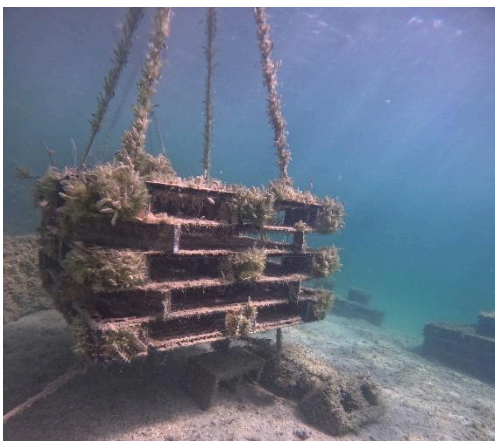
Semi-wild mariculture of the Caribbean King Crab, *Maguimithrax spinosissimus*



Semi-wild mariculture of the Caribbean King Crab, *Maguimithrax spinosissimus*

Final Report

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Management Summary
In this phase of the quarry project, we continued evaluating the abiotic and biotic characteristics of two quarry systems located in the Lower Florida Keys (Cudjoe Key, FL) for their potential use in the semi-wild mariculture of the Caribbean King Crab (*Maguimithrax spinosissimus*). Abiotic conditions in both quarries are suitable to support crab populations throughout the year. We deployed five habitat designs in February 2025, and by April 2025, we saw our first four adult male crabs. From April 2025 to March 2026, we observed 36 adult crabs on the artificial structures. Statistical modeling showed that the probability of crab presence on the structures increased significantly over time. This suggests that as the structures get more mature, their suitability for *M. spinosissimus* to inhabit them would increase. Our work has shown promising results, so we recommend continuing monthly monitoring of quarries and new habitats, as well as crab relocation, to assess the project's feasibility. Additionally, we encourage an exploratory study of other quarries along the Florida Keys to determine their current Caribbean King Crab populations and their associated abiotic characteristics. Given the promising results of our new habitats as a potential boost to the crab population, we could potentially use other quarries (e.g., Marathon, Tavernier, Key Largo) for this purpose. Besides higher total crab production, the benefits of using multiple quarries from Key West to Key Largo encompass a reduction in transportation time (from the quarry to the reef restoration site) and increased genetic diversity.

Executive Summary
In recent years, the potential importance of coral reef herbivory by a guild of reef-dwelling crabs in the Mithracidae family has emerged. The Caribbean King Crab (Maguimithrax spinosissimus) is widespread throughout the Caribbean Sea and graze on a wide variety of macroalgae and algal turfs. Its use for coral reef restoration as a controller of coral-alga competition has been restricted by limiting crab stocks. Years of in-situ (laboratory) production have not been successful. In this project, we studied the abiotic and biotic characteristics of two quarries located in the Lower Florida Keys (Cudjoe Key) that have the potential for semi-wild mariculture of M. spinosissimus.

Between July 2025 and February 2026, temperatures at a depth of 3.51 meters fluctuated between 18.87 °C and 33.11 °C. Dissolved oxygen measurements between July 2025 to February 2026 fluctuated between 7.39 mg/L to 3.42 mg/L. Salinity measurements between July 2025 to February 2026 fluctuated between 35.16 PSU and 29.34 PSU. The benthic habitat across both quarries is dominated by periphyton algal assemblages (~58%), with seasonal variation influenced by cold temperatures. Dominant chlorophyta taxa include Batophora (~40%) and Acetabularia (~3%), also influenced by seasonally cooler temperatures. The average density of crabs observed in Cudjoe North was 0.15 ±0.02 crabs/m^2, and the average density of crabs observed in Cudjoe South was 0.09 ±0.01 crabs/m^2. The low crab densities in areas with high macroalgae abundance (>90%) and a lack of predators (almost none) suggest that habitat is a limiting factor for population growth.

We created and deployed twenty habitats in February 2025 using plastic shipping pallets covered with concrete (1-tier to 5-tier habitats, n = 4 sets) and monitored them from March 2025 to March 2026. In April 2025, the habitats were dominated by periphyton, having between 25 to 30% periphyton cover. In June 2025 the periphyton cover decreased and was replaced by two macroalgal species: *Batophora oerstedii* and *Acetabularia acetabulum*. The artificial structures had between 7 to 20% *B. oerstedii* cover and 3 to 8% *A. acetabulum* cover in June 2025. By September 2025, the artificial habitats were dominated by *B. oerstedii*, having between 40 to 55% *B. oerstedii* cover. Periphyton cover decreased on the artificial structures, having between 10 to 20% periphyton cover. From April 2025 to April 2026 divers have observed a total of 36 crabs on the artificial structures. Based on these trends, we fitted a generalized linear mixed effects model with a logitlink function which predicted that as time increases, the probability of seeing a crab on an artificial structure increases. Our results from this phase support the habitat limitation hypothesis for Caribbean King Crab populations in the quarries. We expect to benefit from this knowledge to increase the crab population in phase III.

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1. BACKGROUND/INTRODUCTION

Over the past several decades, research has highlighted the critical role herbivores play in maintaining the stability and resilience of coral reef ecosystems. On Caribbean reefs, herbivorous organisms help suppress macroalgal dominance, which then reduces the competitive interactions between algae and reef-building corals (Hughes et al., 2007). In recent years, studies have recognized the importance of coral reef herbivory by decapod crustaceans, particularly those of the family Mithracidae. The Caribbean King Crab (*Maguimithrax spinosissimus*) has been proposed as one of the key invertebrate herbivores with potential for use in coral reef restoration in the Caribbean. Studies have recorded that grazing by *M. spinosissimus* can reduce macroalgal biomass on coral reefs, suggesting that increasing their populations could be beneficial for coral reef restoration and management efforts (Butler & Mojica, 2012). Given the low natural densities of the *M. spinosissimus* on Caribbean reefs, and the need to boost their ecological impact, we proposed using quarries as semi-wild mariculture systems.

Previous work has shown that these quarry habitats provide suitable environmental conditions, macroalgal food resources, and structure to support crab survival, growth, and reproduction (Glover & Butler, 2025). *M. spinosissimus* occurs primarily along the rocky edges of quarries in the Florida Keys. They can be found from the surface of the quarries down approximately 6 m in the depth, where habitat complexity, food availability, and water quality conditions are more favorable. In the remaining space of the quarries, *M. spinosissimus* distribution is restricted by lack of food (algae) and shelter (crevices), on the muddy bottom. Consequently, a majority of the available quarry habitat is unfavorable for the growth of *M. spinosissimus* populations.

This study evaluates the effectiveness of increasing habitat complexity and food availability in a quarry habitat in the Lower Florida Keys by deploying artificial structures to increase *M. spinosissimus* populations. These structures were designed to increase habitat, food, and settlement substrate availability. Building upon the first phase of this project, current efforts have focused on long-term monitoring of deployed habitats and naturally occurring quarry populations.

2. METHODS

2.1 Quarry abiotic conditions

We selected two isolated quarries surrounded by mangroves on Cudjoe Key, FL, for this study, which are close to one another (~15 m), or similar size (~6 ha in area), and depth (~12 m), and with similar characteristics (Fig. 1). Both quarries are privately owned with only limited gate access.

Figure 1. Study sites, Cudjoe Quarries North (control) and South (manipulated), where the habitats are located.

YSI EXO2 Multiparameter Sonde instruments were deployed in the quarries, providing us with temperature, dissolved oxygen, and lights readings every thirty minutes. Additionally, we collected salinity and other parameters using a YSI at three different depths: surface, 5 meters deep, and 10 meters deep.

2.2 Quarry natural benthic communities and crab populations

Four permanent transects were established along the western wall of each quarry, spaced about 20 meters apart using stainless-steel screw-eyes drilled into the rock wall at the water's edge. At each of these fixed points, a 4-meter weighted transect line was deployed down the rock wall perpendicular to the quarry's shore. These transect lines were secured to the surface with the screw-eyes to keep the line taught and establish a reference line for creating a vertical profile of the quarry's wall. Divers captured 0.25m by 0.25m photoquadrats along this vertical profile, starting from the 0.5-meter mark at the weighted end of the transect tape and photographing at each 0.5m interval, ending at the 3.5-meter mark near the surface. In total, seven photoquadrats were collected per transect per site during each monthly sampling period. These pictures were taken with an Olympus TG6 underwater camera in a pressure-resistant housing on a custom PVC frame, ensuring that photos were taken from a fixed, perpendicular distance from the benthos and that the total quadrat was in the frame. All images were taken at least three hours before sunset with clear skies and little wind to maintain the highest photo quality. These photos were analyzed using the University of California San Diego's Coralnet image analysis website to estimate the percent coverage of major benthic space holders. Corresponding to these benthic photoquadrats are canopy height measurements taken from the same meter mark locations. These heights were recorded from three randomly sampled measurements of the three most prevalent macroalgae species at each 0.5-meter mark interval, taken from a 0.25-meter by 0.25-meter area on the right side of the transect tape. These heights were measured with an 80mm ruler from the substrate to the highest point of algae growth.

To monitor natural crab populations, divers used the same four fixed points established along the west wall of the quarries. At each of the fixed points, a ten-meter weighted transect line was deployed vertically down the quarry walls. The lines were secured at the surface and weighted at the bottom to maintain a straight vertical profile along the slope gradient. Each diver surveyed a 1-meter area on each side of the tape, resulting in a total surveyed area of 20 m². Divers began their surveys around 8:00 pm at the first transect and surveyed until they reached the next fixed point. At each transect, divers recorded the estimated carapace size, gender, and the number of crabs found at each transect.

2.3 Benthic assemblages and crab populations in new experimental habitats

We placed 20 artificial habitats with five different surface-to-volume ratios in South Cudjoe Quarry (Fig. 2). The abundance of macroalgae was measured at the top, bottom, and sides of each habitat. The percentage of cover of the top and bottom was obtained using 25-centimeter x 25-centimeter quadrats. The side cover was acquired from a 12.5-centimeter x 12.5- centimeter quadrat (one per side, four for each tier). The number of photoquadrats matched the number of habitat tiers. Each 1-tier habitat had four side photoquadrats: 2-tiers had eight; 3-tiers had 12; 4-tiers had 16; and 5-tiers had 20.

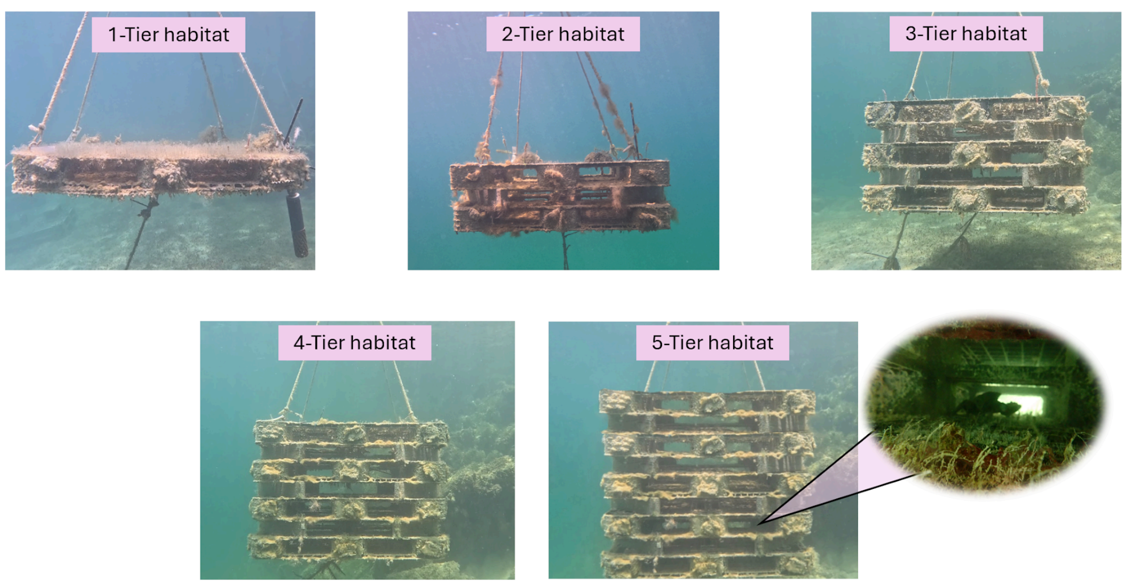

Figure 2. Picture of the artificial habitats (Replicate 1) deployed in Cudjoe South quarry.

The population structure of crabs (i.e., abundance, size, egg production) was monitored at each new experimental habitat during daylight. Working in pairs, divers collected crabs by hand, immediately measured them, determined their sex, and released them at the location where they were collected while underwater. This data was used to make production estimates of crabs for restoration and to compare those estimates based on habitat enhancement and adult wild crab stocking in quarries.

2.4 Crab translocation

We introduced adult male and female crabs to Cudjoe South quarry monthly. Divers collected crabs by hand from nearby (< 10 kilometers) rocky natural habitats at night. The number of monthly introductions was 25 crabs per month. After capture, crabs were transported in aerated, insulated containers to the experimental quarry (Cudjoe

South), where they will be acclimated to quarry water conditions (in case of slight differences in temperature or salinity between sites) for 24 hours prior to release by hand along the entire perimeter edge of the quarry. Divers collected a tissue sample of one leg for each crab introduced to determine the genetic population structure of the adult and juvenile crabs produced in the first year within the quarries. However, the genetic analysis of these samples will not happen until another phase of this project.

3. Results

3.1 Quarry abiotic conditions

Abiotic conditions, such as dissolved oxygen, temperature, light, and salinity, exhibited parameters similar to those found in marine environments but with notable temporal variations. Between July 2025 and February 2026, temperatures at a depth of 3.51 meters fluctuated between 18.87 °C and 33.11 °C. Dissolved oxygen measurements between July 2025 to February 2026 fluctuated between 7.39 mg/L to 3.42 mg/L (Fig. 3). Salinity measurements between July 2025 to February 2026 fluctuated between 35.16 PSU and 29.34 PSU (Fig. 4).

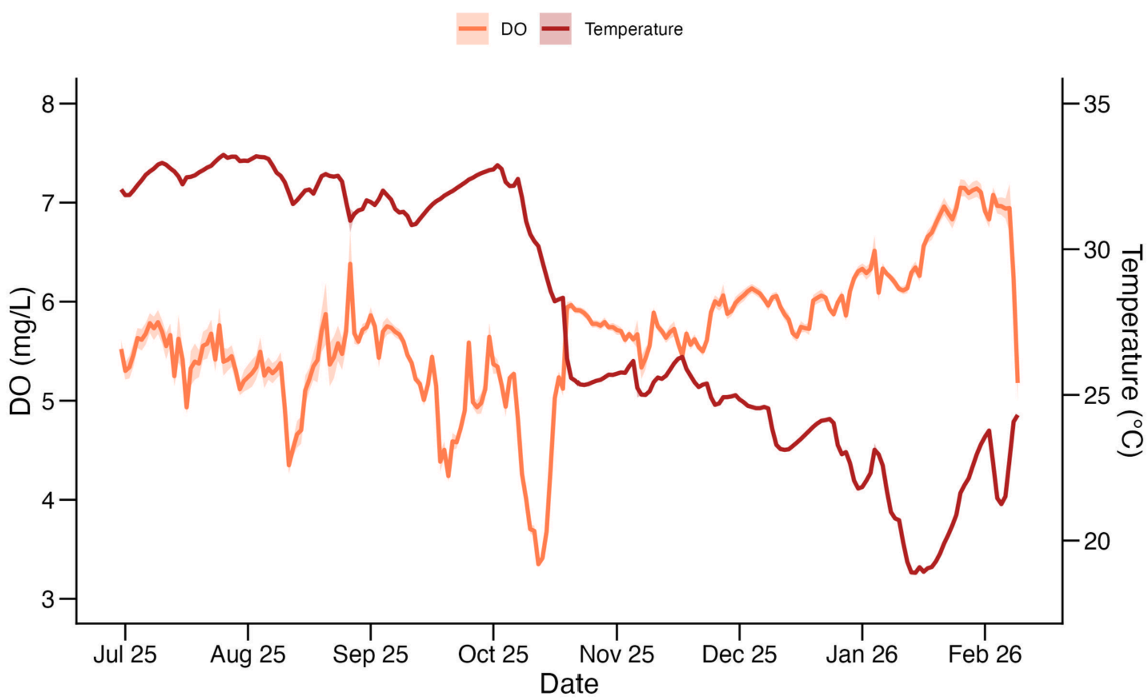

Figure 3. Average dissolved oxygen (DO) and temperature at both quarries over time, as measured by YSI EXO2 sensors (July 2025 to February 2026). Error bands indicate the range of the parameters.

Figure 4. Average salinity in both quarries over time, as measured by YSI EXO2 sensors (July 2025 to February 2026). Error bands indicate the range of parameters.

3.2 Quarry natural benthic communities and crab populations

The benthic habitat across both quarries is dominated by periphyton algal assemblages (~58%), with seasonal variation influenced by cold temperatures. Dominant chlorophyta taxa include Batophora (~40%) and Acetabularia (~3%), also influenced by seasonally cooler temperatures. Chlorophyta algae exhibited peak abundance (percent surface area coverage) during the end of the summer and into fall, August-October 2025. Inversely, periphyton mats were most abundant during the peak of winter, February 2026 (Fig. 5)

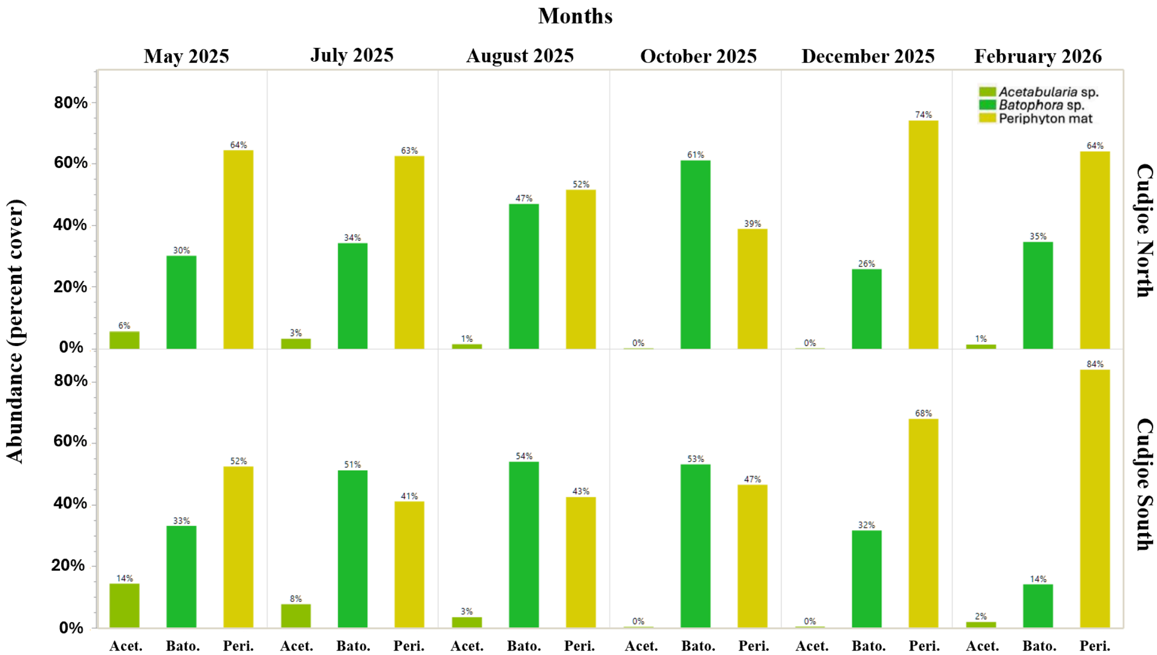

Figure 5. Temporal composition of benthic assemblages at both quarries over time (May 2025 to February 2026).

We found a total of 92 females, 7 gravid females, and 32 males in Cudjoe North during nightly crab surveys throughout April 2025 to March 2026. We found a total of 84 females (Fig. 6), 15 gravid females (Fig. 7), and 57 males (Fig. 8) in Cudjoe South during nightly crab surveys throughout April 2025 to March 2026. The average density of crabs observed in Cudjoe North was 0.15 ±0.02 crabs/m^2, and the average density of crabs observed in Cudjoe South was 0.09 ±0.01 crabs/m^2.

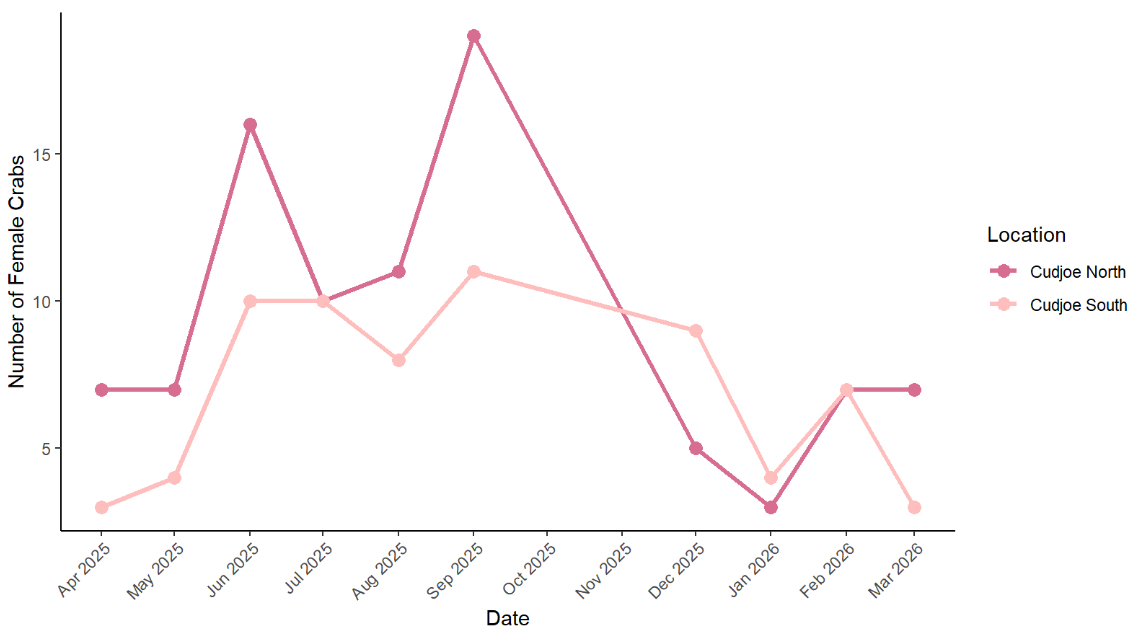

Figure 6. Total number of female crabs found on wild-crab population surveys in both quarries over time (April 2025 to March 2026).

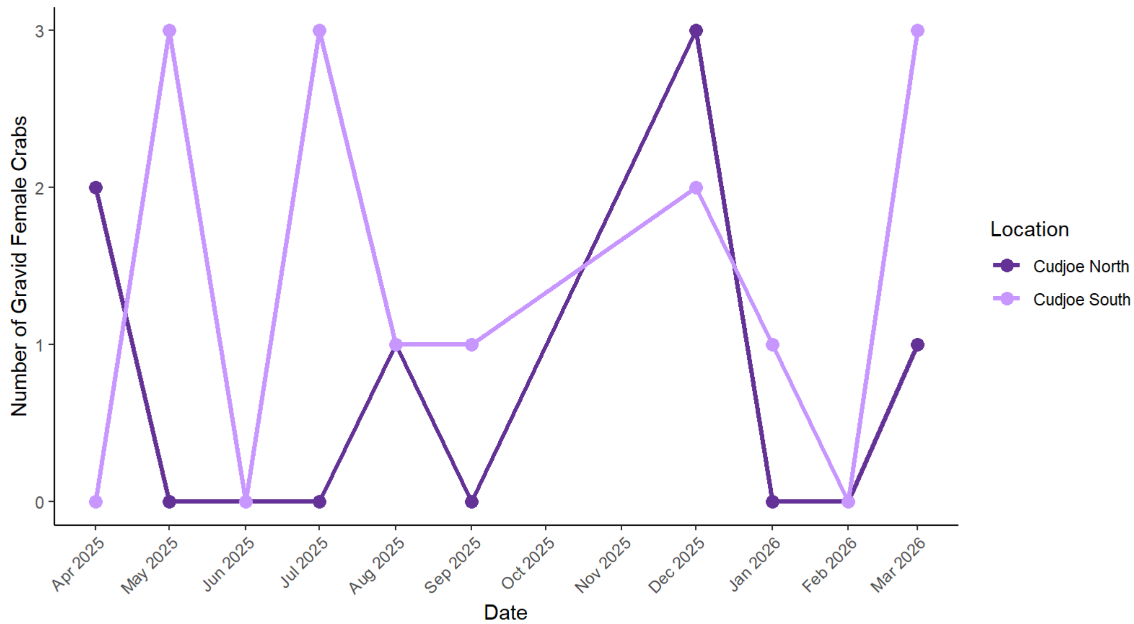

Figure 7. Total number of gravid female crabs found on wild-crab population surveys in both quarries over time (April 2025 to March 2026).

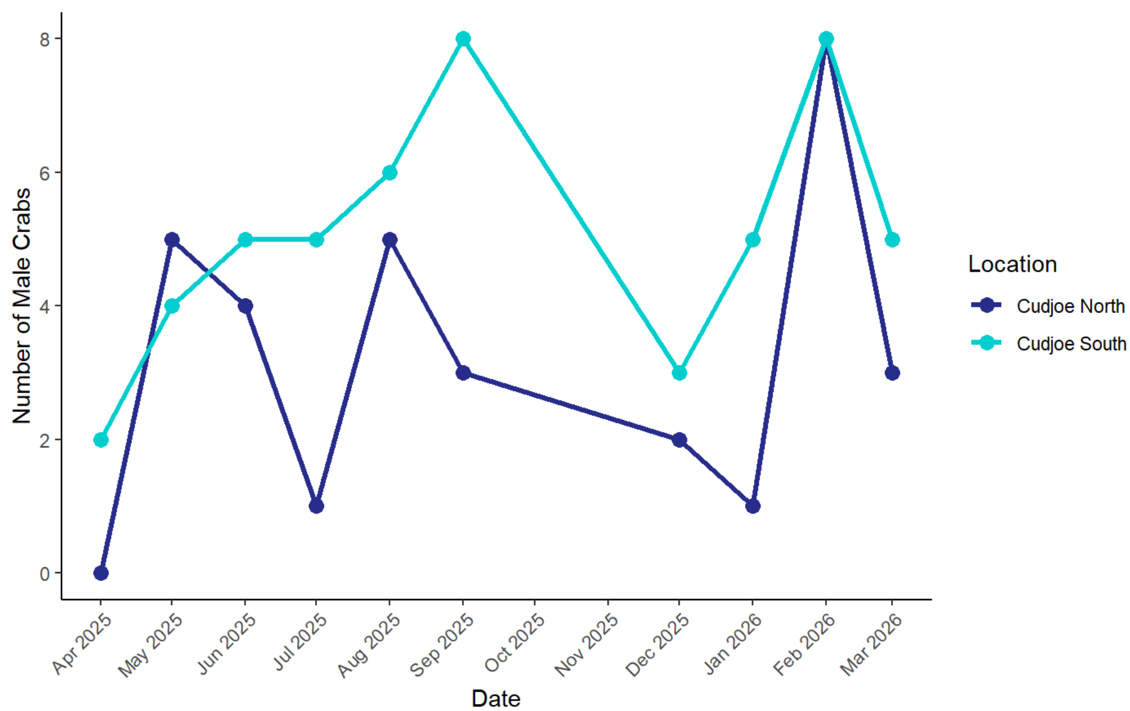

Figure 8. Total number of male crabs found on wild-crab population surveys in both quarries over time (April 2025 to March 2026).

3.3 Benthic assemblages and crab populations in new experimental habitats

The artificial habitats deployed in February 2025 had between 15 to 25% periphyton cover after one month of deployment. In April 2025, the habitats were still dominated by periphyton, having between 25 to 30% periphyton cover. In June 2025 the periphyton cover decreased and was replaced by two macroalgal species: *Batophora oerstedii* and *Acetabularia acetabulum*. The artificial structures had between 7 to 20% *B. oerstedii* cover and 3 to 8% *A. acetabulum* cover in June 2025. By September 2025, the artificial habitats were dominated by *B. oerstedii*, having between 40 to 55% *B. oerstedii* cover. Periphyton cover decreased on the artificial structures, having between 10 to 20% periphyton cover. The artificial structure also began to become inhabited by Aiptasia, Mangrove tunicates, bivalves, and feather duster worms. By December 2025, Aiptasia cover on the artificial structures was between 0.8 to 2.5% Aiptasia cover (Fig. 9).

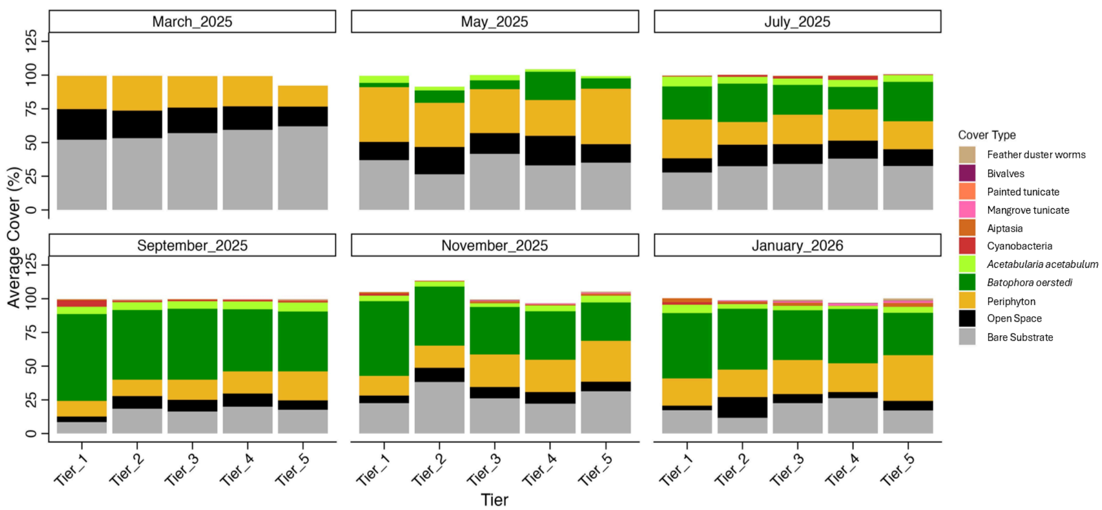

Figure 9. Ecological succession of artificial habitats over time (March 2025 to January 2026) by average cover, tier, and month.

In April 2025, we observed our first presence of *M. spinosissimus* on the artificial structures. From April 2025 to April 2026 divers have observed a total of 36 crabs on the artificial structures. Of those 36 crabs, 19 were females, 9 were gravid females, and 11 were males. Based on these trends, we fitted a generalized linear mixed effects model with a logitlink function which predicted that as time increases, the probability of seeing a crab on an artificial structure increases (Fig. 10, Table 1).

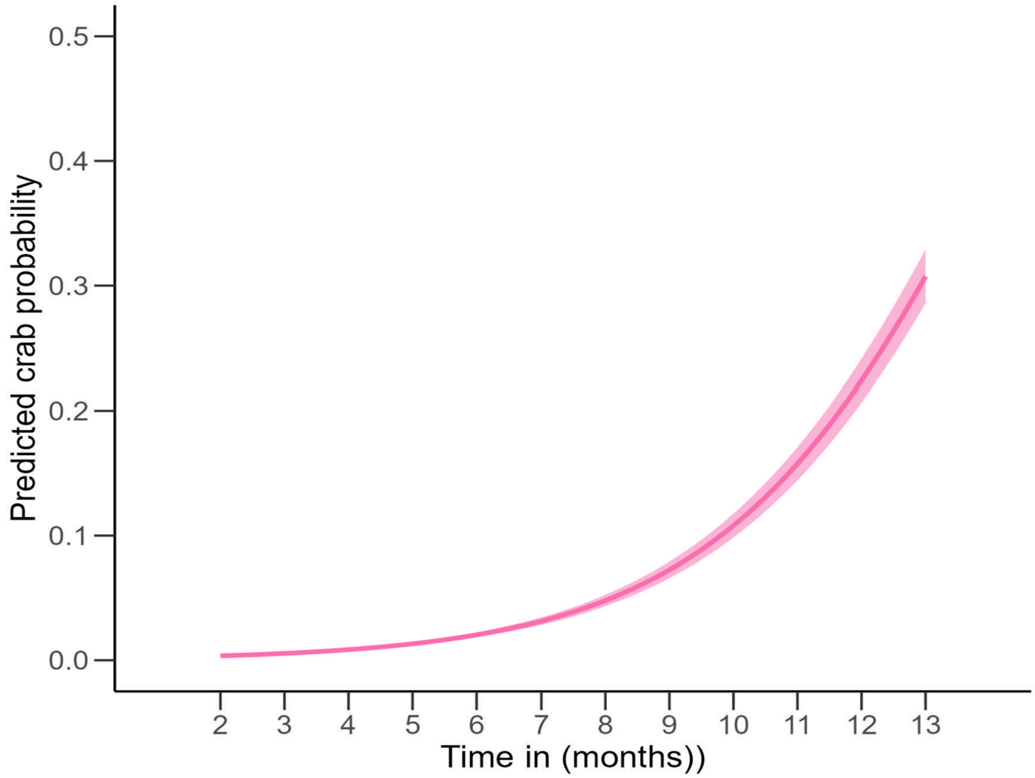

Figure 10. Predicted probability of crab presence on deployed habitats through time.

Table 1. Predicted probability of crab presence on deployed habitats through time.

	Estimate	**SE**	**z**	**p**
Intercept	-6.557	1.303	-5.031	<0.001
Time in Months	0.443	0.109	4.054	<0.001
Habitat Tier 2	-0.810	0.932	-0.870	0.384
Habitat Tier 3	0.527	0.735	0.718	0.473
Habitat Tier 4	-8.59e-16	0.787	0.000	1.000
Habitat Tier 5	-1.616e-15	0.787	0.000	1.000

3.4 Crab translocation

Between April 2025 to March 2026, 231 crabs were translocated from the bay side of Sugarloaf Key, FL and Cudjoe Key, FL, to our experimental quarry, Cudjoe South (Table 2). Of the total crabs translocated, 176 were female and 55 were males. Of the 176 females, 95 were gravid.

Table 2. Number of crabs, by gender, translocated from Sugarloaf Marina, Sugarloaf Key, FL and Venture Out Marina, Cudjoe Key, FL, to Cudjoe South Quarry (manipulated quarry) over time (April 2025 to March 2026).

Gender	Total number of crabs translocated
Female	81
Gravid Female	95
Male	55
Range carapace length (mm)	60-110

4. DISCUSSION

The abiotic and biotic characteristics of the two studied quarries seem to be suitable for the semi-wild mariculture of the Caribbean King Crab (*Maguimithrax spinosissimus*). Salinity and temperature levels resemble those of tropical marine ecosystems, despite seasonal fluctuations associated with colder winter temperatures. There is an abundance of food, with almost 100% of the quarry walls covered by periphyton and macroalgae, as well as very low predation pressure. When the habitats were first deployed, the initial growth and dominance of the periphyton cover supports the model that microbial communities function as a pioneer species in marine systems. The quick observation of macroalgal species like *Batophora oerstedii* and *Acetabularia acetabulum* suggests that the periphyton was able to create a suitable environment for the macroalgae to establish itself. After rapid colonization, the artificial habitats were able to successfully increase both habitat and food availability for *M. spinosissimus*.

Natural quarry populations of *M. spinosissimus* remained relatively low throughout the experiment. However, continuous observation of gravid females at various stages and crabs of multiple size classes suggests that both Cudjoe North and Cudjoe South quarries are supporting reproductively active populations of *M. spinosissimus*. The translocation of 231 adult crabs into Cudjoe South quarry may increase the reproductive potential within the system, as well as contribute to future recruitment of juveniles on the artificial structures. Monitoring of the natural quarry populations will continue long-term to determine whether habitat enhancement and translocation efforts are increasing crab abundance, recruitment, and population stability.

The deployed artificial structures proved to be ecologically functional throughout the monitoring period. We first observed crabs within the structures approximately two months after they had been deployed in the quarry system. The generalized liner mixed effects modeling showed that the probability of crab presence increased significantly over time. This trend suggests that the process of ecological succession will continue to improve habitat complexity and food availability for *M. spinosissimus*.

The findings in this study continue to support the idea that quarry systems in the Lower Florida Keys may function as an effective and sustainable semi-wild mariculture system for *M. spinosissimus*. Long-term monitoring and future genetic analyses will help to improve the understanding of recruitment, habitat use, and overall effectiveness of using quarries for semi-wild mariculture to support coral reef restoration efforts.

5. MAIN FINDINGS AND MANAGEMENT RECOMMENDATIONS

The importance of invertebrate herbivores for coral reef restoration is a primary priority in the Caribbean. There are current successful efforts to boost the production of sea urchins in Puerto Rico (Dr. Stacey William at the Institute for Socio-Ecological Research), Saba (Dr. Alwin Hylkema at Dutch Caribbean Nature Alliance), and Florida (Dr. Josh Patterson at the University of Florida). However, the mariculture of the Caribbean King Crab (Maguimithrax spinosissimus) remains in a bottleneck (Glover and Butler, 2025). Recruitment rates of juvenile crabs within the quarry systems have not been quantified yet. This can make it difficult to estimate the potential long-term production of the crabs. Along with this lack of information, the survivorship of the crabs following deployment onto coral reefs remains poorly understood. It is important to evaluate these gaps before large-scale restoration efforts.

This project showed that the quarry systems in Cudjoe Key provide suitable abiotic conditions for *M. spinosissimus* to survive and reproduce. It also demonstrated that the artificial habitats were able to successfully increase habitat complexity and food availability for *M. spinosissimus*. The artificial structures were able to rapidly develop macroalgal species as well as support crab occupancy over time. The findings collected in this phase have shown that artificial structures may be an effective strategy for increasing Caribbean King Crab production in semi-wild mariculture systems like quarries. By increasing the habitat availability in the quarry, restoration managers may be able to solve the limitation of population growth. This could have the potential to generate larger number of crabs for future reef deployment and restoration projects. By using quarry systems and artificial structures, it can provide managers with an alternative method for increasing crab production while avoiding the challenges associated with laboratory rearing. If successful, this approach could provide a sustainable source of Caribbean King Crabs for coral reef restoration projects throughout the Florida Keys.

Through future genetic analysis of translocated adults and naturally recruited juveniles, we hope to determine the connectivity between quarry and reef populations throughout the Florida Keys. Maintaining genetic diversity is also an important consideration for the future of this project as well as restoration programs. Evaluating the genetic diversity within the quarry populations will help determine whether habitat enhancement efforts are also supporting a genetically diverse population.

While this current study has shown that quarries can support Caribbean King Crab populations, additional research needs to be done. Future monitoring and experiments will be done to quantify the production capacity within the quarries. Future genetic analysis will help us evaluate the genetic diversity among the quarry populations. This research can help determine whether quarry produced crabs can be deployed onto reefs at the capacity needed to sufficiently influence macroalgal abundance and support coral recovery in the Florida Keys.

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