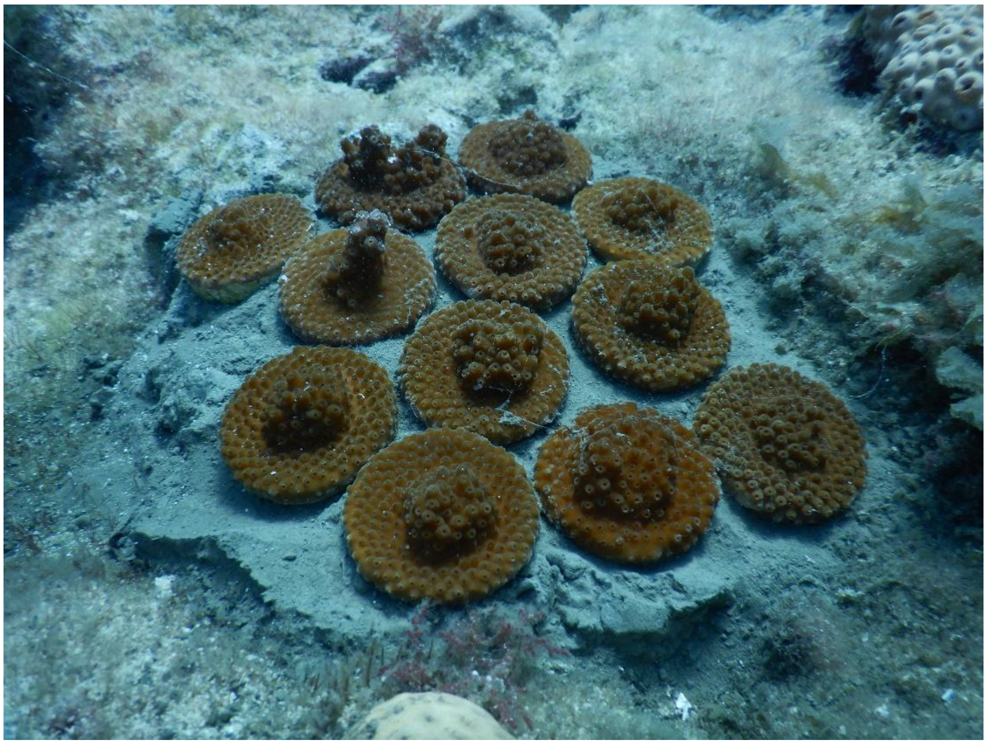
The Role of Outplant Density on Coral Survivorship, Growth, Predation Impacts, and Disease Spread



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The Role of Outplant Density on Coral Survivorship, Growth, Predation Impacts, and Disease Spread

Final Report

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Management Summary

Our project has shown clearly that *A. palmata* fragments can be transferred from Monroe County into Miami-Dade and Broward Counties to increase the genetic and genotypic diversity of this species that has a very low extant abundance outside the Florida Keys. The high survivorship (>97%) of elkhorn clusters grown *ex situ* indicates the viability of the assisted migration of this keystone species.

In the absence of source populations outside the Florida Keys, only the *ex situ* husbandry of this species will provide the tissue needed for successful restoration. We strongly encourage management agencies to provide the financial resources needed to expand these coral transfers to preserve and restore the connectivity of this depleted species along Florida's Coral Reef.

Fish predation continues to be the main driver of tissue losses for outplanted massive corals. While differences in predation impacts were found among species and sites, outplant density was not a significant driver of predation impacts. Thus, planting corals in dense arrays does not appear to provide any benefits to corals through predation dilution. Additional measures will need to be explored to reduced fish predation, which reached an average of >30% tissue removal for the most susceptible species (*C. natans* and *O. faveolata*) after just one week.

We encourage management agencies to continue to allocate resources to understand the drivers of fish predation and design mitigation strategies so that massive corals can be effectively incorporated into large-scale restoration efforts. Until these bottlenecks have been explored, we suggest focusing restoration on species like *D. labyrinthiformis* that are not as susceptible to predation (other species still need to be propagated and outplanted to help understand drivers of species susceptibility to predation).

Executive Summary

Restoration partners from The University of Miami, Nova Southeastern University, Mote Marine Laboratory, Biscayne National Park, NOAA Southeast Fisheries Center, and the Florida Aquarium collaborated to evaluate the role of coral outplant density on the survivorship and growth of corals with branching (*Acropora palmata*) and massive (*Colpophyllia natans*, *Diploria labyrinthiformis*, and *Orbicella faveolata*) colony morphologies. In addition, we completed the assisted migration of *A. palmata* colonies from Monroe County into Miami-Dade and Broward counties to increase the genetic and genotypic diversity of this species that has a very low extant abundance outside the Florida Keys.

Fish predation was found to be the main driver of tissue losses for massive corals. While differences in predation impacts were found among species and sites, outplant density was not a significant driver of predation impacts. Thus, planting corals in dense arrays does not appear to provide any benefits to corals through predation dilution. Additional measures will need to be explored to reduced fish predation, which reached an average of >30% tissue removal for the most susceptible species (*C. natans* and *O. faveolata*) after just one week.

We completed the successful transfer of 54 genotypes of the endangered *A. palmata* from the MML *ex situ* facility onto five reefs from Monroe to Broward County. Cluster survivorship was very high (99.9%) across the five sites, with only four clusters experiencing complete mortality within the first month. Three months after outplanting, survivorship ranged from 96.2-97.2% Finally, no disease was observed at any of the outplanted corals or the areas surrounding the outplant plots during this study. While cluster size did not appear to influence survivorship, extended monitoring will be needed to evaluate the role of cluster density on growth and branching patterns of these corals in their new habitats.

Acknowledgements

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List of Acronyms

Apal	*Acropora palmata*
Dlab	*Diploria labyrinthiformis*
Ofav	*Orbicella faveolata*
Cnat	*Colpophyllia natans*
SCTLD	*Stony Coral Tissue Loss Disease*

1. DESCRIPTION

The goal of this collaborative proposal (UM, NSU, MML, NPS, NOAA, FLAQ) was to explore the role of outplant density, utilizing three SCTLD-susceptible coral species (*C. natans*, *D. labyrinthiformis*, and *O. faveolata*), in restoration success, an important research gap that needs to be studied as the scale of restoration increases regionally. Density can have a key influence on the outcome of predation as well as the spread and impacts of disease on SCTLD-susceptible species. A secondary objective of this project is to complete the assisted gene flow (or assisted relocation) of the threatened species *A. palmata* from the Florida Keys to Miami and Broward counties where only a handful of colonies of this keystone species survive today. The role of density in determining outplant success directly addresses a direct restoration activity priority and the coral species to be used in this project have been identified as priority species for propagation and restoration by the State of Florida in the "State of Florida Restoration Priorities for Florida's Coral Reef: 2021-2026" report.

Goal 1: Evaluate the role of outplant density on the survivorship, growth, predation impacts, and disease prevalence (if observed) of SCTLD-susceptible juvenile corals
Goal 2: Evaluate the role of outplant density and genotype diversity on the survivorship, growth, predation impacts, and disease prevalence (if observed) of *A. palmata*
Goal 3: Evaluate whether *A. palmata* corals grown from larvae from Florida Keys parent colonies can be effectively introduced into Miami-Dade and Broward counties for propagation and restoration.

2. TASKS AND RESEARCH OUTCOMES

2.1 Task 1a: Grow and transfer corals (SCTLD-susceptible species)

Colonies of C. *natans*, O. *faveolata*, and D. *labyrinthiformis* grown from larvae and attached to ceramic plugs were sent to the partners by FLAQ to outplant onto 3 reefs as part of an outplant density experiment. FLAQ completed all nursery-transfer paperwork and conducted a veterinary inspection prior to delivery of the corals.

Juvenile corals (total = 835 corals) were used for this project: UM (210 *C. natans* and 205 *D. labyrinthiformis*), NSU (210 *C. natans*), and BNP (210 *O. faveolata*). These corals were outplanted onto three reefs by NSU, UM, and BNP within 72 hours of delivery in January 2023. All corals conditioned at FLAQ arrived in excellent condition and were outplanted with no signs of partial mortality.

Figure 1 *Images of the juvenile corals grown and transferred by FLAQ to partners (left images) and corals outplanted to the reef (right).*

2.2 Task 1b: Grow and transfer corals (*Acropora palmata*)

MML fragmented and grew *A. palmata* colonies attached to ceramic plugs to outplant onto 5 reefs in different density arrangements. These corals represent 54 distinct genotypes that were settled and propagated at MML. Corals were delivered to partners for outplanting in January 2023. All corals were assessed for condition (vet check) and measured prior to transfer.

The *Acropora palmata* corals were distributed to MML/Lower Keys (818 corals), UM (842 corals), NSU (795 corals), NOAA/Upper Keys (818 corals), and BNP (828 corals) for outplanting. A total of 4,111 corals were made available for outplanting onto 5 reefs. All corals, mounted on ceramic plugs, arrived in excellent condition and were outplanted without transport mortality in January-February 2023.

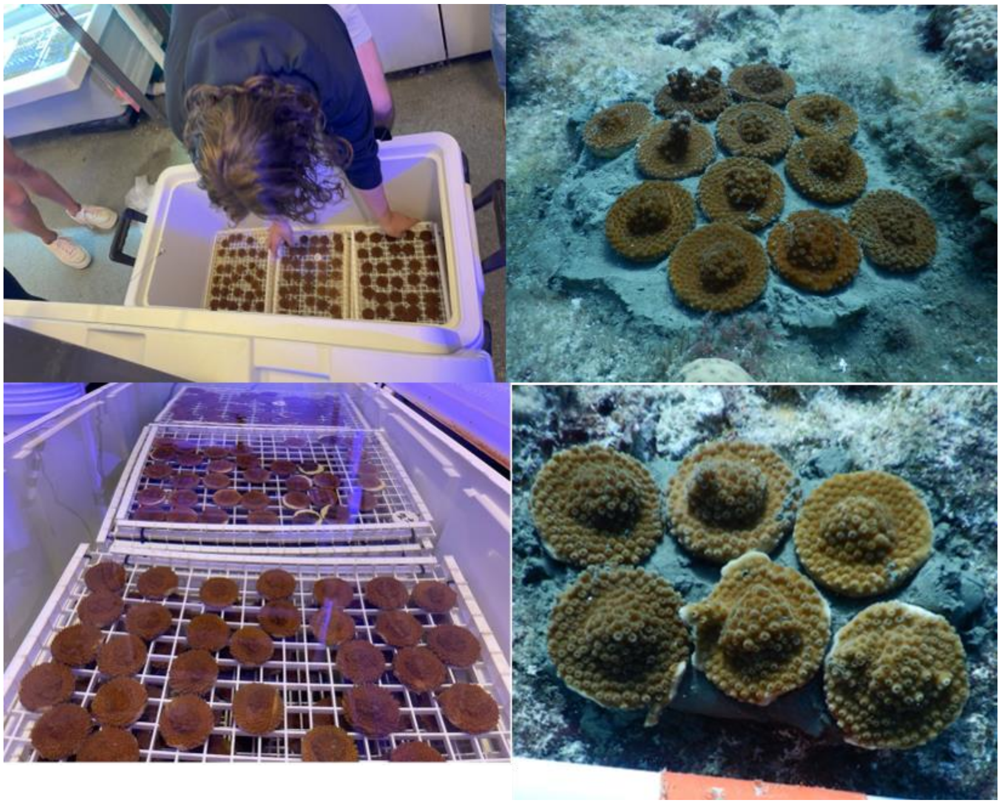

Figure 2 *Images of the A. palmata corals grown and transferred by MML to partners (left images) and corals outplanted to the reef (right).*

2.3 Task 2: Outplant and Monitor Corals

All corals grown and transferred by MML and FLAQ to project partners were successfully outplanted in January-February 2023. DRM (Disturbance Response Monitoring) and RVC (Reef Fish Visual Surveys) were conducted at each reef prior to outplanting. Outplanted corals (individual colonies in the case of massive corals and coral clusters in the case of Apal) were monitored visually and photographically at 1 week, and 1, 3, and 5 months after deployment to document coral survivorship, growth, predation impacts by fish (presence of bites and coral removal), other potential causes of mortality (e.g., algal overgrowth), as well as disease prevalence and spread if observed (no disease was observed).

Table 1 *Outplant sites used in this project.*

Agency	Species Outplanted	Latitude (°N)	Longitude (°W)	Depth (ft)
NSU 1	Apal	26.2060	80.0856	15
NSU 2	Cnat	25.9768	80.1000	20
Miami	Apal, Cnat, Dlab	25.6441	80.0969	21
BNP	Apal, Ofav	25.4698	80.1317	15
NOAA	Apal	25.1541	80.2677	15-22
MML	Apal	24.4823	81.7042	12-15

2.3.1 Massive Corals

2.3.1.1 Methods

At each reef site (one in Broward with Cnat, one in Miami with Dlab and Cnat, one in Biscayne National Park with Ofav), plots, approximately 15m x 25m in size, were set up using nails and tags. Each treatment plot was 1m x 1m in size, spaced 5m apart. Corals were outplanted using cement in the following treatments:

1) High density quadrats (six plots; 15 corals m^{-2})
2) Medium density quadrats (six plots, nine corals m^{-2})
3) Low density quadrats (six plots, three corals m^{-2})
4) Control/Protected corals (20 corals protected by bamboo skewers)

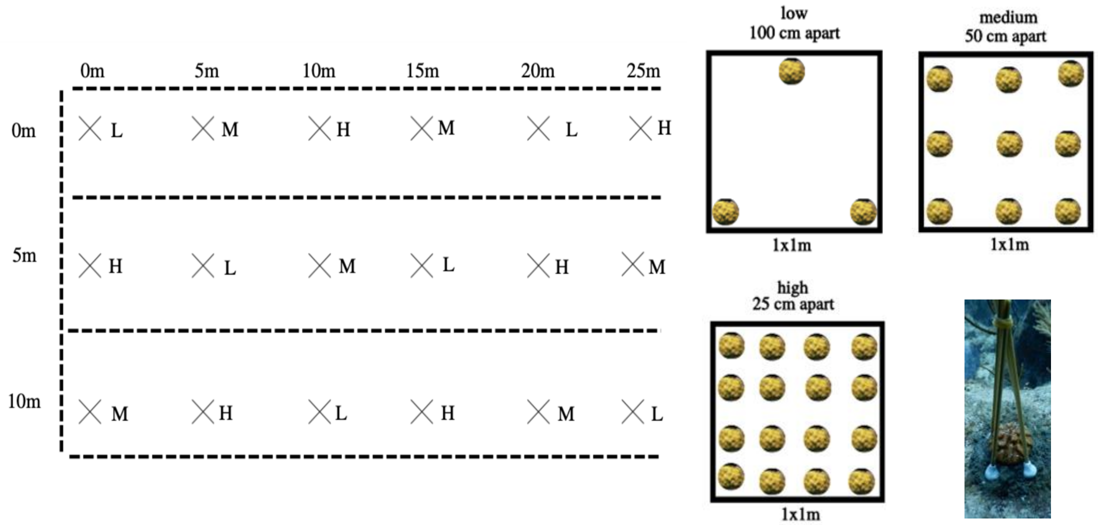

Figure 3 *Schematic of the design used to assess the role of coral outplant density on fish predation showing the site layout, the density arrangements, and the teepees used for coral protection.*

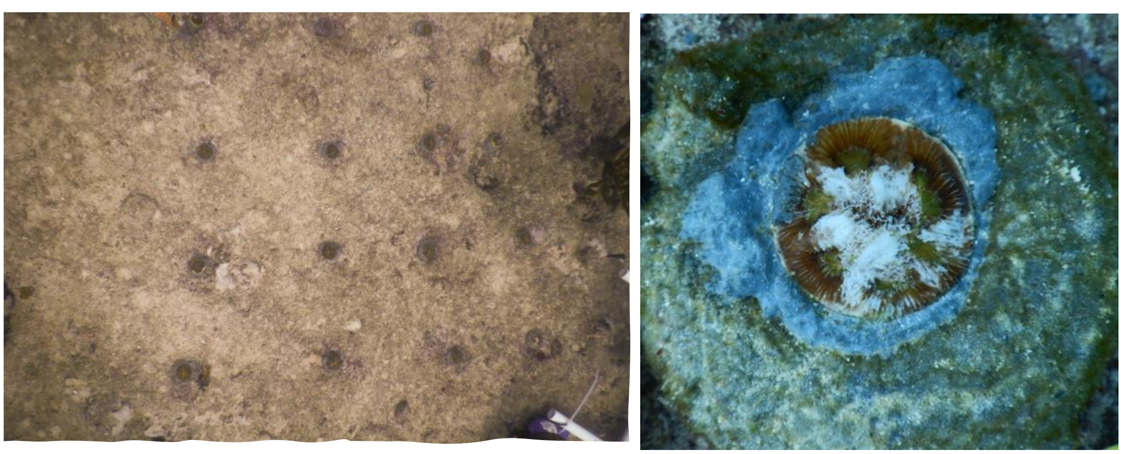

Figure 4 *Image of a high-density coral outplanting plot (left) and a Cnat colony with heavy predation after 1 week (right).*

2.3.1.2 Results

The teepees provided excellent protection against fish predation, with no evidence of predation recorded for protected corals after 1 month compared to corals within the density treatments. This confirms that fish predation was the primary driver of tissue losses during the first month of this experiment.

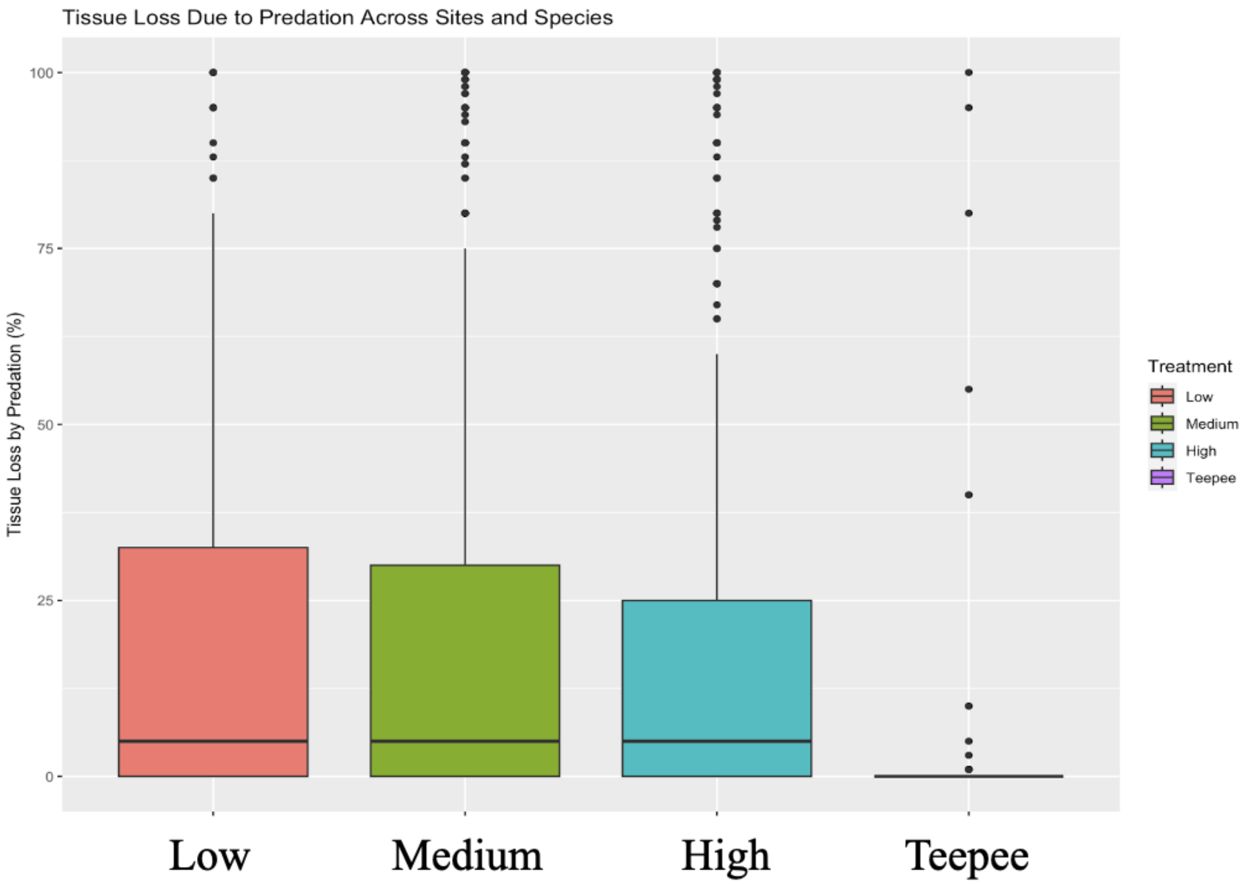

Figure 5 *Percent tissue removed by predation for corals (all species and sites combined) without (corals in the low, medium, and high-density treatments) and with protection (teepees) after one month. Tissue losses were significantly lower for protected corals.*

The density treatments had no significant influence on the level of fish predation for any reef or species. No significant differences in percent tissue removal were observed at one week and 1 month for all species at all sites.

Predation impacts were higher during the first week and declined significantly over time, with only limited new predation observed after 1 month, with only limited new predation observed after one month (three- and five-month surveys). This was consistent among sites and species.

Predation impacts were species-specific. *C. natans* (35.3% tissue removed) experienced significantly higher average tissue removal due to predation than *D. labyrinthiformis* (2.6%) after only one week at the same site in Miami. Predation impacts were also high for *O. faveolata*, which had > 29% tissue removed on average during the first week.

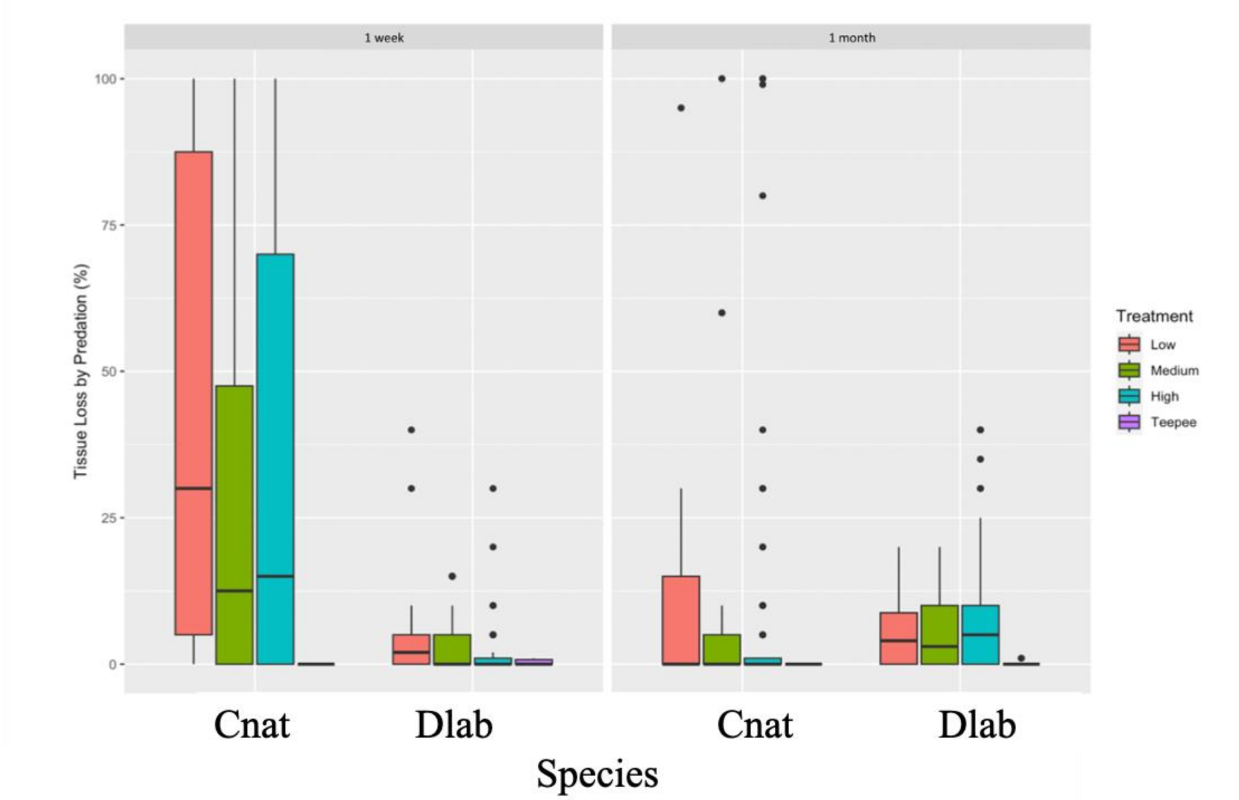

Figure 6 *Percent tissue removed by predation for C. natans and D. labyrinthiformis corals in the low, medium, and high-density treatments after one week and one month.*

2.3.1.3 Discussion

In this study we tested the potential for outplanting massives in high density arrangements and found that density did not significantly impact susceptibility to fish predation. However, fish predation continues to be a bottleneck for outplanting massive species, so it is important for management agencies to continue exploring methods to mitigate impacts.

2.3.2 Acropora palmata

2.3.2.1 Methods

At each site, 23 plots were set up to receive 7 cluster groups of *A. palmata* plugs of a single genet each (to minimize intraspecific competition and allow for fusion among fragments). Individual clusters were separated by at least 25 cm within a plot and were arranged along transects to facilitate repeated surveys. To ensure that an equal number of fragments (n = 12) were outplanted into each cluster size treatment, we outplanted four clusters comprised of 3 fragments, two clusters comprised of 6 fragments, and one cluster comprised of 12 fragments per plot. Each site received 23 sets of 36 corals for a total of 828 fragments per reef, and 4,140 fragments in total. Corals were outplanted using cement by 4 of the 5 groups (MML used Zspar) and corals within each cluster were outplanted as close together as possible to facilitate fusion as corals grow.

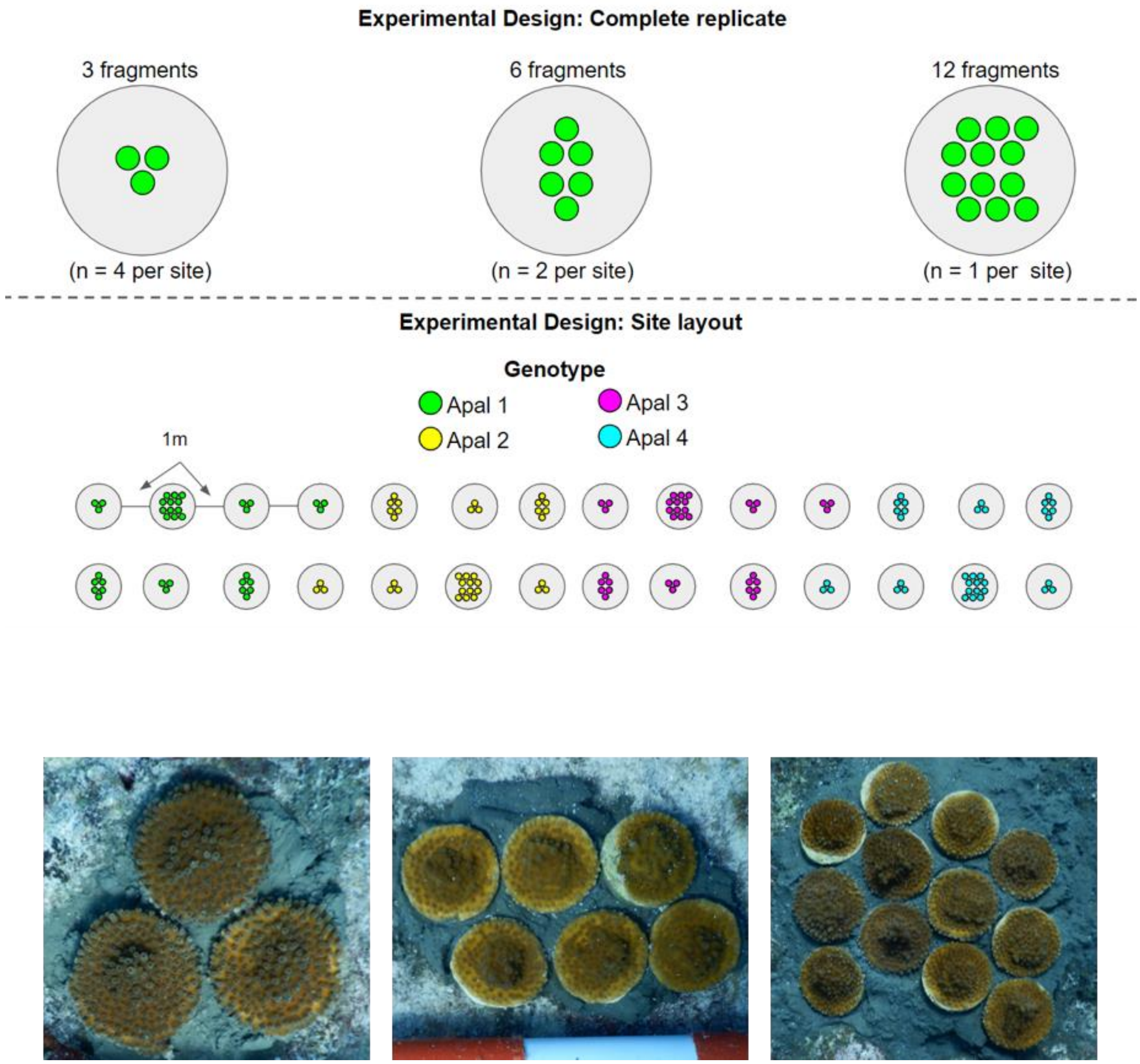

Figure 7 *Schematic of the A. palmata deployment with images of the corals within 3, 6, and 12-fragment clusters.*

2.3.2.2 Results

One month after outplanting, overall survivorship of *A. palmata* outplants remained high (99.9%) across the 5 sites, with only 4 clusters experiencing complete mortality. Across all sites (N=805 clusters), only 3 clusters (0.4%) were missing 1-2 fragments. Among those 805 clusters, 35.3% had partial mortality and 64.7% were completely healthy. Partial mortality varied by genotype, with some genotypes performing consistently well across multiple sites and other genotypes performing differently by site, suggesting that some genotypes may have more phenotypic plasticity and adaptability compared to those genotypes whose performance varies by site. Cluster size did not appear to influence survivorship of *A. palmata* outplant at any of site.

Table 2 *Average survivorship of A. palmata outplants across five restored plots three months after outplanting.*

Group	**Average Survivorship (%)**
BNP	94.0
MML	96.1
NOAA	98.5
UM	96.9
NSU	99.2

Three months after outplanting, survivorship of *A. palmata* clusters was high, ranging from 96.2% in the 12-cluster groups to 97.2% in the 3-cluster groups (the 6-cluster groups averaged 96.7% survivorship across the 5 reef sites). With cluster type pooled, the average survivorship of *A. palmata* outplants across the 5 reefs ranged from 94.0% - 99.2% (average survivorship across all sites and clusters was 96.9%; Table 1). Among the 805 clusters across the 5 restored plots, only 0.6% were pale, and none showed any signs of disease or bleaching.

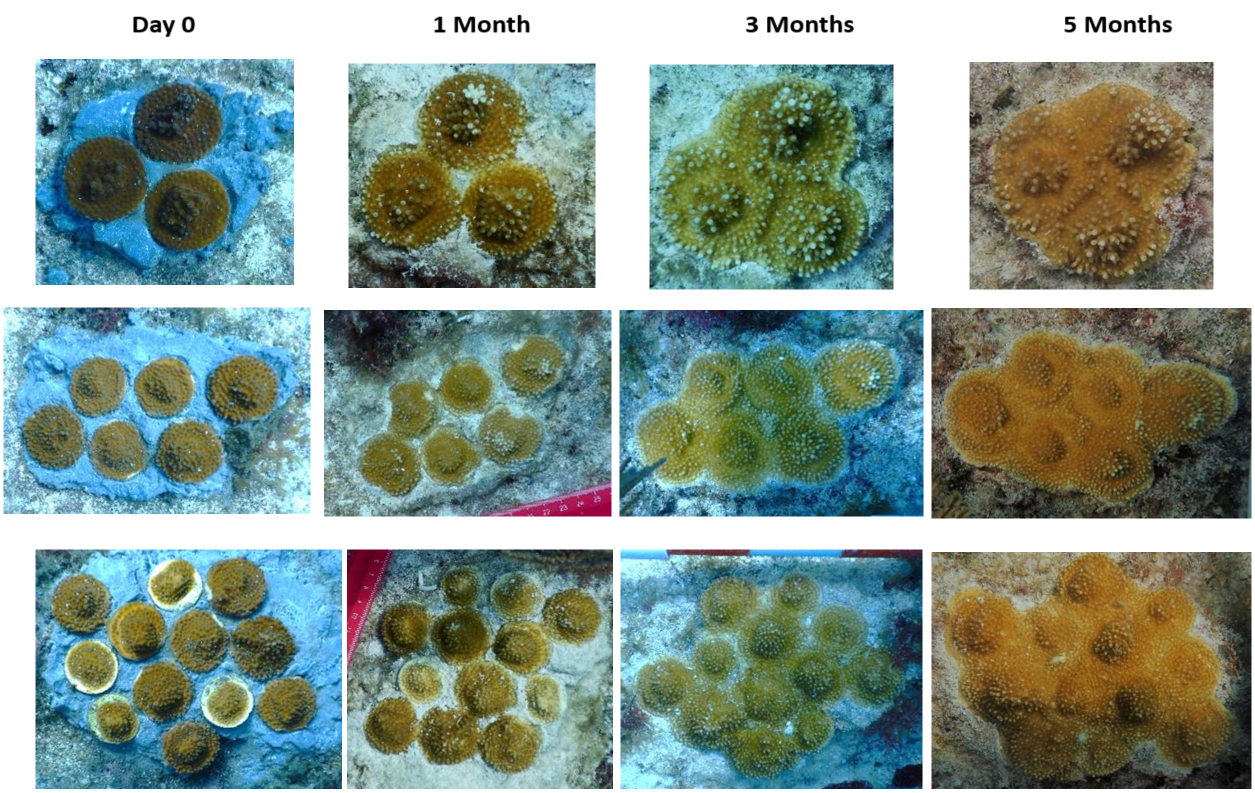

Figure 8 *Images of the A. palmata clusters over time.*

A total of 54 genotypes of *A. palmata* were distributed among the 5 groups, with each genotype being represented at 1-5 sites. Average survivorship of genotypes across the 5 sites with cluster types pooled ranged from 66%-100%. The genotype ("AP59") with the lowest average survivorship was only represented at the BNP site so it is not possible to determine if the performance was a result of genotype or environment. In the first month of monitoring, the AP59 genotype at the BNP site was heavily predated, though subsequent surveys at the BNP site have shown less predation impacts among coral outplants. The next genotype (“AP65”) had an average survivorship of 84.8% and was represented at 3 sites, so it is likely a better representation of genotypic performance across sites. Of the 54 genotypes outplanted across the 5 sites, 16 genotypes (30%) had 100% survivorship across sites and 34 genotypes (63%) had >98% survivorship across sites.

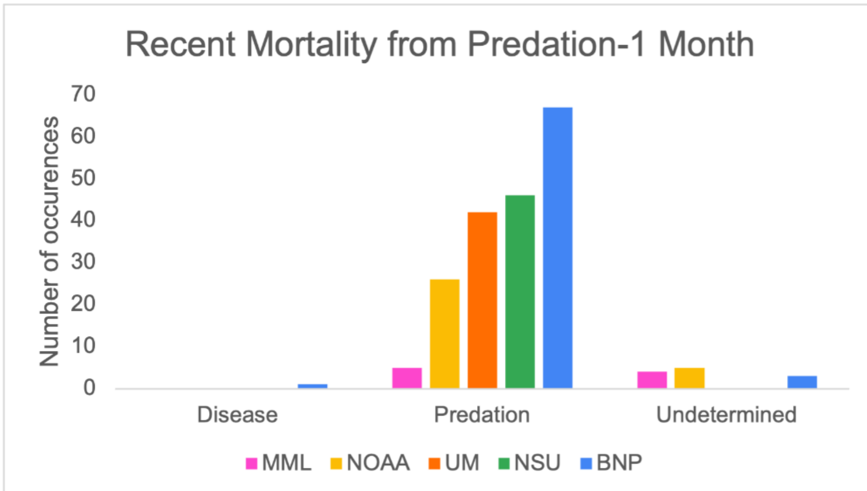

Figure 9 *Partial mortality of A. palmata clusters after one month across five sites.*

After 1 month, predation impacts were observed across all 5 sites and accounted for most of the recent partial mortality. Average tissue removal of *A. palmata* clusters by corallivores averaged 14.6% across the 5 sites, ranging from 2.2% (NSU) to 24.2% (BNP) average tissue loss by cluster. Of the 805 clusters outplanted at the 5 restored plots, 186 clusters (23.1%) were documented to have predation impacts after 1 month. The primary predators observed were snails, though fewer instances of fish bites and complete colony removal by fish were noted. Only 2 cases of fire worm predation were documented. Smaller clusters appeared to be more susceptible to predation impacts, with 54.3% of predation prevalence (percent of clusters with any level of predation) observed among the 3-cluster corals, compared to 27.2% of the 6-cluster, and 18.5% of the 12-cluster corals. No disease was observed.

After 3 months, recent predation impacts declined to 9.8% of average tissue removal by cluster across the 5 sites, ranging from 1.0% (NSU) to 15.2% (MML). Of the 805 clusters outplanted at the 5 restored plots, only 24 clusters (3%) were documented to have some level of tissue removal by corallivores after 3 months (Fig. 10). The smaller density clusters continued to be targeted preferentially by predators, with 45.8% of total documented instances of predation occurring among the 3-cluster groups, compared to 29.2% of 6-cluster and 25% of 12-cluster groups. The amount of tissue mortality caused by predation ranged between 1% - 33% of the affected coral clusters. No disease was observed.

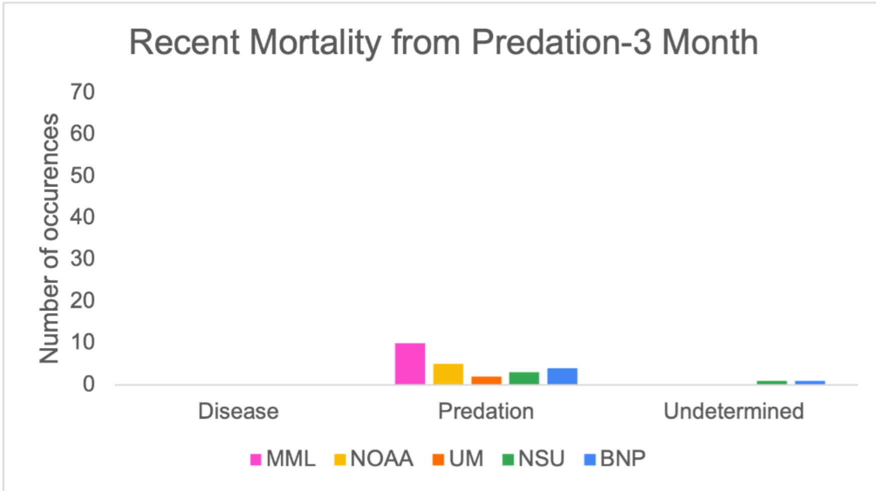

Figure 10 *Partial mortality of A. palmata clusters after three months across five sites.*

2.3.2.3 Discussion

Through this project, we were able to demonstrate a successful transfer and outplanting of >4,000 plug-sized *A. palmata*. Our initial findings have shown high survivorship (>97%) across regions, demonstrating the feasibility of the assisted migration of this keystone species. Based on this information, we encourage management agencies to continue restoring this endangered coral across the Florida Coral Reef to restore connectivity of this depleted species. Outplanting *A. palmata* in dense clusters, as we have done in this study, enhances fusion and growth between corals and as such is a good approach for restoration activities involving plug-sized *A. palmata* to encourage rapid growth.