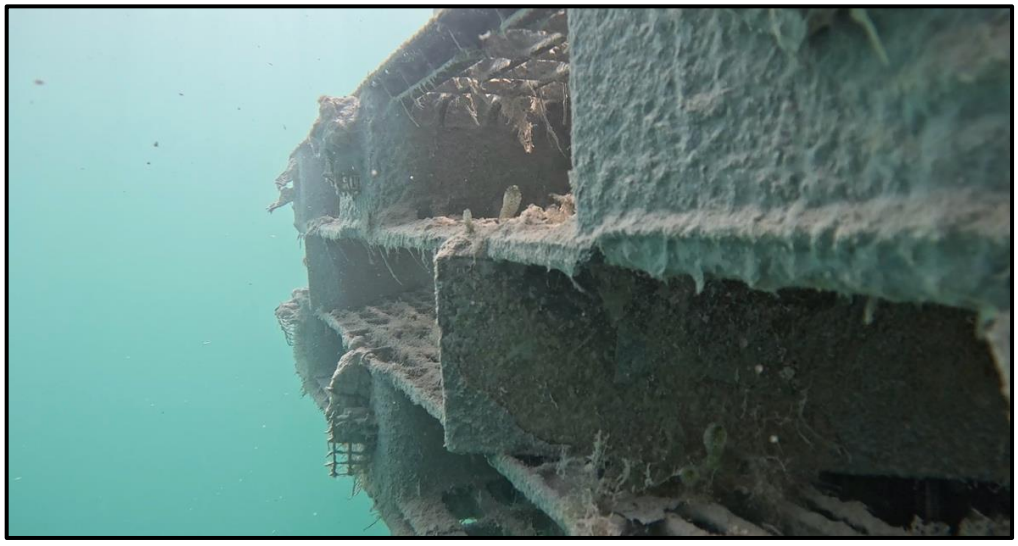
Scaling up mariculture of a native herbivore in support of "*Mission: Iconic Reefs*" coral reef restoration



FIU FLORIDA INTERNATIONAL UNIVERSITY
Department of Biological Sciences

Scaling up mariculture of a native herbivore in support of "*Mission: Iconic Reefs*" coral reef restoration

Final Report

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Management Summary

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 the semi-wild mariculture of the Caribbean King Crab (*Maguimithrax spinosissimus).* Abiotic variables in both quarries are suitable to support crab populations throughout the year. We created five new habitats in February 2025, and by April 19th, we already found four male adult crabs, suggesting that habitat availability is limited in these quarries. 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 August 2024 and April 2025, surface temperatures at a depth of 1.67 meters fluctuated between 20.16°C and 33.47°C. Dissolved oxygen and salinity were 6.19 ± 0.02 Mg/l) and 30.56 ± 0.03 PSU, respectively, year-round for both quarries. The benthic habitats of both quarries are dominated by periphyton mats (~50%), macroalgae (Batophora, ~35%), and Acetabularia (~10%), with apparent seasonal variations. The density of crabs in these habitats is approximately 0.09 ± 0.03 crabs/m². 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 three new habitats in February 2025 using plastic shipping pallets covered with concrete (1-tier to 5-tier habitats, n = 4 sets) and monitored them in March and April. One month after deployment (March), the habitats had between 15 to 25% periphyton algae cover. By April, the average periphyton cover was 27.71 ± 0.78%, and other macroalgal species were starting to grow (e.g., *Acetabularia* sp.). On April 19th, four male adult crabs were found in our new habitats, suggesting that improved habitat conditions resulting from two months of macroalgal recruitment and succession- are triggering adult crab migration, which hopefully translates into enhanced crab production. 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 II.

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1. BACKGROUND

Mithrax spinosissimus occurs primarily along the rocky edges of quarries in the Florida Keys, from the surface down to approximately 6m. Their distribution elsewhere in quarries is limited by a lack of food (algae) and shelter (crevices) on the muddy bottom, as well as by inappropriate water quality below the stratified surface waters. Therefore, most of the area in quarries – which can be many hectares in surface area – is uninhabited by crabs that dwell only along the quarry's rocky rims. A potential way to increase crab production in quarries is to expand benthic areas in quarries that lie above 6 m where macroalgae grow (i.e., crab food) and water quality is conducive to crab existence. We propose testing this by providing additional crab habitat in one quarry designated for experimental purposes (Cudjoe South) and comparing the outcome to a nearby unmanipulated control quarry (Cudjoe North).

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), of similar size (~6 ha in area), and depth (~12 m), and with similar benthic characteristics (Fig. 2). Both quarries are privately owned with only limited, gated access.

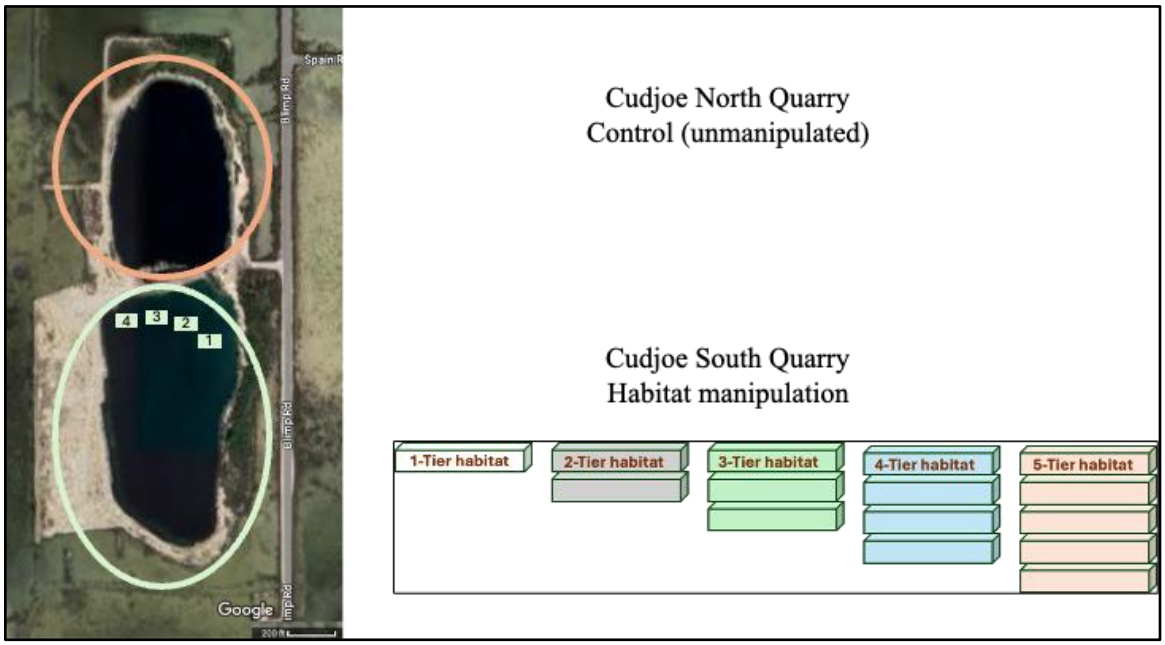

Figure 1. Study sites, Cudjoe Quarries North (control) and Cudjoe South (manipulated), where the new habitats were added.

HOBO Onset MX801 Sensors were deployed, providing us with temperature, oxygen, and light readings every thirty minutes. Additionally, HOBO Pendant sensors collected light and temperature at the same interval. Additionally, we collected salinity and other parameters each month 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 m^2. 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

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, eight; 3-tiers, 12; 4-tiers, 16; and 5-tiers, 20.

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 the 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 won't happen until another phase of this project.

3. RESULTS

3.1. Quarry abiotic conditions

Abiotic conditions, such as dissolved oxygen, temperature, conductivity, and salinity, exhibited parameters similar to those found in marine environments but with notable temporal variations. Between August 2024 and April 2025, surface temperatures at a depth of 1.67 meters fluctuated between 20.16°C and 33.47°C (Figure 2). Dissolved oxygen and salinity were 6.19 ± 0.02 Mg/l and 30.56 ± 0.03 PSU, respectively, year-around for both quarries.

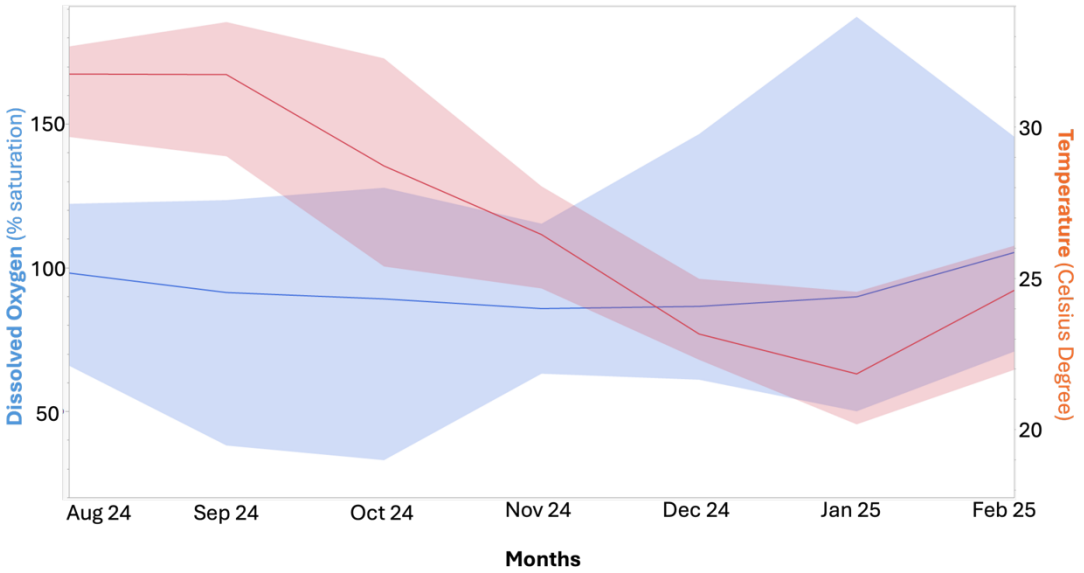

Figure 2. Average dissolved oxygen and temperature at both quarries over time obtained from Hobo sensors (August 2024 to February 2025)

3.2. Quarry natural benthic communities and crab populations

The benthic habitats of both quarries are dominated by periphyton mats (~50%), macroalgal taxa (phylum Chlorophyta), including Batophora (~35%), and Acetabularia (~10%), with apparent seasonal variations. These green macroalgal taxa exhibited an abundance (percent cover) peak during the summer season (August 2024) and declined over the winter (Figure 3). On the contrary, the abundance (percent cover) of periphyton mat doubled from November 2024 to February 2025, the coldest months of the year.

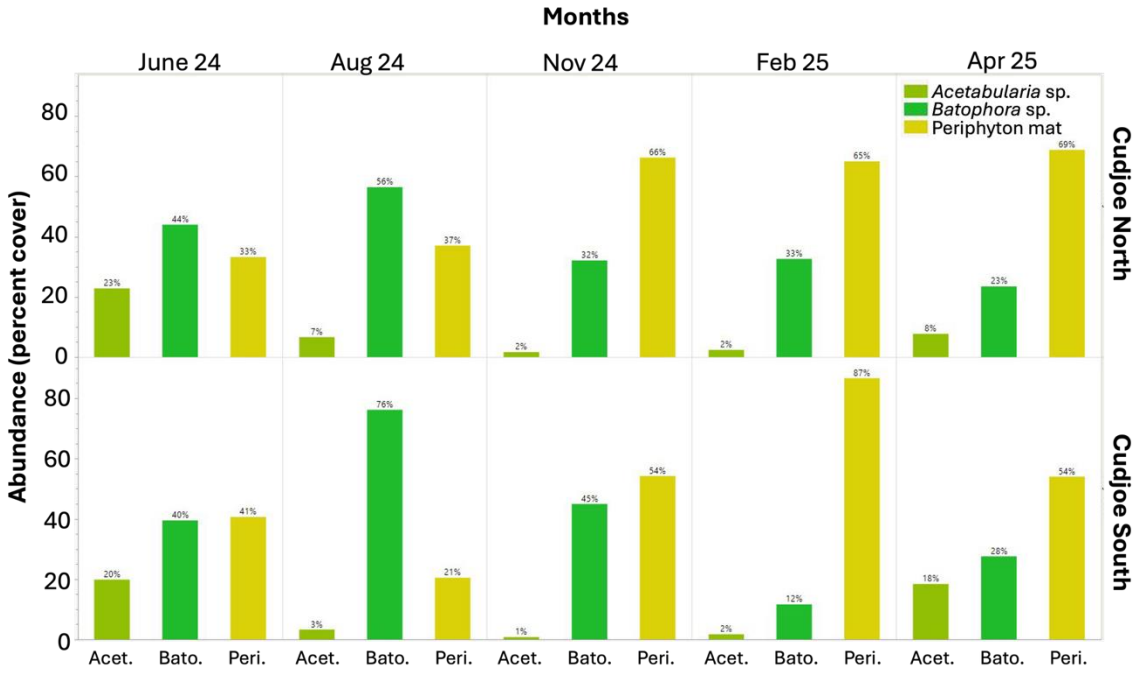

Figure 3. Temporal composition of benthic assemblages at both quarries over time (June 2024 – April 2025)

We found a total of 11 crabs in Cudjoe North and five crabs in Cudjoe South, averaging 0.09 ± 0.03 crabs/m² (Table 1). Over 75% of all crabs were female, and two were gravid.

Table 1. Number of crabs observed by quarry. Each site was surveyed at night along 4 (20 m^2) transects

Surveyed crabs	Cudjoe North	Cudjoe South
Female	9	3
Female, gravid	2	0
Male	0	2
Range Carapace Length (mm)	71-99	71-99

3.3. Benthic assemblages and crab populations in new experimental habitats

The new habitats we created in February 2025 had between 15 to 25% periphyton cover one month after deployment (Figure 4). By April, the average periphyton cover was 27.71 ± 0.78%, and other macroalgal species were starting to grow (e.g., *Acetabularia* sp.). On April 19th, four male adult crabs were found in our new habitats, which coincided with our predicted results (Figure 5). Notice that this report includes data only until April (two months after deployment)

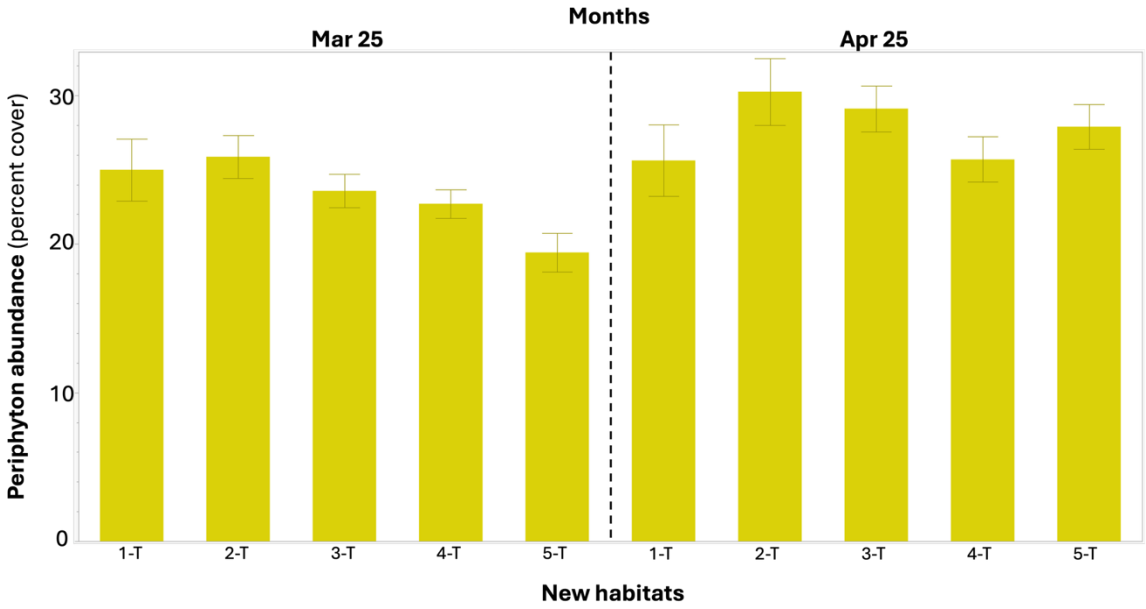

Figure 4. Average abundance of periphyton mat on experimental new habitats. 1-T (one-tear habitat), 2-T (two-tear habitat), 3-T (three-tear habitat), 4-T (four-tear habitat), and 5-T (five-tear habitat).

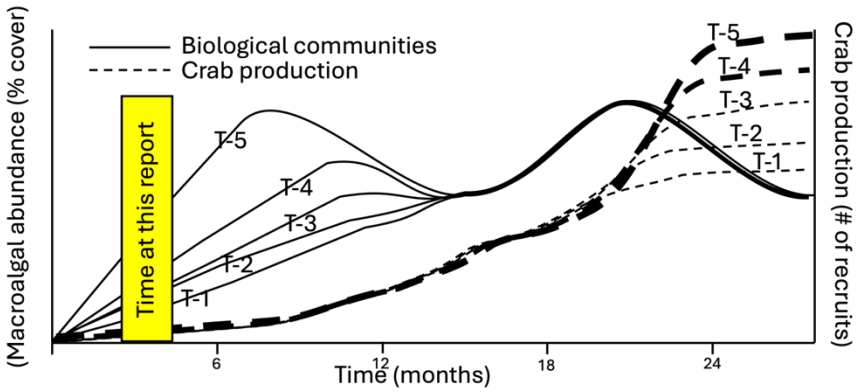

Figure 5. Expected results of experimental new habitats. Notice that the abundance of macroalgae in our results matches the predicted results three months after new habitat deployment.

3.4. Crab translocation

Between April 20th and May 6th, 25 crabs were translocated from the bay side of Sugarloaf Key, FL, to our experimental quarry, Cudjoe South (Table 2). Of the total crabs translocated, 20 were female, and five were male. The average carapace length of the females translocated was between 84.5mm, and the average carapace length of the males translocated was 108mm. Of the 20 females collected, nine were gravid.

Table 2. Crab Translocations from Sugarloaf Marina, Sugarloaf Key, FL, to Cudjoe South Quarry (manipulated quarry)

Number of crabs translocated	April	May
Female	5	6
Female, Gravid	4	5
Male	3	2
Range carapace length (mm)	71-99	71-99

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, and 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. However, the low crab densities reported in this report suggest that habitat is a limited factor for population growth. Our new experimental habitats were quickly covered by periphyton (~30%), which may have attracted adult crabs, as four individuals were found in April. We still need to wait until the new habitats complete their benthic community succession and adult crabs start reproducing, but we feel optimistic about the final results.

Artificial habitats have been used for generations to enhance the fisheries of both vertebrates and invertebrates. Yet, there has been a long-term debate about whether these devices simply attract adult organisms that benefit from shelter or boost fisheries by promoting the reproduction and survival of newly hatched individuals (Wilson et al. 2001, Layman and Allgeier 2020). In the Florida Keys and other tropical areas, artificial reefs have been shown not only to gather lobster but also to increase recruitment and ultimate production by mitigating habitat loss (Jensen et al. 2002). Our results match the conclusions by Glover and Butler IV (2025), who first proposed the use of Florida quarries as potential for semi-wild mariculture of *M. spinosissimus*. Sixty days after deployment, the artificial habitats are partially covered by macroalgae, and we observed early recruitment of adult crabs- which can potentially reproduce and increase the production of new larvae.

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 (Glober and Butler, 2025). 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.

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