Addressing Florida's Reef Restoration Bottlenecks

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Draft Final Report

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MANAGEMENT SUMMARY

Predation by fireworms and snails causes tissue mortality on coral species like *Acropora cervicornis*. We documented increased predator abundance and predation impacts on restoration plots over time. **However, we showed that periodic removal (once per month) of snails (hand collections) and fireworms (trap collections) can reduce predator abundance for extended periods and reduce predation impacts, representing a viable restoration tool to mitigate predation impacts.**

The survivorship of outplanted corals may be enhanced by the deployment of reef grazers like sea urchins to curb macroalgal competition. **We showed that culturing *Diadema* urchins in the lab and growing them to adult size prior to reef deployment can be achieved effectively, providing a steady source of urchins for coral-urchin tandem restoration. To expand the capabilities to raise urchins, we designed and built field urchin pens to expand on existing land-based rearing capabilities.**

Predation by parrotfish is a major restoration bottleneck, causing high tissue mortality. We tested the use of parrotfish grazing blocks aimed at focusing predation onto these blocks and away from outplanted corals. **While predation blocks were successfully designed and deployed, these units did not produce the expected benefit and were not effective at reducing the impacts of fish predation.** Future efforts may expand by testing different block designs as fish predation continues to limit the efficiency of coral restoration.

Finally, we assessed the performance of three attachment materials used for coral outplanting. Performance varied slightly based on substrate (higher on reef vs coral skeleton) and the size of the cement bases (higher for single vs 3-coral bases). **Both cement and epoxy had very high attachment success, while the Seatak glue tested had lower attachment success. We support the continued use of cement and epoxy and suggest the use of smaller, lighter cement bases for enhanced attachment success, especially on coral-skeleton substrates.**

EXECUTIVE SUMMARY

Restoration partners from The University of Miami, NOAA Southeast Fisheries Science Center, and The University of Florida collaborated to address several of Florida's reef restoration research needs and bottlenecks: 1) improving outplanting success, 2) expanding the use, husbandry, and availability of sea urchins for coral-herbivore tandem restoration, 3) and reducing fish and invertebrate predation pressure on outplanted corals.

As the need for herbivore-coral tandem restoration grows, novel methods are needed to expand the capacity to grow urchins both *in situ* and *ex situ*. Underwater rearing pens designed in this project to expand *D. antillarum in-situ* rearing were constructed and deployed. These pens represent a relatively inexpensive, modular design that can be replicated by restoration practitioners throughout Florida to scale up production of urchins and support herbivore restocking efforts. In an effort to increase our knowledge on the use of urchins as a mechanism to enhance outplant survival when in competition with algae, we conducted a grazing assay with the sea urchin *Tripneustes ventricosus* grown in the lab to evaluate its potential for deployment as part of coral-urchin tandem restoration. While challenging to spawn, *T. ventricosus* proved to be an effective *ex-situ* grazer at all density treatments tested, providing another local urchin that may be used for tandem restoration in the future.

Predation by fish on newly outplanted corals has been shown to be a major bottleneck to coral restoration efforts, particularly for massive coral species. Here, we tested the use of fish grazing blocks as a potential method to reduce predation. Grazing blocks made out of a calcium carbonate base mixed with various ingredients (e.g., algae wafers and pellets), were tested as potential fish predation deterrence (focusing the predation by fish predators away from outplanted corals). Tank-based testing revealed that grazing blocks were not able to withstand high flow environments. Moreover, no differences in predation on outplanted corals were seen between the controls and the corals protected by the grazing blocks, indicating that the grazing blocks were not an effective method to mitigate fish predation.

Outplanted corals need to be attached to different substrates on reefs, and attachment efficiency has been identified as a potential restoration bottleneck. Here, we tested different attachment methods and materials to evaluate their performance. Coral attachment success varied by attachment material (cement, epoxy, Seatak) and attachment (reef substrate vs coral skeleton). There was better attachment on the reef substrate compared to coral skeleton across all attachment materials. Cement and Epoxy had higher attachment success compared to Seatak, which is not recommended here as an effective outplant material. Attachment success was highest for corals outplanted on cement bases. Survivorship, largely driven by fish predation, was significantly influenced by species and genotype but not attachment method.

Acropora cervicornis plots with coral colonies of different sizes were outplanted to document predation by fireworms and snails and evaluate predation mitigation methods. Within the *Acropora* plots, the impacts of *Hermodice carunculata* (fireworm) and *Coralliophila*

abbreviata (snails) predation increased over time and were higher on larger coral colonies, with fireworm predation having the biggest impacts. Predator removal was an effective way of reducing the abundance and impacts of fireworm and snails.

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LIST OF ACRONYMS

ACER: *Acropora cervicornis*

CIMAS: Cooperative Institute for Marine and Atmospheric Studies

DLAB: *Diploria labyrinthiformis*

FWC: Florida Fish and Wildlife Conservation

MCAV: *Montastrea cavernosa*

NOAA: National Oceanic and Atmospheric Administration

OFAV: *Orbicella faveolata*

PCLI: *Pseudodiploria clivosa*

PSTR: *Pseudodiploria strigosa*

SAL: Special Activity License

TD: Test diameter

TFA: The Florida Aquarium

UF: University of Florida

UM: University of Miami

1. BACKGROUND AND OBJECTIVES

With the continued decline of coral reef ecosystems, restoration practitioners are shifting their focus to incorporate key reef community components, such as grazers, to improve site conditions and the long-term survivorship of outplanted corals. Active interventions to restore *Diadema antillarum* (urchin) populations have been identified as a crucial reef restoration need, as it could take decades for urchin recovery to occur naturally. As present populations of *D. antillarum* are not sufficient to support large scale translocations, one option for restocking depleted populations is using hatchery-propagated individuals. Here, we expanded the capacity for *D. antillarum* husbandry by spawning, settling, and growing *D. antillarum ex situ*. The urchins were spawned and raised initially by the University of Florida (UF) until juvenile stage. The juvenile urchins were sent to The University of Miami (UM) for raising to adult stage, becoming available for deployment onto restoration reefs. We also completed a lab-based grazing assay to document the ability of lab-raised *Tripneustes ventricosus* sea urchins to evaluate their grazing rates and impacts and potential for deployment as part of coral-urchin tandem restoration

Recent advances in the rearing and propagation of urchins have increased the number of juvenile urchins available for herbivore restoration activities. However, before urchins can be deployed to the reef, they must be grown out to a sufficient size to avoid heavy losses from predation. Beyond the fundamental process of urchin grow-out, basic questions regarding size, density, and best practices for tandem coral-urchin grow-out remain unresolved, impeding our ability to effectively implement these restoration interventions. Thus, we built and deployed prototype modular units designed to facilitate *in situ* urchin grow-out and restoration-focused experimentation. These units were designed such that they can easily be replicated at additional locations throughout south Florida and the Caribbean.

Predation by *Hermodice carunculata* (fireworms) and *Coralliophila abbreviata* (snails) poses a threat to coral health and hinders the success of reef restoration. Acroporid corals, especially older and larger colonies, have been observed anecdotally to be very susceptible to predation. Our manipulative experiment quantified predator abundance and impacts on *A. cervicornis* outplants. These results inform the optimal strategy for increasing survivorship after outplanting in areas where predation by snails and fireworms is prevalent to make science-based recommendations for predator removal needs and interventions.

Predation by parrotfish has emerged as a major impediment to efforts aimed at restoring massive species of corals to Florida's reefs, particularly in places like Miami-Dade County. Despite several years of research to understand why particular locations, species, and genotypes result in higher predation rates, we still do not understand the drivers of predation on these outplanted corals. Addressing this knowledge gap, i.e., understanding why some corals are preferentially targeted over others, will allow us to better design restoration approaches that minimize coral loss and thus can make restoration more efficient. We tested and developed a novel restoration tool, parrotfish grazing blocks, as a tool to facilitate effective predator deterrent strategies, assist with coral outplant site selection, and better understand drivers of coral predation. These grazing blocks were hypothesized to focus fish bites away from newly outplanted corals. Moreover, the development of this tool would allow us to assess predation levels at sites without sacrificing any corals and

enhance our ability to mitigate coral predation, a fundamental bottleneck for outplanted corals on Florida's reefs.

Small coral outplants have encountered survivorship and growth bottlenecks due to impacts from algal competition and sediment accumulation. To enhance early outplant survivorship, explore the use of cement bases that raise the corals off the substrate to evaluate the role of cement bases in enhancing outplant performance. In addition, we compared the performance of three attachment materials (cement, epoxy, and a newly available glue called Seatak) on the attachment performance using bases (single corals and 3-coral clusters) deployed on the reef substrate and on dead coral skeletons.

These objectives were designed to fill specific research and restoration gaps that have become restoration bottlenecks as identified by the Florida's Coral Reef Resilience Program's (FCRRP) Ecosystem Restoration working group. These projects focused on three main themes: (1) enhancing outplant success via herbivory and substrate type, (2) improving strategies to produce and rear herbivores prioritized for restoration, and (3) documenting and reducing impacts of predation on outplanted corals. All of the activities (nursery and reef) were completed at Paradise Reef (25.659° N, 80.097° W, depth 6-8 m). Husbandry of urchins was completed at UF, The Florida Aquarium (TFA), and at UM.

2. Task 2. CORAL-URCHIN TANDEM RESTORATION

2.1 Objectives

Expand tandem urchin-*Acropora* restoration to improve urchin retention and document potential grazing benefits to coral survivorship.

2.2 Methods

On July 1st, 2024, *Acropora* restoration plots (n = 4) were deployed at 5 m from each other in a square array at Paradise reef. Plots were divided into 36 quadrats, and each quadrat (1 m^2), spaced 1-2 m apart, received nine corals of each size class in a 3 x 3 array. Size classes were small (single branch), medium (30-40 cm total linear extension (TLE)), or large (> 50 cm TLE) colonies, equally spaced within the quadrat (Fig 1). In addition to the staghorn corals, we outplanted 5 fragments (3-4 cm in diameter) of *Pseudodiploria strigosa* (PSTR), *Pseudodiploria clivosa* (PCLI), *Diploria labyrinthiformis* (DLAB), *Orbicella faveolata* (OFAV), and *Montastraea cavernosa* (MCAV) within each quadrat (Figure 1). Six control quadrats without any outplanted corals were marked using a center stake in the area between the plots. Each quadrat was tagged using plastic tags and nails.

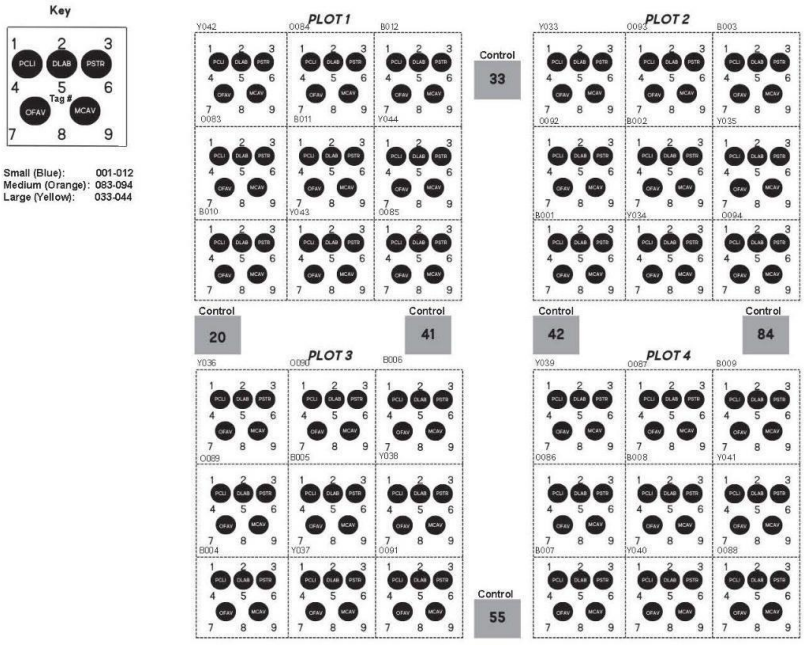

Figure 1. Schematic of the *Acropora* plot design to be used to assess the role of *Acropora cervicornis* size on *Diadema antillarum* retention and macroalgae grazing dynamics.

D. antillarum juveniles were transferred from the UF to the UM on October 15th, 2024. We received 450 urchins ranging from 3 mm – 12 mm in test diameter (TD). During this project we documented all that it takes to rear urchins to restocking size. Biweekly (twice a week) each tank was siphoned to remove any waste material (excess food, or fecal pellets), fed fresh macroalgae, and health checks were completed to look for any signs of tissue loss or spine shedding. If urchins appeared sick, they were treated with 100 ppm oxytetracycline baths, for one hour every other day for one week. Every week water quality was monitored to make sure they fell within normal parameters. Monthly a subset of 25 urchins per tank were measured, to track urchin development and growth. Urchin test diameters (TD) were measured to the nearest 0.1 mm using long-jawed calipers or a bin with a ruler underneath.

Urchins were fed *Agardhiella subulata, Gracilaria spp*., or *Ulva* purchased from The National Resource of Aplysia at UM (Figure 2).

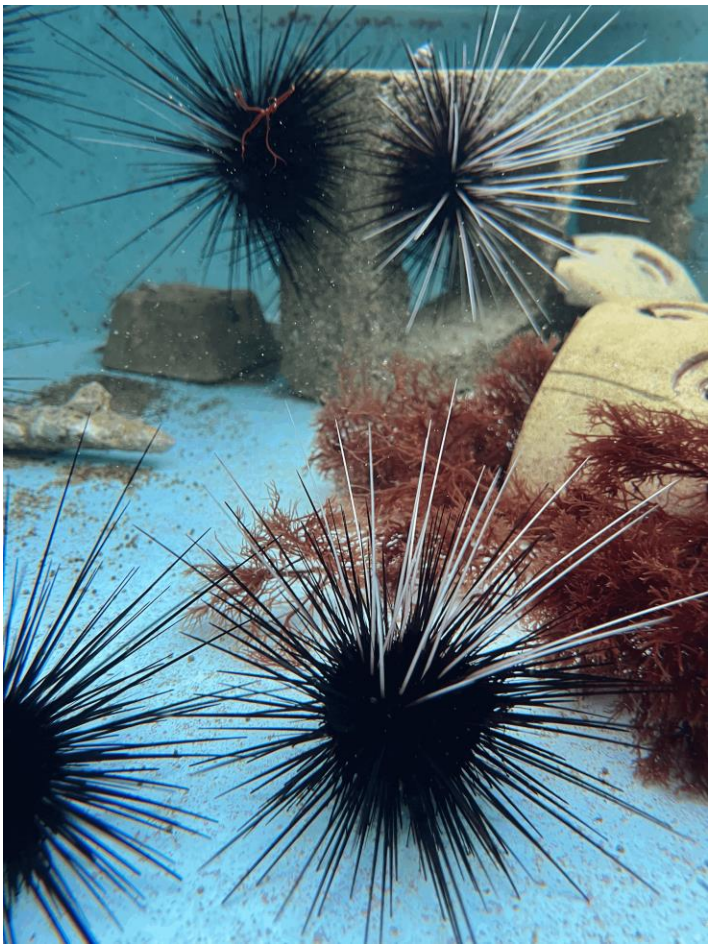

Figure 2. *Diadema antillarum* grazing on *Agardhiella subulata.*

2.3 Results

While at UM, *D. antillarum* grew 7.2 mm over eight months, with the average TD being 30.1 ∓ 4.9, on June 3rd, 2025 (Figure 3). As a consequence of our Florida Fish and Wildlife Conservation Commission (FWC) Special Activities License (SAL) not getting issued in a timely manner, *D. antillarum* held in our land-based lab were not released into the *A. cervicornis* plots.

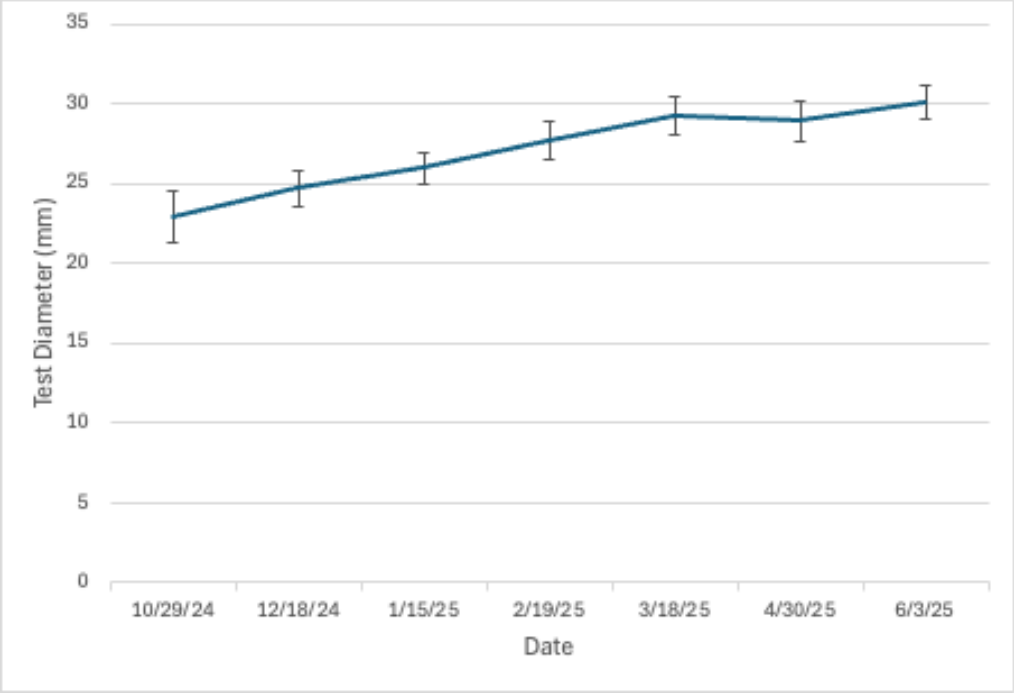

Figure 3. The test diameter (mm) ± SE of *Diadema antillarum* at UM land-based facilities.

2.4 Discussion

Delays beyond our control in securing the FWC SAL for *Diadema* work prevented us from the completion of tasks that included urchin deployments. As a consequence of not obtaining the SAL we instead focused our efforts on documenting all the time and effort it takes to rear and maintain *D. antillarum* in land-based systems for future tandem restoration efforts. We were able to document that all of the required steps (spawning, rearing larvae, transferring juveniles among partners, growing urchins in the lab to adult size) have been developed successfully and that *Diadema* can be effectively reared for urchin-coral tandem restoration at meaningful scales once permits for deployment have been secured. While successful, it is important to note that rearing urchins for deployment is a time-consuming and labor-intensive undertaking. The grow-out period is especially time-consuming as urchin tanks need to be maintained (water quality checks, feeding, cleaning) and sufficient tank space needs to be available to avoid overcrowding and disease outbreaks. Future studies should focus on determining the optimal size of urchins for reef deployment that minimizes time in the lab and maximizes retention success at restoration plots to maximize the cost-benefit of growing urchins for tandem restoration.

3. Task 3. PREDATOR IMPACTS ON *ACROPORA* OUTPLANTS

3.1 Objectives

Evaluate the role of colony size and predator removal, *H. carunculata* (fireworms) and *C. abbreviata* (snails), on the survivorship of *A. cervicornis* outplants (Figure 4).

Figure 4. Photographs of *Hermodice carunculata* (A, fireworm) and *Coralliophila abbreviata* (B, snail) predation on *Acropora cervicornis* colonies.

3.2 Methods

Two *A. cervicornis* restoration sites were established at Paradise Reef (Site 1 = 25.640° N, 80.095° W, depth = 25ft; Site 2 = 25.64471° N, 80.09608° W) to evaluate the role of coral colony size on predator recruitment and impacts, as well as the potential benefit of predator culling on mitigating predation impacts. The *Acropora* restoration plots were set up as described above in Task 2. Two of the plots at each site served as predation controls (without removal) while the other two plots (Plots 3 and 4) were used as experimental plots where predators (worms and snails) were removed every 4 weeks. To complete these removals, traps were constructed of PVC and baited with frozen squid (Bowden-Kerby, 2014). One trap was deployed at the center of each quadrat within the removal plots at each site (Figure 5). Traps were deployed at the beginning of the dive day and retrieved during the last dive. Before the traps were collected, divers conducted surveys to assess percent tissue mortality of the *A. cervicornis,* noted signs of predation, presence of fireworms and snails, and recorded the trap number in each of the removal quadrats. Traps were brought back to land and the quantity of fireworms per trap were recorded.

Figure 5. Images of the different *Acropora cervicornis* size-class quadrats: small (A), medium with a fireworm trap (B), and large (C) colonies.

3.3 Results

The impacts of fireworm and snail predation increased over time at both sites, with fireworm predation having the biggest impacts. At Site 1, fireworm predation occurrence (i.e., percentage of colonies showing signs of predation) increased from 6.7% of colonies one month after deployment to 46.4% by February 2025. Snail predation occurrence at Site 1 followed a similar but less pronounced trend, increasing from 4.9% to 20.3% over the same period. At Site 2, fireworm predation occurrence increased from 9.3% of colonies at initial surveys to 35.9% by February 2025, while snail predation increased from 6.2% to 18.6% over the same period.

Snail removal was an effective way of keeping the abundance (and impacts) of snails low (Figure 6). In control plots, a larger number of snails were found on large colonies compared to medium and small ACER colonies. In contrast, fireworms were more abundant on removal plots compared to controls, likely due to the presence of bait within traps which may have attracted a higher number of worms to the quadrats.

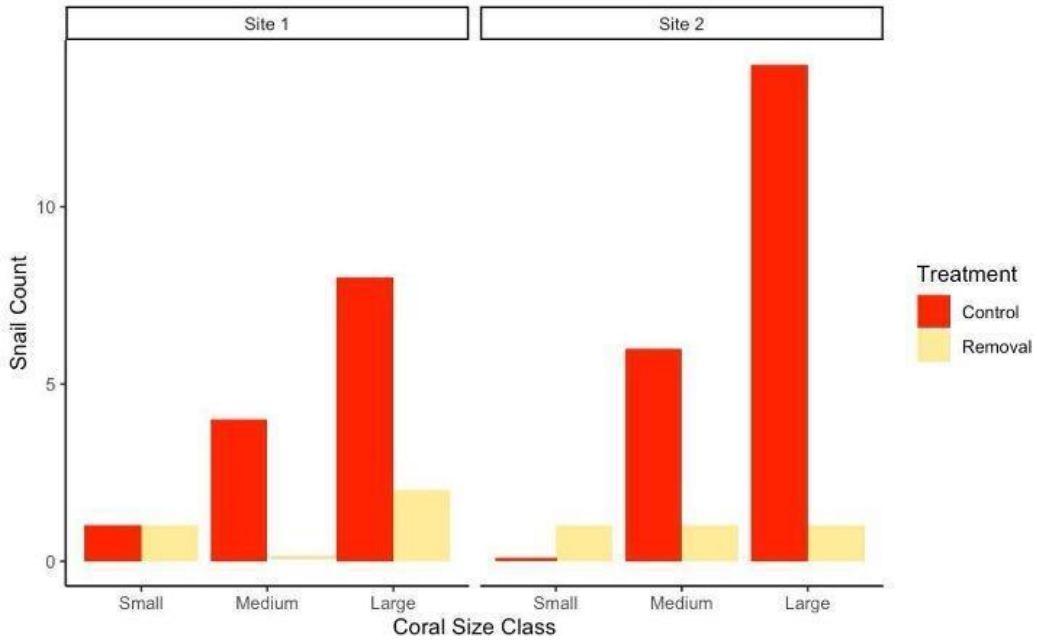

Figure 6. Cumulative number of *Coralliophila abbreviata* (snails) observed within control and removal plots separated by both sites and coral size class (small, medium, large) at the end of the experiment.

The removal of predators mitigated predation impacts. The proportion of colonies affected by fireworm and snail predation was lower in removal plots compared to control plots, with the biggest differences in predation occurrence due to removal were observed for fireworm predation (Figure 7).

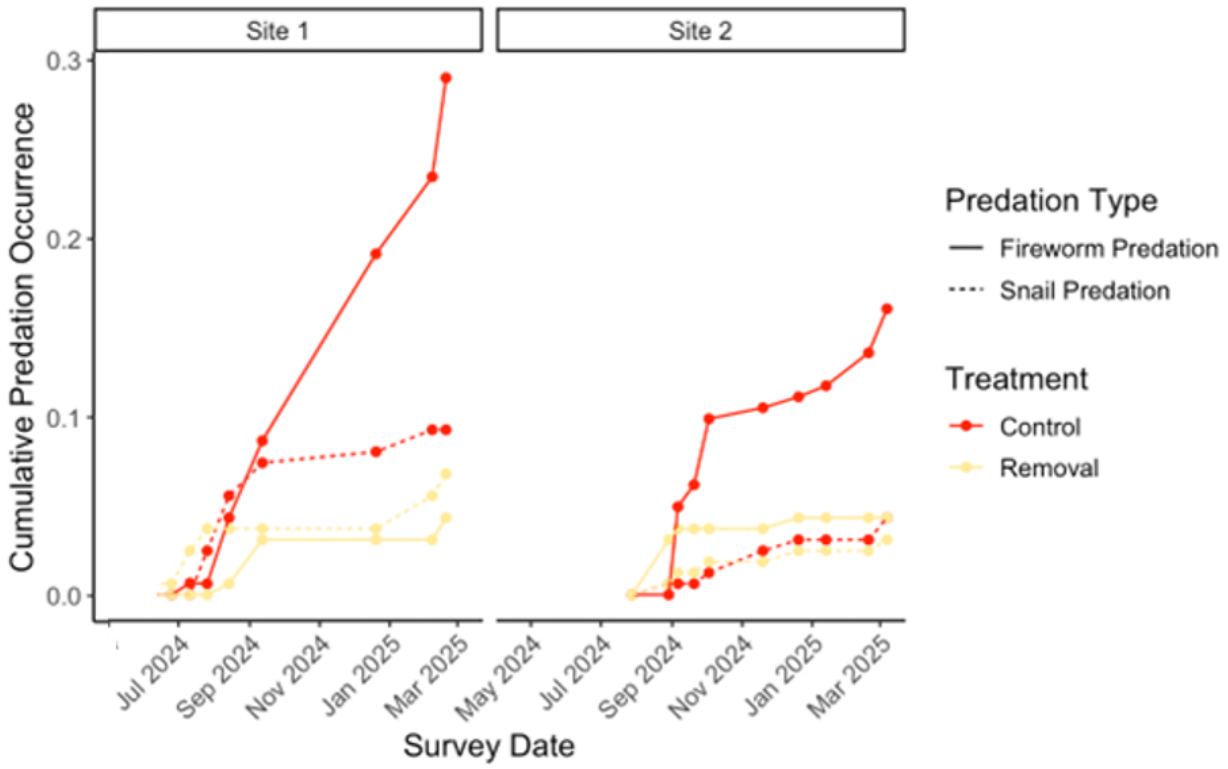

Figure 7. Cumulative predation occurrence caused by fireworms and snails on *Acropora cervicornis* colonies over time in control and removal plots at two restoration sites.

At both sites, colonies of all sizes in control quadrats experienced greater predation intensity (e.g., % tissue removed by predators) by fireworms compared to colonies within removal quadrats (ANOVA, $p < 0.0001$). In addition, smaller colonies experienced significantly higher predation intensity by fireworms compared to medium and large colonies ($p < 0.0001$). In contrast, predation intensity by snails did not vary significantly based on colony size ($p > 0.05$, Figure 8).

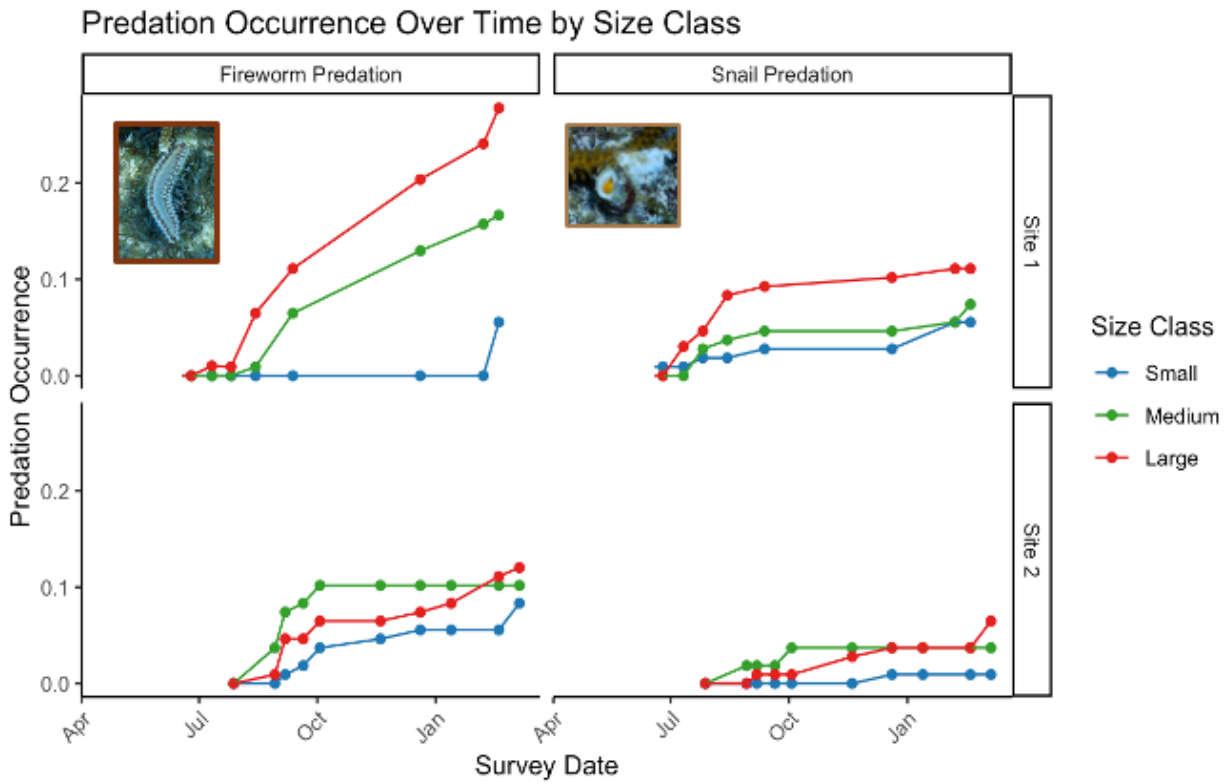

Figure 8. Predation occurrence on *Acropora cervicornis* (small, medium, and large colonies) during the experiment by *Hermodice carunculata* (fireworms) and *Coralliophila abbreviata* (snails).

3.4 Discussion

Restoration sites with a high density of *Acropora* coral outplants often experience a decline in coral survivorship over time, largely attributed to biological stressors such as invertebrate predation (Ladd et al., 2016). To preserve these sites and extend the longevity of restoration success, proactive management strategies and mitigation protocols must be implemented to reduce the impact of invertebrate corallivores.

A. cervicornis colonies in control plots, where predators were not actively removed, experienced higher predation impacts compared to removal plots, demonstrating that targeted predator removal can reduce coral damage. This increased impact in control plots is likely due to the unrestricted recruitment and accumulation of fireworms and snails over the course of the experiment. Without removal activities, predators were able to establish more persistently in these plots, leading to increased predation impacts. Snail removal proved to be an effective way to keep snail abundance (and predation intensity on larger colonies) lower within removal plots compared to controls. In contrast, higher fireworm abundance was recorded in removal plots where traps had been deployed. This pattern is likely explained by the baited traps themselves acting as attractants.

Based on the results of this experiment, predator trapping in the case of fireworms and hand removal in the case of snails are effective tools to reduce predation on outplanted *Acropora* corals. While future research should be completed to evaluate the optimal frequency for predator removal in a more formal cost-benefit analysis, we recommend the removal of all visible invertebrate predators during each outplanting and monitoring visit to enhance coral survivorship.

4. Task 4. *TRIPNEUSTES VENTRICOSUS* GROW-OUT AND GRAZING ASSAYS

4.1 Objectives

Document the potential for rearing and using the sea urchin *T. ventricosus* for future tandem urchin-coral restoration.

4.2 Methods

T. ventricosus were acquired by UF from a licensed marine life collector in the Florida Keys. Prior to the project period, a volitional spawn of these animals was obtained, gametes successfully fertilized, and larviculture/settlement completed (Figure 9). Juvenile *T. ventricosus* were then reared at The Florida Aquarium's Coral Conservation and Restoration Center by UF and TFA staff (Figure 10) from the beginning of the project period until November 11, 2024 when a UF graduate student delivered cultured animals to UM. These animals were health inspected by TFA veterinarians and transfer paperwork was completed.

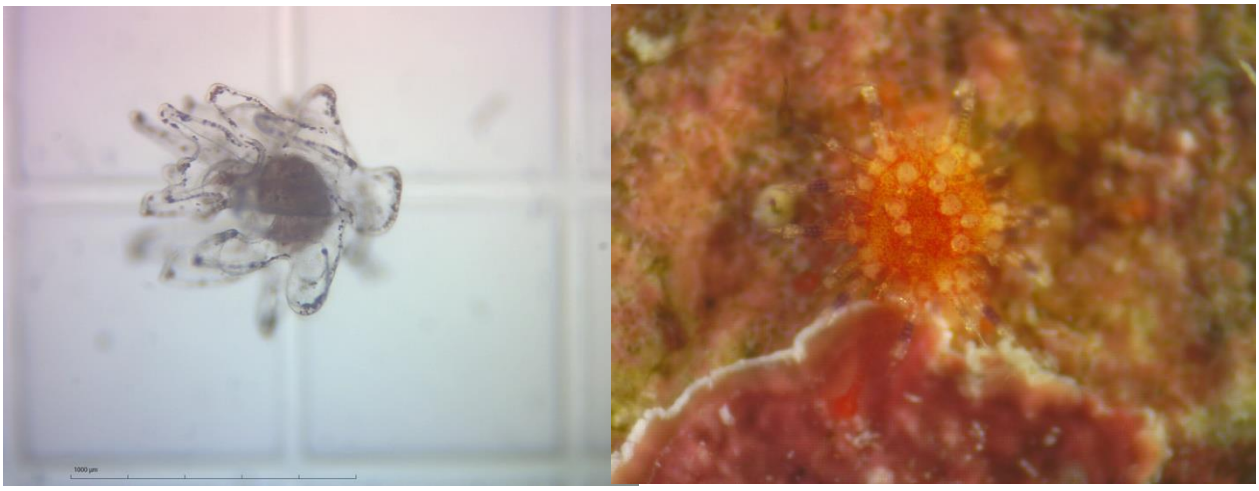

Figure 9. Early life stages of *Tripneustes ventricosus*. Larvae were maintained in a specialized recirculating aquaculture system and fed a mixture of live *Rhodomonas* and *Chaetocerous* microalgae produced on site (left). Juveniles were settled using methods established for other tropical urchin species, including the provision of settlement cues from crustose coralline algae (right).

Figure 10. UF biologist Jessica Smith holds a small *Tripneustes ventricosus* being reared in a recirculating aquaculture system.

Once at UM, the *T. ventricosus* were kept in a 115-gallon tank and fed *ad libitum* the red macroalgae *Agardhiella subulata* and *Gracilaria spp*. purchased from The National Resource of *Aplysia* at UM.

In March, 2024, terracotta tiles deployed onto a Miami reef to accumulate macroalgae were collected and brought back to UM's Land Based-Coral Facility. Two 90-gallon tanks were partitioned into 8 smaller experimental sections using plastic mesh (Figure 11a). Four different urchin densities were created varying the number of tiles per aquarium, with each aquarium (except the control) receiving one urchin. The densities treatments were: control (0 urchins, 1 tile), 5 urchins m^{-2} (8 tiles), 11 urchins m^{-2} (4 tiles), and 44 urchins m^{-2} (1 tile). Each treatment had two replicates.

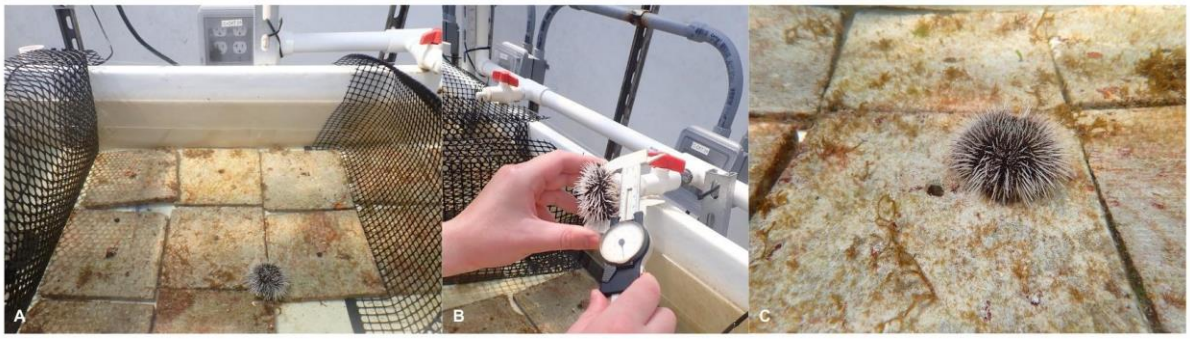

Figure 11. The experimental tanks with mesh partitioning for the *Tripneustes ventricosus* grazing assay (A), measuring the test diameter (B), *T. ventricosus* grazing on one of the algae tiles (C).

The TD of the urchins were measured using long-jaw calipers at the beginning and end of the experiment (Figure 11b). Prior to adding urchins into the partitions, baseline images of each tile were captured to assess the initial percent cover of macroalgae using Coral Point Count with Excel Extensions software. Images of each tile were taken every 3-4 days to track changes in macroalgal cover over time.

4.3 Results

T. ventricosus proved to be an effective macroalgal grazer at all density treatments. At the beginning of the experiment, urchins across treatments had an average TD of 46.2 cm ± 0.45 SD. At day 14, the average TD was 46.3 ± 0.88 SD. At all density treatments, macroalgae cover declined over time (Figure 12). On day 0, the average algal cover among tiles was 96.4%, mostly consisting of low-lying algal turfs. By day 14, the average algal cover for control tiles was 91%, 61% with 5 urchins m^{-2}, 58% with 11 urchins m^{-2}, and 22% with 44 urchins m^{-2}. There were minimal changes on algal cover in the control treatment.

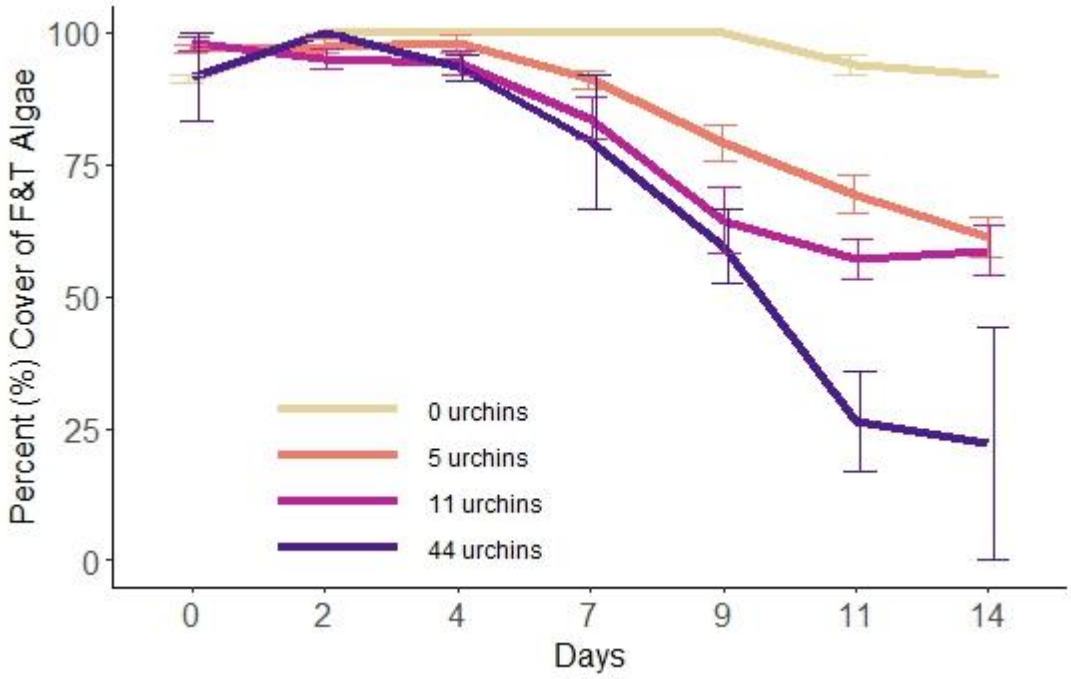

Figure 12. The percent cover of fleshy and turf algae exposed to differing urchin densities over a 14-day period.

4.4 Discussion

T. ventricosus are effective algae grazers within *ex-situ* tanks and exhibited similar gazing patterns to those previously observed with *D. antillarum*, *Lytechinus variegatus,* and *Echinometra viridis*. These findings reinforce the species potential to be an effective grazer on reefs. It is worth noting that 44 urchins m^{-2} is an unrealistic restoration goal, and even if it could be achieved would likely result in overgrazing or bioerosion. Thus, low to intermediate urchin densities (< 5 urchins m^{-2}) should be considered for offshore deployments.

In future studies, it would be beneficial to conduct field deployments similar to those completed by Lachnit et al. (2025), for *D. antillarum, L. variegatus,* and *E. viridis* to determine the potential of using *T. ventricosus* in coral-urchin tandem restoration.

5. Task 5. MODULAR *IN-SITU* URCHIN UNITS

5.1 Objectives

Develop, build, and deploy multipurpose *in-situ* units that can be used for rearing and experimentation to facilitate herbivore restocking efforts in Florida.

5.2 Methods

Multipurpose *in-situ* units were designed and built by UM Cooperative Institute for Marine and Atmospheric Studies (CIMAS) employees at the National Oceanic and Atmospheric Administration (NOAA)'s Coral Research and Assessment Lab in Miami, FL. These units were designed and built using relatively inexpensive materials and in a modular fashion to facilitate replication of the design by other restoration programs in Florida. The units were constructed of PVC and vexar mesh, such that the parts (floor, walls, and tops) are easily replaceable and can be interchanged to comprise 1, 2, 4, 8, or 16 individual compartments (30cm x 30cm x 30cm (L x W x H) (Figure 13). Upon completion of the initial modular rearing unit prototype, we constructed three additional rearing units for deployment to the Paradise Reef Nursery. These units were built in an identical manner, providing a total of up to 64 rearing compartments spread evenly among the four units.

Urchin-rearing units were deployed to the UM Paradise Reef nursery located offshore of Key Biscayne, Florida, (permitted under SAJ-2019-03863). Two of these rearing units were deployed in December of 2024. Rearing units were attached to the sandy bottom using the same method as the existing tables at the site, with the addition of two additional sand anchors as a backup in the event that the rebar became dislodged.

5.3 Results

Four modular urchin rearing units were successfully constructed using inexpensive and readily available materials (Figure 13). The units were effective in their goal of being easily modified to accommodate various compartment sizes ideal for rearing organisms like urchins that may require different sized rearing areas as they grow.

Despite using the same attachment methodology proven to be successful at this site for coral tables (rebar pounded into the sand), the two urchin rearing pens deployed in December 2024 were lost at some point in January 2025. It is unclear what resulted in the attachment failure as they were deployed in an identical manner to an existing table at the nursery that has remained anchored and stable for years. It is likely that an anchor dragged over the site and dislodged the units. Because of the loss of the first two rearing pens, we developed an alternative strategy to secure the final two rearing pens to the benthos to ensure that they would not be lost. However, as a consequence of our SAL not being issued in a timely manner, we did not deploy the final two cages as the permit

was never issued. We were unable to deploy the *D. antillarum* to the modular *in-situ* urchin units to conduct a proof-of-concept experiment due to the delay in the approval of permits.

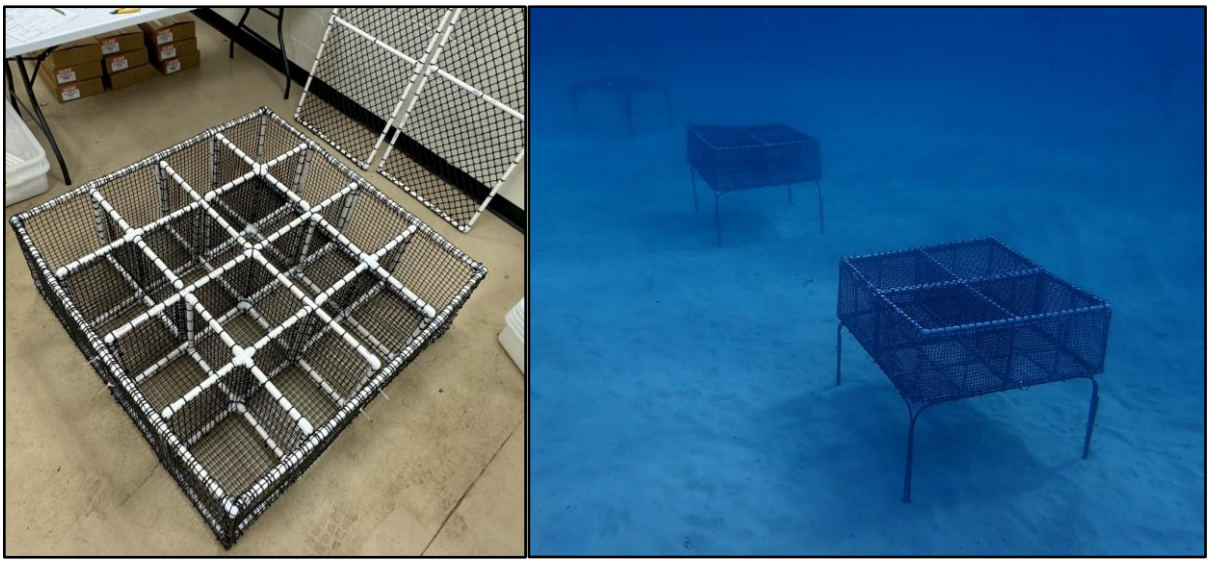

Figure 13. (Left) The modular units that were constructed in the lab. (Right) The units deployed at Paradise nursery. The existing table that the attachment method was based upon can be seen in the background.

5.4 Discussion

The modular rearing units developed here represent an inexpensive and modular option for *in-situ* rearing of organisms like urchins that are targeted for herbivore replenishment activities on Florida reefs. Importantly, these units are easy to construct and require minimal tools, making them accessible to various user groups that may not have access to specialized equipment. The modular nature of the rearing units provides versatility to meet different needs. For example, separating the units into 16 individual compartments may be ideal for field-based experiments.

The two rearing pens deployed during the initial deployment were removed despite using attachment methods proven to be successful for this type of structure at this site. Thus, we believe it is most likely that the rearing units were impacted by a boat anchor that could have dragged and dislodged them and the sand anchors that were meant to provide a failsafe. Future deployment of these or similar structures could incorporate additional attachment methods such as cinderblocks that would provide a stable, weighted base and reduce the probability of dislodgment and unit loss.

6. Task 6. PARROTFISH GRAZING BLOCKS

6.1 Objectives

Develop and deploy parrotfish grazing blocks as a tool to predict and minimize predation on massive species of corals outplanted to Florida's coral reefs.

6.2 Methods

Parrotfish grazing blocks were created from molds of three different coral species:*Colpophyllia natans* (CNAT), PSTR and DLAB, using a mixture of dental gypsum (calcium carbonate), ALGAEMAX pellets and wafers, amino acids, and spirulina. Trials were conducted to identify the ideal ratio of ingredients that allows for the incorporation of potential food items but does not result in rapid disintegration of grazing blocks.

Upon determining the ideal recipe, aquaria-based trials were conducted to determine longevity of the blocks. These trials were conducted at the University of Miami Experimental Hatchery in Miami, FL using individual 20-gallon aquaria (30 x 30 x 90 cm; L x W x H) each with their own 20-gallon sump. Aquaria were filled with UV-sterilized and filtered seawater (20 microns), a 300-watt heater to maintain temperature, and an individual powerhead placed at the back of the aquarium. Five aquaria were divided into three sections based on water flow - high, medium, and low flow. Five different block treatments were made: 1) plaster mixed with tap water, 2) plaster mixed with pellet and wafers, 3) plaster mixed with amino acid liquid solution, 4) plaster mixed with spirulina, and 5) plaster mixed with all three ingredients. Three blocks of each treatment were placed in each section of the aquarium. To quantify block longevity, we recorded the presence or absence of each block on days 1, 4, and 8. The time frame was based on FWC and Florida Keys National Marine Sanctuary (FKNMS) post-outplant monitoring guidelines, from the "*Protocols for the Management of Coral Outplanting*" document, requiring the monitoring of outplants 7-10 days after initial outplant.

To test the ability for grazing blocks to decrease predation on outplanted corals, we deployed the first round of grazing blocks in tandem with 100 DLAB colonies to Paradise Reef on November 25, 2024. Corals and grazing blocks were divided among eighteen plots, with each plot containing three different treatments: 1) control - two corals, 2) one grazing block with two corals, and 3) cement control and two corals (Figure 14). Each plot was spaced ~2 m apart, while each treatment type within a plot was spaced ~1 m apart. The corals and grazing blocks were cemented directly to the substrate. Scaled photos were taken of each coral as well as length (cm), width (cm), and height (cm) of grazing block. Scaled photos of corals and block measurements were taken 10 days after outplanting. Corals were also surveyed for signs of predation.

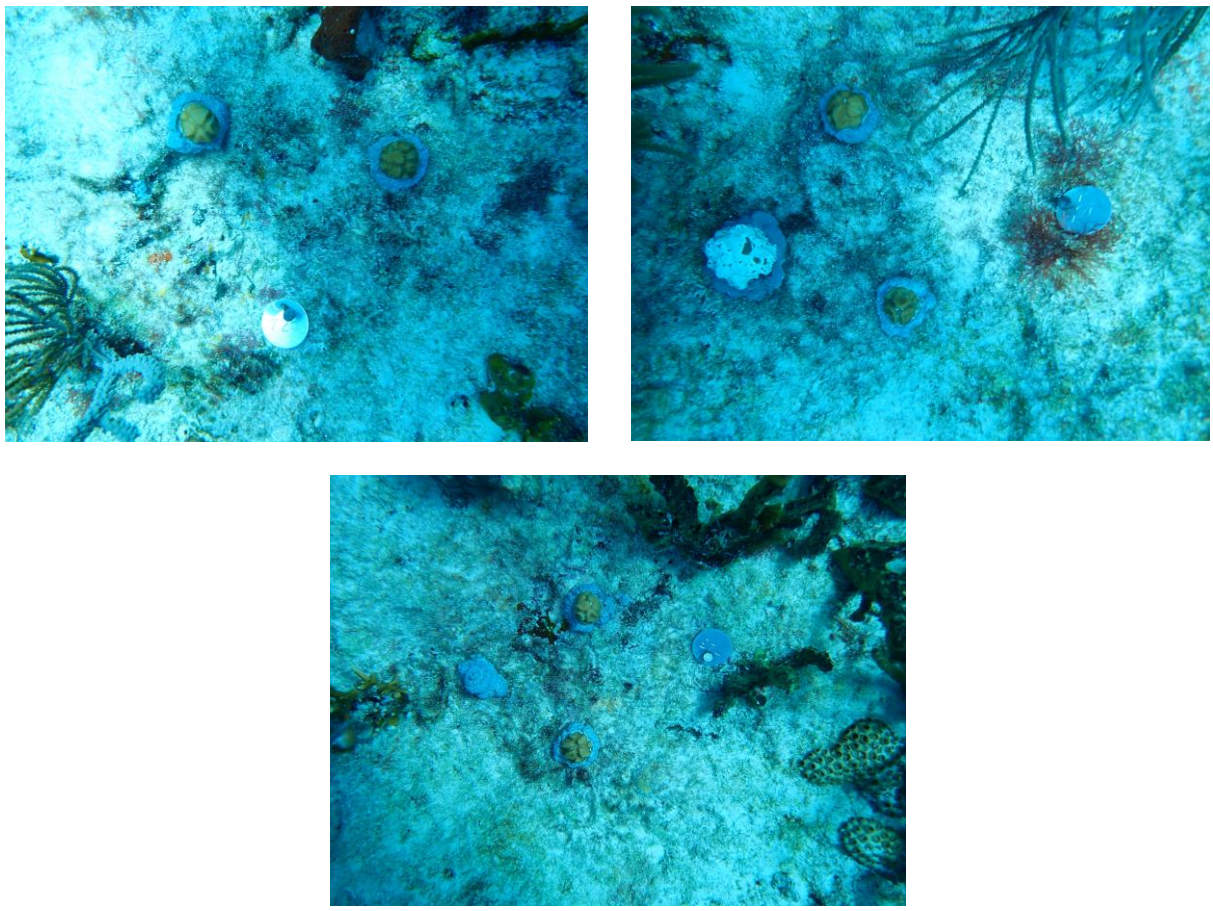

Figure 14. (Top left) Treatment 1: control with two DLAB. (Top Right) Treatment 2 with two DLAB and one grazing block. (Bottom Center) Treatment 3 with two DLAB and a cement control.

On May 5, 2025, we tested the ability for grazing blocks to decrease predation on outplanted coral recruits with DLAB and OFAV recruits on Paradise Reef that were divided into twelve plots. Each plot was further divided into three treatment types: 1) control - corals only, 2) corals with grazing block, and 3) corals with umbrella protectors. The corals and grazing blocks were attached to bases with epoxy and each base was cemented to the substrate. Each plot was approximately two meters apart and each treatment type was approximately one meter apart. Two DLAB recruits and one OFAV recruit were epoxied onto the control base and base with the umbrella protector. One DLAB and one OFAV recruit was epoxied onto a base with one grazing block. Scaled photos were taken of each coral and grazing block. Predation rate was determined based on a scale of 1-5: 1 = no predation, 2 = some predation observed with majority of coral tissue and skeleton still present, 3 = predation observed with half of the coral tissue and skeleton still present, 4 = heavy predation with little coral tissue and skeleton present, 5 = extreme predation with no coral tissue or skeleton present.

6.3 Results

Grazing block composition: We identified the ideal ratio of grazing block ingredients to be: 125g calcium carbonate, 5g ALGAEMAX wafers, 5g ALGAEMAX pellets, 32.5g amino acid liquid solution, and 0.25g spirulina powder. It was determined that the calcium carbonate, wafers, pellets, and liquid should be combined first to create a plaster consistency with the spirulina incorporated into the mixture last. If the spirulina is added before the plaster is made, the blocks will crumble and not retain their structure. After 15 minutes, the blocks can be transferred to a freezer to remain setting for 24 hours. The blocks should remain in the freezer until ready for use to keep the ALGAEMAX pellets and wafers fresh and prevent spoilage.

Grazing block longevity: Water flow influenced block longevity across all treatment types with none remaining by day eight under high flow conditions (Figure 15), indicating that grazing block longevity is inversely related to flow rate, and that those used in our experiment are unable to withstand high-flow environments.

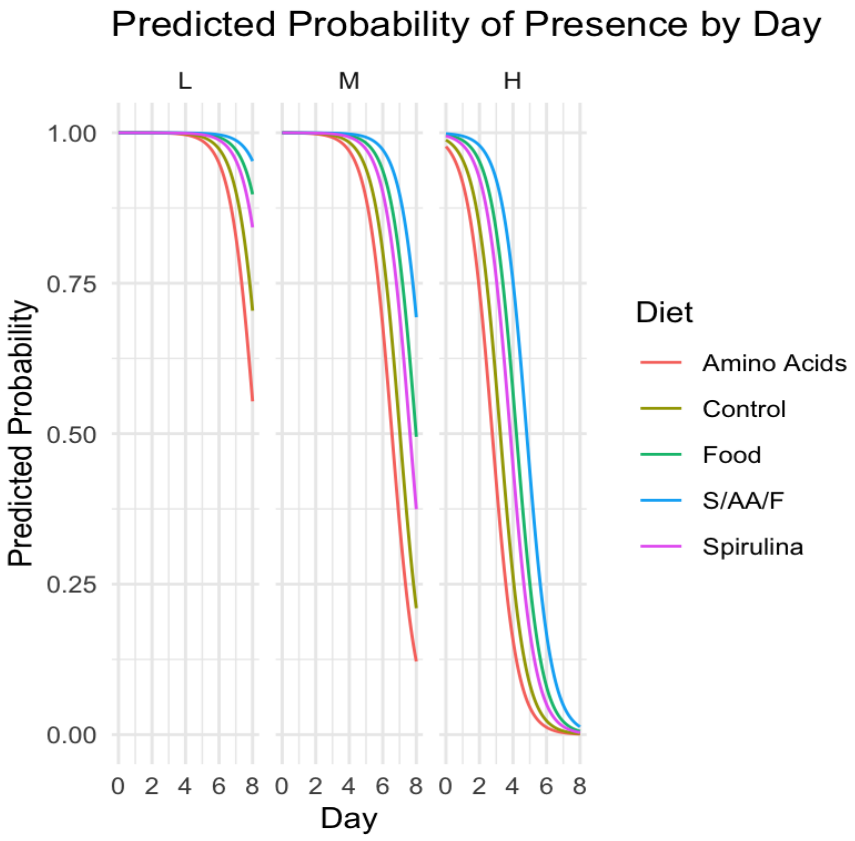

Figure 15. Probability of grazing block presence for each ingredient type based on water flow conditions (L = low flow; M = medium flow; H = high flow). "S/AA/F" = Spirulina, Amino Acids, and Food.

Field deployment: DLAB corals outplanted in November had no signs of predation after 10 days. No grazing block remained at any plot to be able to take height, width, and length measurements. For our May deployment, while all three treatments had signs of predation, corals under the umbrella protectors showed the lowest predation rate (Figure 16). No differences in predation were

seen between the controls and the corals protected by the grazing blocks, indicating that the grazing blocks were not an effective method to mitigate fish predation.

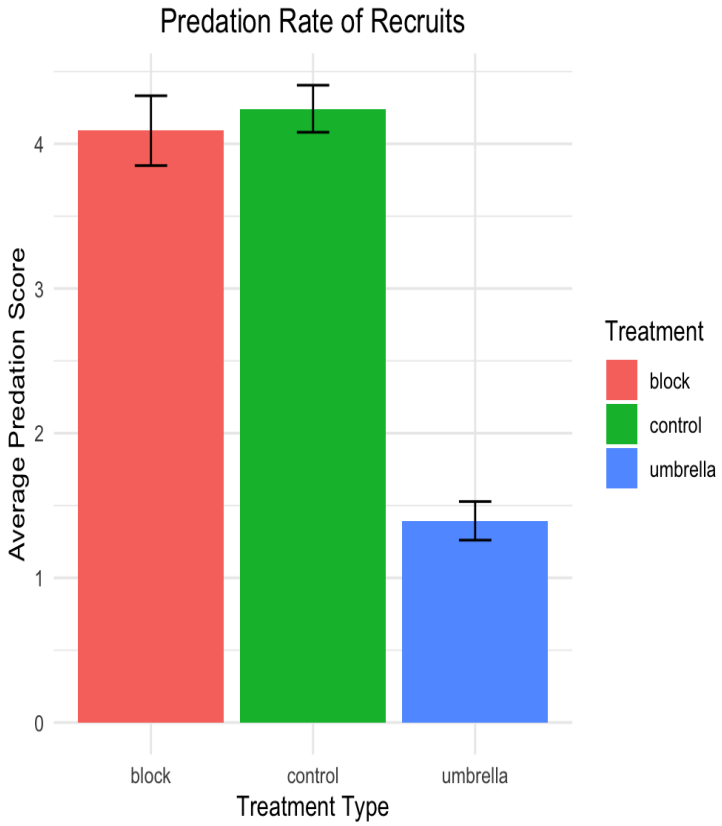

Figure 16. Average predation score of coral recruits outplanted on bases with different predation protection (parrotfish grazing blocks, control = no protection, or umbrellas = physical deterrents) at day 10.

6.4 Discussion

Predation by parrotfish has emerged as a major impediment to efforts aimed at restoring massive species of corals to Florida's reefs, particularly in places like Miami-Dade County. Despite several years of research trying to understand why particular locations, species, and genotypes result in higher predation rates, we still do not understand the drivers of predation on these outplanted corals. Addressing this knowledge gap, i.e., understanding why some corals are preferentially targeted over others, will allow us to better design restoration approaches that minimize coral loss and thus can make restoration more efficient. Here, we took the initial steps to test and develop a novel restoration tool, grazing blocks, as a tool to facilitate effective strategies to reduce the impacts of predation, assist with coral outplant site selection, and better understand drivers of coral predation. This strategy was modeled after grazing blocks, a common veterinarian-approved practice that has been safely used in the aquarium industry since the 1970's.

First, we conducted tank-based assessments to test multiple 'recipes' that could be used for effective grazing blocks. Numerous recipes were tested, revealing that not only the composition,

but also the order in which ingredients were mixed, impacted the longevity of grazing blocks. Namely, we found that adding particular ingredients, such as spirulina, too early in the process, compromises the structural integrity of the blocks and causes them to rapidly crumble. Further, we identified that blocks should be stored frozen until they are going to be used in order to keep the ALGAEMAX pellets and wafers intact and prevent spoilage.

Our aquaria-based longevity experiments identified that water flow rates have a large impact on the longevity of grazing blocks once they are placed into the water. Regardless of their composition, blocks rapidly disintegrated in high flow environments, suggesting that blocks may only be effective if deployed in low-flow environments, or the recipe may need to be adjusted to increase the longevity of the blocks. This would suggest that the blocks may not be reasonable for deployments on the reef or in high flow locations. Future studies could include alternative ingredients, recipes, or sizing that may be more resistant to water flow.

The first deployment of DLAB had 100% survivorship and no signs of predation, regardless of if corals were controls or a calcium carbonate grazing block treatment. This was surprising given such high levels of predation previously found at this site (Koval et al. 2020). One potential explanation for the low rates of predation observed may be due to outplant timing during cooler, winter months. These findings suggest that future research to assess the importance of outplant timing on coral success may be useful in improving coral restoration outcomes.

On our second deployment, contrary to our hypothesis, we also found no difference in predation between outplanted corals on control bases and those with a calcium carbonate block on the base. Both control and block treatments had an average predation score of 4 - indicating heavy predation with little coral tissue and skeleton presence - compared to corals in the umbrella treatment, which had an average score of 2 (some predation observed with majority of coral tissue and skeleton still present). As such, our findings indicate that the 'umbrella' guards were most effective, supporting prior research suggesting that physical structures may be required to substantially reduce predation in high predation areas (Rivas et al. 2020). It was interesting and noteworthy that corals deployed to the same reef but at different times of the year experienced such different levels of predation. Future research could assess the importance of coral age and outplant timing on coral success.

7. Task 7. ATTACHMENT METHODS AND SUBSTRATE TYPE

7.1 Objectives

Evaluate the benefits of using cement bases for outplanting massive coral fragments and testing the influence of attachment materials and arrangements on coral and base retention and outplant growth.

7.2 Methods

On March 15, 2025, we established our experimental coral-attachment plots at Paradise Reef, totaling 12 plots divided into two groups: 1) Coral bases designed and built by ReefCells outplanted to the reef substrate, and 2) Corals placed directly onto dead coral skeletons (without using cement bases) (Figure 17). A total of 252 corals of two species, PCLI and PSTR, each represented by three different genotypes, were used. Corals were deployed as single fragments or in groups of 3 corals of the same species and genotype. Each plot included replicates with: 1) a single coral fragment, 2) groups of three fragments in direct contact (fragments touching), 3) and

groups of three fragments spaced 1-cm apart. Each of these treatment groups within a plot were attached using cement (Unsworth et al. 2021), epoxy (Apoxie Sculpt), or Seatak cement (www.seatak.com).

Figure 17. Plots with corals outplanted onto skeleton (left) and cement bases on reef substrate (right) with the three different attachment materials (cement, epoxy, Seatak).

7.3 Results

Attachment success varied by attachment material (cement, epoxy, Seatak) and the deployment substrate (reef substrate vs coral skeleton). There was better attachment on the reef substrate compared to coral skeleton across all attachment materials (Figure 18). After 3 months, attachment success on the reef was 94% for cement, 94% for epoxy, and 61% for Seatak. Attachment success on coral skeleton was 57% for cement, 50% for epoxy, and 20% for Seatak. There was a significant difference in retention based on attachment material, with Seatak having the lowest retention success, while no significant differences were found between cement and epoxy (GLM, $p < 0.01$). There was higher retention of coral fragments that were outplanted on reef substrate compared to coral fragments outplanted onto coral skeleton (Figure 18). Additional analyses are being conducted to evaluate differences in growth rates among corals deployed as different arrangement treatments.

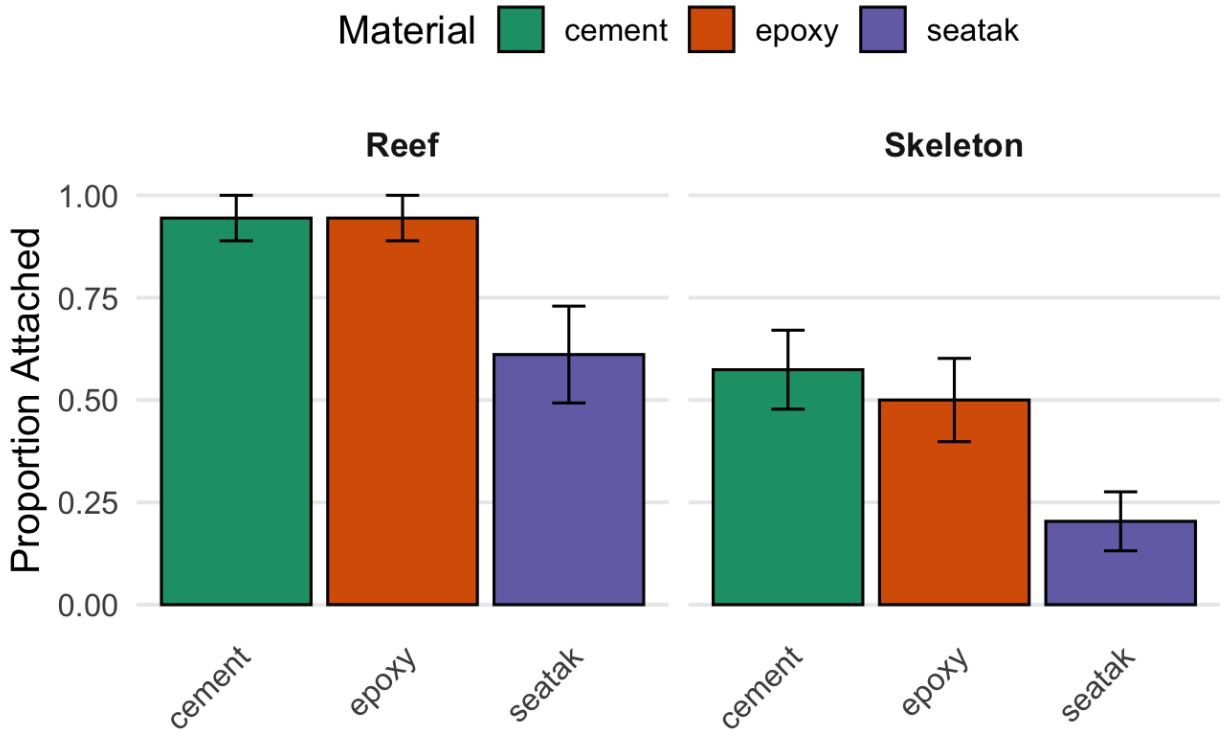

Figure 18. The proportion of coral fragments attached at the 3-month survey by outplant location (reef substrate, coral skeleton).

Predation intensity by fish was influenced by coral species and genotype, but not by substrate type (Figure 19). By the 3-month survey, genotypes PCLI1, PCLI2, PSTR2, PSTR3 had ~25% total percent tissue mortality, while genotypes PCL3 and PSTR1 had > 80% mortality on the reef. Corals that were outplanted onto skeleton saw slightly higher levels of mortality compared to corals outplanted onto the reef substrate. Predation impacts on both substrate types and species declined to very low levels after the first month (Figure 19).

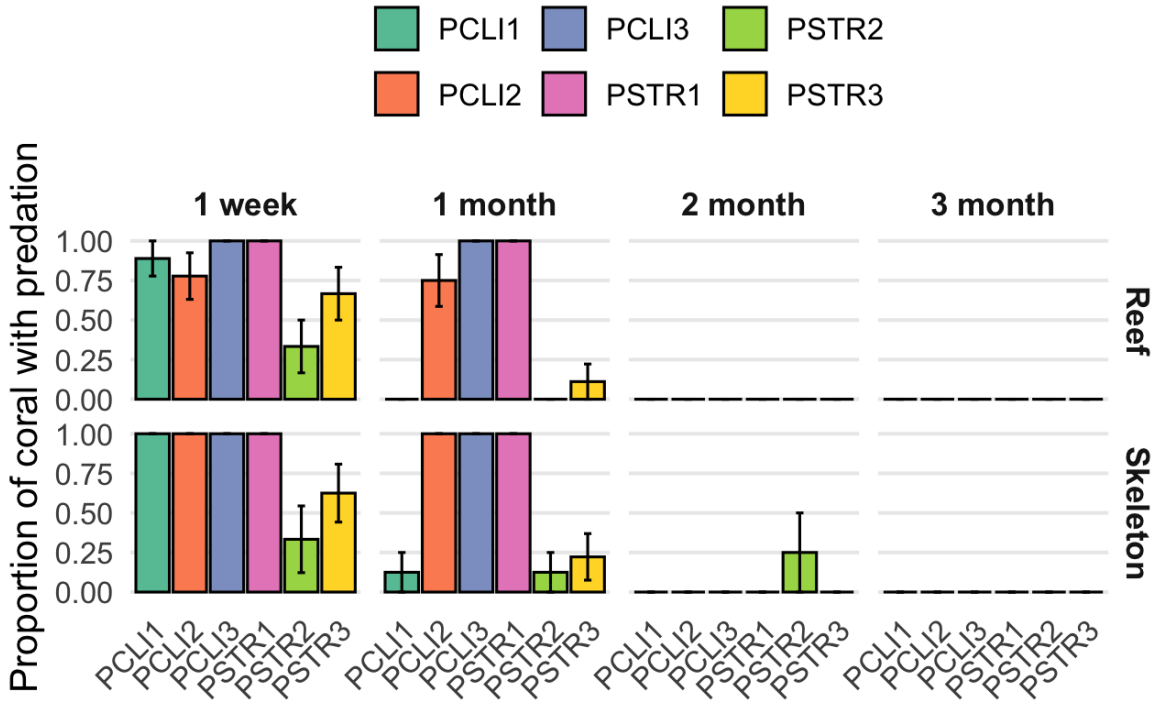

Figure 19. The proportion of coral fragments that experienced predation over time. Three genotypes of *Pseudodiploria clivosa* and three of *Pseudodiploria strigosa* were used.

7.4 Discussion

After testing two commonly used attachment materials in the restoration field (cement and epoxy) and a novel material (Seatak), both cement and epoxy appear to be the best attachment materials. Seatak proved to have low attachment success across all treatments, was messy to deploy, and, if used at scale, would be costly. Outplanting coral directly onto coral skeletons proved to have low attachment success likely caused by the roughness of the skeleton making it difficult for the attachment materials to adhere. Corals that were outplanted onto skeleton saw slightly higher levels of mortality compared to corals outplanted onto the reef substrate, possibly due to the elevated location making them more visible to predators. Predation susceptibility proved to be influenced by both species and genotype, but not by substrate type. Based on the findings of this experiment we recommend the continued use of epoxy and cement (with cement being the cheaper option) as these showed to be the most effective attachment method. Similarly, unless practitioners are interested in reskinning old coral skeletons, we recommend placing corals onto the reef substrate using bases due to higher retention success.

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