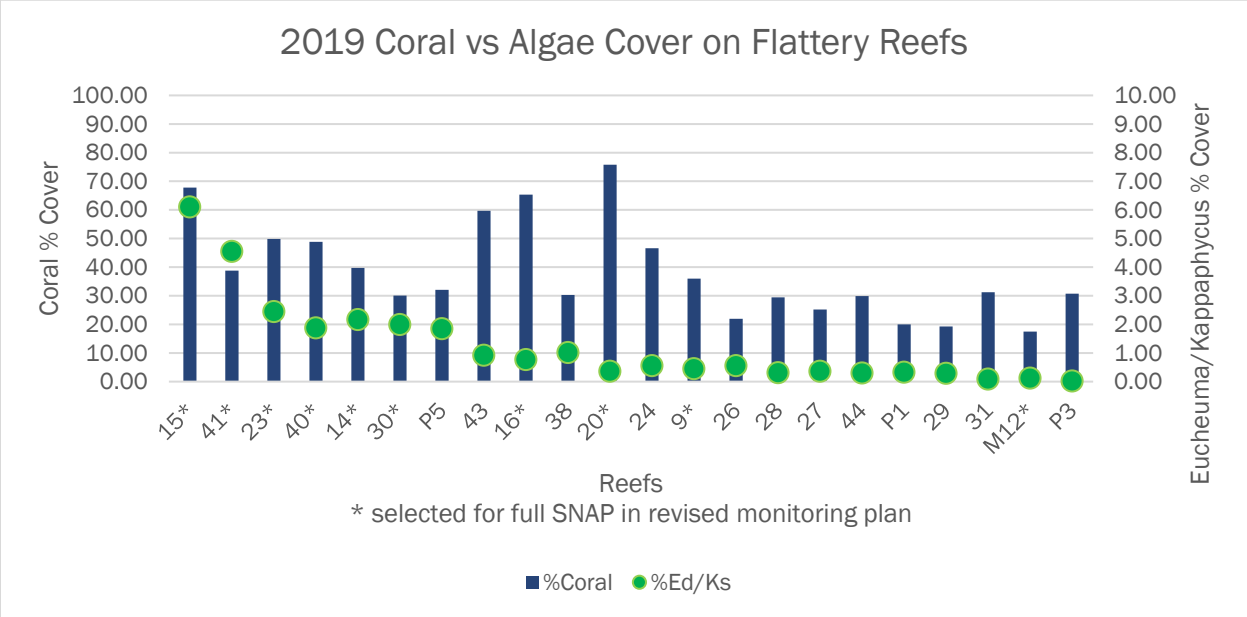


Figure 2. Coral and Eucheuma/Kappaphycus (E/K) on restoration reefs

SNAP survey methods

Surveyors spaced approximately 5-10 m apart, swim transects across the reef and randomly place a 0.5 meter measuring stick (SNAP stick) every 5-10 meters (Figure 3). Surveyors swim multiple passes across the reef to sample the reef's flat, crest and slope to depths of ≤ 3 meters. Surveyors make every attempt

to avoid bias by haphazardly selecting survey points by tossing the stick at regular intervals and not looking at the reef bottom when tossing the survey stick on a point.

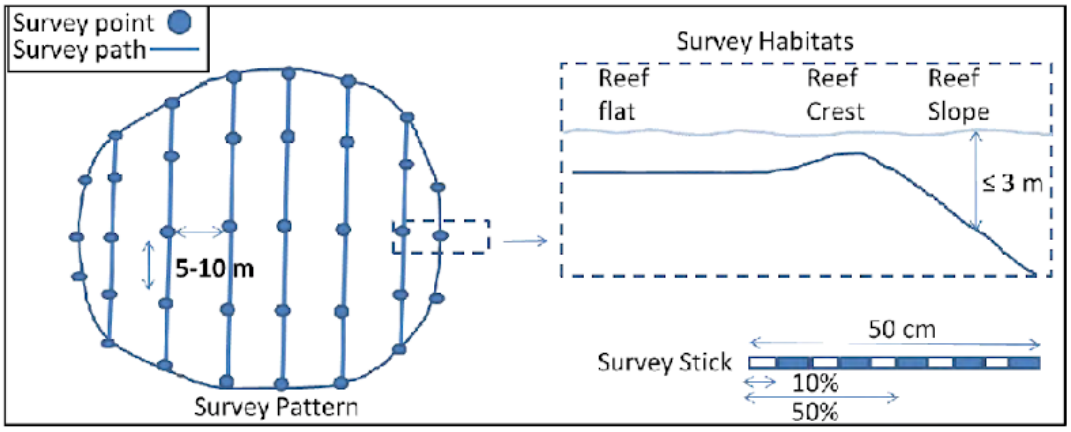


Figure 3. SNAP assessment protocol for measuring density and distribution of live coral and invasive algae

At each survey point, a waypoint is taken using a GPS, the habitat (slope, crest, and flat) and percent cover (live coral, *Eucheuma/Kappaphycus, and Gracilaria/Acanthophora*) are estimated based on the benthic composition below the SNAP stick. Invasive algae were grouped into two categories: 1) *Eucheuma* and *Kappaphycus* and 2) *Gracilaria* and *Acanthophora* (composed of *Gracilaria salicornia* and *Acanthophora spicifera*).

The SNAP stick is partitioned into ten, five-centimeter increments. Coral and algae data is categorized into five separate cover classes delineated across the stick (Table 3).

Table 2. Cover classification for the SNAP assessment

Percent Cover	Cover Code
0%	0
1-10%	1
11-50%	2
51-75%	3
76 – 100%	4

Data management and mapping

GPS points from SNAP surveys are downloaded and matched with SNAP coral, invasive algae, and substrate data. The resulting dataset is checked for errors, compiled in an MS Excel spreadsheet, and imported into ArcGIS. Coral, *Eucheuma/Kappaphycus*, and *Gracilaria/Acanthophora* are mapped using ArcGIS software for each reef. Interpolated raster coverage maps of the reef are created using the ArcGIS inverse distance weighting (IDW) tool, which averages each 1 m^2 pixel based on the 12 closest surrounding survey data points. Once completed, all data are archived on the AIS Google Drive.

Urchin production and biocontrol

The Flattery project also tracks the number of sea urchins that have been raised in the DAR urchin hatchery and released to the treatment area. From the urchin aquaculture process, the project tracks both food production and urchin larval production (Table 3). Food production includes both the liters phytoplankton grown for urchin larvae and kilograms of macroalgae grown for juvenile urchins. Three phases of the urchin grow-out process are tracked: number of urchins spawned, number of the resulting larvae moved into the settlement phase to grow out into juvenile urchins, and number of urchins originating from the hatchery that are released in the restoration area. Urchin outplants are logged including the reefs where urchins were deployed, number of urchins released, and reef area treated (Table 4). Urchins are outplanted at a target density 2-4 urchins/m^2 of *Eucheuma/Kappaphycus* on managed reefs.

Table 3. Sample urchin hatchery monitoring metrics

	food production		urchin production		
Date	**phytoplankton produced (L)**	**macroalgae produced (Kg)**	**urchins spawned**	**larvae moved into settlement/grow out phase**	**hatchery urchins outplanted**
Totals					

Table 4. Sample urchin release tracker

Date	**Urchin source**	**Reef Number**	**Number of Urchins Released**	**Area treated (m^2)**

Totals				

Monitoring Frequency and Schedule

Monitoring Frequency:

	Frequency	
Monitoring Metric	**Measurements**	**Reporting**
1. Management plan actions implemented	Monthly	Annually
2. Coral and invasive algal cover	Annually	Annually
3. Urchin production and biocontrol	Production = Monthly Number Released = After each urchin release	Production = Annually Number Released = Annually

Monitoring Schedule:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Management plan actions implemented	Report											
Coral and invasive algal cover	Report		X									
Urchin production and biocontrol	Report	X	X	X	X	X	X	X	X	X	X	X

Data Sharing Plan

The Reef Restoration for Kāneʻohe Bay Project, implemented by the Department of Land and Natural Resources (DLNR), Division of Aquatic Resources (DAR) will generate environmental data and information, including benthic habitat maps, percent cover calculations of coral and algae, number and density of urchins released. Datasets will provide specifics on information collected and collection dates. Data will be collected by DAR staff according to the procedures described in project monitoring plan and stored at the DAR Anuenue Fisheries Research Center (AFRC) on a shared server, with data back-ups on an external hard drive and on a laptop computer. Contact Kim Fuller, DAR Aquatic Biologist, kimberly.h.fuller@Hawaiʻi.gov, for more information or to make a data request. All future sub-recipients

not identified in this plan will have as a condition of their contract acceptance of this data sharing plan. Any additional data sharing stipulations for future sub-recipients may be outlined at that time and described in their contract.

Appendix C: Reef Reprioritization Tool

Flattery Reprioritization Scoring System

Updated: 10/19/22

Reef Score Calculations

To reprioritize reefs for urchin outplanting annually, scores are calculated for each reef based on data collected during SNAP surveys from the previous year. These individual reef scores are then ordered in descending order to determine reef priority (1-22). To calculate a score for each reef, coral, E/K, and G/A median percent cover along with reef area values are classified separately as a score of 0-3 (Table 1 in green). This value is then weighted by multiplying by a scaler that reflects management priorities (below in red). This results in a final score for each of the 4 categories that are then summed together to get a total score for each reef. All calculations are done for you when using the "SNAPS%Cover" spreadsheet on the AIS Shared Google Drive. See the example below for a visualization of how scores are calculated:

Table 1: Scoring system and associated scaling factors for each category

Factor	Scaling	0	1	2	3
Coral Cover (%)	× 1.5	0	>0 – <30	30 - <60	60 – 100
E/K Cover (%)	× 2	0	>0 - <2.5	2.5 - <5	≥5
G/A Cover (%)	× 1	0	>0 - <2.5	2.5 - <5	≥5
Reef Area (m^2)	× 1.5	0	>0 - <10,000	10,000 – <50,000	≥50,000

All these scores are summed together to get a score total that can be used for ranking reefs and prioritizing urchin outplant efforts like so:

eg. 25% coral (1 x 1.5 = 1.5) + 3% E/K (2 x 2 = 4) + 2% G/A (1 x 1 =1) + 60,000 m^2 (3 x 1.5 = 4.5) = **11**