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Long-Term Stony Coral Transplantation Success Offshore Southeast, Florida, USA

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LONG-TERM STONY CORAL TRANSPLANTATION SUCCESS OFFSHORE SOUTHEAST, FLORIDA, USA.

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I dedicate this thesis to my parents, uncle and host family, Michaelene and Donald Robitaille, Allen Walski, and Margaret Watkins and Les Calvert. Without their love, support, and guidance from Heaven none of this would have been possible. They have been my backbone throughout my life and have always encouraged me to follow my dreams. I cannot thank you all enough for the things you have done for me.

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Abstract of Thesis

Transplanted coral (Order: Scleractinia) colony condition was surveyed at five injury event sites, two coral nurseries, and one impact minimization location off the coast of Broward County, Florida, USA in 2012. Because stony corals are long-lived and slow growing, generally growing less than one centimeter in diameter per year, determining transplantation success requires long-term (greater than two years) monitoring. Long-term monitoring efforts, however, are rarely completed. This study is unique in that it examined stony coral transplantation success of several projects over a time period of 6-17 years. Control colonies were also surveyed in order to compare naturally growing coral colonies to the experimental (transplanted) colonies. Because the transplantation activities at the projects examined in this study occurred over a long time period (oldest population occurred 17 years prior to this study and the youngest occurred six years), colony percent partial mortality was used as a measure of success (colony condition). A successful effort should result in transplanted colonies experiencing partial morality similar to that of control colonies over extended periods of time.

The control colonies used came from Broward County Annual Monitoring sites, and the *M/V Firat* and the *C/V Hind* ship grounding sites. The experimental colonies used came from five injury events (*C/V Hind*, *Clipper Lasco*, *M/V Firat*, and *M/V Spar Orion* ship grounding sites and Hillsboro Cable Drag location), two stony coral nurseries (DERM Modules and Warren Modules), and one impact minimization location (Broward County Mitigation Boulders). With all control colonies pooled and experimental colonies pooled, no significant differences in colony partial mortality were found between the experimental and control colonies. Once each experimental coral colony was reattached to the substrate, it generally appeared similar to the control colonies; the mean percent mortality for control colonies was 50% (2.95 ±SE) and the mean percent mortality for experimental colonies was 56% (1.24 ±SE). However, differences were found between stony coral species within each treatment (control and experimental). Colony mortality for identified control corals was greatest for *Porites astreoides*, *Siderastrea siderea*, and *Montastrea annularis* complex. For experimental colonies, *S. siderea* and *P. astreoides* had the most mortality. The least mortality of the control corals were found in *Montastrea cavernosa*, *Solenastrea bournoni*, and *Meandrina meandrites*. Of the

experimental colonies, *S. bournoni*, *M. meandrites*, and *Montastrea annularis* complex had the least mortality.

Resource managers need to consider colony transplantation location, coral species, and percent initial colony mortality when allocating efforts for injury and impact minimization events. Also, project initial restoration and final reports documenting transplantation locations and colony species, size and/or mortality should to be more detailed; this would be beneficial for future monitoring efforts.

Keywords: Stony Coral, Transplantation, colony partial mortality, coral reef injury, Southeast Florida

Table of Contents

List of Figures

List of Tables

1.0 Introduction

Background of the Study

Coral reefs are one of the most diverse and complex marine ecosystems (Wilkinson, 1992). For coastal communities, they are globally essential in providing food, protecting shorelines and beaches, and supporting socioeconomic growth (Gomez, 1997). However, around the globe, coral reefs have been declining due to direct local human impacts and global climate change. As population increases, the ocean and its ecosystems are increasingly impacted by these local and global pressures (Wilkinson, 1992). One impacted coral reef ecosystem in particular is off the coast of southeast Florida, USA. Ship groundings, anchor and cable drags, beach renourishment, and other coastal construction activities are a few of the many physical impacts that occur off Florida's southeast coast (Jaap, 2000; Precht *et al*., 2000; Bruckner and Bruckner, 2001; Precht *et al*., 2001; Stephens, 2007). Stony coral colonies are greatly impacted by such events, for they can become covered in debris/sand, crushed, fragmented, fractured, scarred, scraped, and/or bleached, typically resulting in either partial or whole colony tissue mortality (Gittings *et al.,* 1990; Gittings *et al*., 1994). Without proper transplantation which secures the colony to the substrate, dislodged and/or fragmented coral colonies may not survive (Hobbs and Harris, 2001; Epstein *et al*., 2003).

Transplantation is the process by which targeted fragmented and/or dislodged corals are reattached to the substrate generally via epoxy and/or cement. Transplantation efforts may occur at the same location the colonies initially came from or to new locations. At injury events, such as ship groundings, fragmented and/or dislodged corals are generally transplanted back to the stabilized injury site. This transplantation effort is a restoration tool which decreases the impacted reef resources and promotes recovery of the colonies and the community. Transplantation efforts which utilize colonies removed from un-injured locations may also help increase coral abundance on reefs that have been injured by humans and/or storms (Garrison and Ward, 2012). Taking corals that have been injured and reattaching them to the substrate gives the coral colony a greater chance at survival; the coral spends less effort reattaching itself and more effort repairing itself.

Colony transplantation efforts are also utilized as a part of impact minimization efforts associated with coastal construction activities. Impact minimization is a management tool utilized to reduce impacts associated with permitted resource damaging events. Impact minimization may require a portion of the stony coral community within the permitted area to be removed and transplanted to a location away from the damage event area. The new area may be natural reef or deployed mitigation artificial reefs. Beach renourishment is an example of an event which may require stony coral removal and transplantation as part of impact minimization efforts. Beach renourishment is an active process of replacing lost sand to maintain beaches and help decrease the effects of shoreline erosion. However, when beaches are renourished coral communities adjacent to the beach being nourished are at risk due to increased sediment influx and/or habitat destruction from burial. By removing the corals and placing them in a safer area, they have a better chance at survival. Impact minimization allows corals to continue to thrive by relocating them to safer, non-impacted areas, thus minimizing the impacts to the permitted area.

Another activity which utilizes transplanted stony corals is the establishment of coral nurseries. Nurseries frequently utilize artificial substrate (reefs) as transplantation locations to cache stony coral colonies. The source of these stony coral colonies can be targeted removal from permitted or known injury events or colonies of opportunity from unknown events (Monty, 2006). Nurseries are a restoration and mitigation tool designed to cache stony coral colonies until a time that they can be removed from the nursery and transplanted to reef injury sites. Propagation through transplanting nursery corals is important in helping to reestablish damaged reefs and establishing coral reef communities in locations where coral abundance is low and could be enhanced through the introduction of new corals.

In the United States, stony coral transplantation activities require a permit from appropriate resource management agencies. These permits generally require monitoring to determine the success of the effort. Success is usually defined by transplanted colony attachment, survival, and condition (percent tissue mortality and presence of disease and bleaching). Generally, the permits require several monitoring efforts to document and record survivorship (Jaap, 2000). Transplantation monitoring projects are usually short-term, and the coral colonies are monitored for five years or less (Hudson and Diaz, 1988;

Gittings *et al*., 1988; Yap *et al.,* 1998; Gittings *et al*., 1990; Gittings *et al*., 1994; Bruckner and Bruckner, 2001; Stephens, 2007).

However, once colonies are reattached to the substrate their survival is not guaranteed. Sublethal effects including colonization by the boring sponge, *Cliona delitrix*, overgrowth by algae or other sessile organisms, partial or whole colony bleaching, and/or disease can impact (lead to partial mortality) or even kill the transplanted coral colonies. This thesis will observe the impact, if any, sublethal effects play in the role of transplanted coral colony success.

1.1 Florida Reef Tract

Offshore southeast Florida's coast there are three parallel reef tracts and a series of near shore hardbottom ridges which are separated by sand areas (Banks *et al.,* 2007; Walker, 2012) (Figure 1). The reefs of southeast Florida (Miami-Dade, Broward, Palm Beach, and Martin counties) are the northern extension of the Florida Reef Track which begins in the north at the St. Lucie Inlet, located in Martin County, and ends in the south at the Dry Tortugas, in Monroe County (Banks *et al.,* 2007; Walker, 2012). The inner reef, or first reef, is the reef tract closest to shore. The inner reef crests in about five meters (m) of water (Banks *et al*., 2007). The second reef tract, termed middle reef, is first a reef platform then it slopes downward to the east. It crests in about nine meters depth and generally consists of a low profile reef. The western edge of the middle reef is distinct in many areas because it has a two to three meter rocky ledge (Goldberg, 1973; Banks *et al*., 2007). The third reef tract, outer reef, is marked along its western edge by another rocky ledge in places as much as three meters high. This reef crests in about 16 m of water and is the most well established continuous reef along southeast Florida. It is mostly composed of a reef platform with some spur and groove formations along its eastern edge (Banks *et al*., 2007). Each of these reef tracts are separated from one another by stretches of sand. Inshore of the inner reef lies an area of nearshore ridges and colonized pavement. Overall, the three reef tracts have distinguishing physical and biological features among one another (Goldberg, 1973; Moyer *et al*., 2003; Sathe *et al*., 2008; Walker *et al*., 2008).

Geological research suggests that continued sea level rise created environmental conditions which promoted growth of each reef tract separately. The outer reef tract was the first to be created about 12,000 years ago during the Holocene. Environmental conditions during the Holocene gave rise to the first stony corals that were able to thrive and survive off the coast of South Florida (Lightly *et al*., 1978). About 7,000 years ago, sea level began to rise which contributed to growth of the middle reef tract. The final/inner reef tract was established 6,000 years ago after the continuation of sea level increase (Moyer *et al*., 2003). Along with the inner reef formation, the present day beach and nearshore ridge system was further developed during this time (Banks *et al*., 2007). The framework of these reefs was found to be largely previously composed of *Acropora palmata* (Lightly *et al*., 1978). Back reef deposits/rubble are suspected to have been utilized as building substrate for *A. palmata* and *Acropora cervicornis* to promote continued growth to follow increasing sea level rise during the Holocene (Lightly, 1977). Cores, diver observations, radio carbon analysis, sub-bottom profiling, and bathymetric surveys are just a few of the techniques that have been used in a variety of research projects that have come to the aforementioned conclusions (Lightly *et al*., 1978; Moyer *et al*., 2003 and Banks *et al*., 2007).

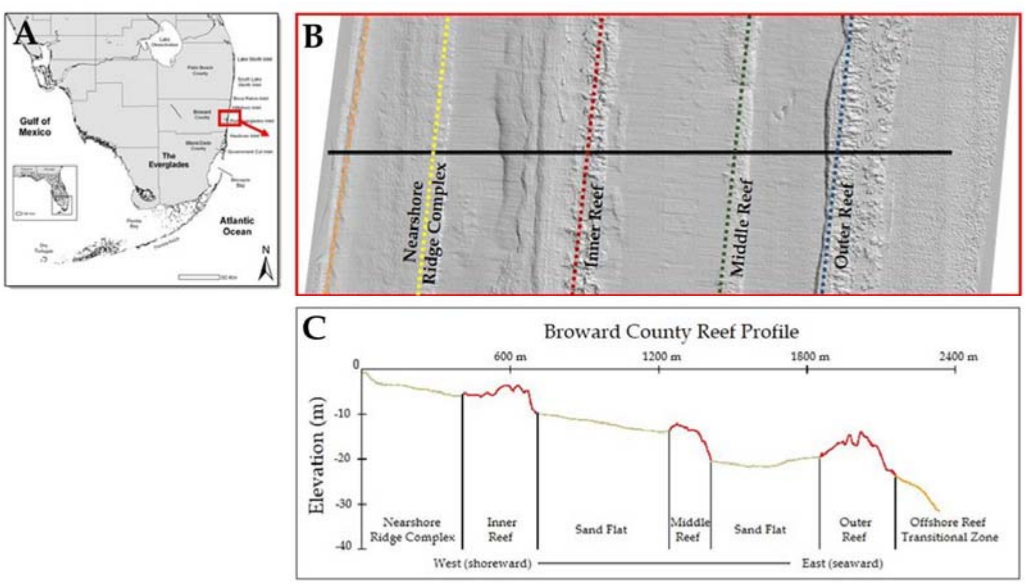

Figure 1: Panel A is a view of southern Florida showing an area off Broward County in red that corresponds to Panel B which is sea floor bathymetry from LIDAR (Light Detection and Ranging) data. The black line in Panel B shows the location of a bathymetric profile illustrated in Panel C.

1.2 Statement of Problem

With monitoring being the generally accepted method to determine stony coral transplantation success and with corals mostly being slow growing, short-term monitoring (one to five years) is not ideal (Jaap, 2000; Connell *et al.*, 1997; Muko and Iwasa, 2011). Extensive time is required to document successful transplanted stony coral survival and growth (mortality). If coral colonies require this much time to grow, coral reefs require even more time for the habitat to develop into a thriving coral reef community. Additionally, coral sexual reproduction occurs by spawning events usually once a year when environmental conditions are ideal. When the spawning event takes place, the planktonic larva have an increased chance at being preyed upon due to their small size and near location to a reef community that is home to variety of predator organisms. If a larva survives, it will settle and begin to grow and develop. Coral recruits are extremely sensitive and can only propagate in certain, ideal conditions required for their life (Kruzynski and Fletcher, 2012).

The aforementioned life history of stony coral growth and reproduction further supports the fact that long-term monitoring is necessary (Collier *et al*., 2007). Past scientific studies of long-term (five or more years) transplantation survival are minimal (Garrison and Ward, 2012). If transplantation is to continue being a widely used management tool, then knowing corals long-term survival potential is essential (Thomas and Dodge, 1999; Spieler *et al*., 2001; Gilliam *et al*., 2007; Collier *et al*., 2007). Success of stony coral transplantation is defined as a coral that remains attached, survives, recovers (reduction in colony partial mortality), and grows at rates similar to natural corals. Without understanding how stony corals react to transplantation over an extensive period of time in relation to natural control corals of the same species, it is possible that short-term studies could over estimate success. If this is the case, developing new methods to ensure coral survival is critical.

1.3 Significance of the Study

This study examined the long-term success of transplanted stony coral colonies for several reef injury events, an impact minimization event, and a two coral nurseries offshore Broward (southeast Florida) County. In this study, success was defined as transplanted colonies being in a similar heath condition (colony percent mortality) as naturally occurring colonies. The success of a transplantation effort is defined as transplanted corals not only having survival rates similar to naturally occurring corals but also being of similar health condition indicating recovery from the colony dislocation event. Not only will the results of this study help guide southeast Florida restoration and impact minimization efforts, it will be useful in the Caribbean-Atlantic basin for these coral reefs have similar species composition and growth rates.

2.0 Research Objectives and Hypotheses

The goal of this thesis was to examine the long-term success of previously completed stony coral transplantation efforts. The experimental corals used are associated with completed transplantation projects which occurred between 6 - 17 years prior to this 2012 study. The health (colony percent mortality) of naturally occurring control corals was compared to that of the experimental colonies in order to comment on success.

1. *Ho*: There is no significant difference in partial colony mortality between transplanted and control stony coral colonies (all sites and species pooled) or within species between transplanted and control coral colonies (species within each treatment pooled).

2. *Ho*: There is no significant difference in the presence of boring sponge, *Cliona delitrix*, bleaching, and disease, between transplanted and control coral species (all sites pooled).

3. *Ho*: There is no significant difference in partial colony mortality between transplanted and control stony coral species between study sites.

4. *Ho*: There is no significant difference in partial colony mortality between whole and fragmented transplanted coral species (all sites pooled).

5. *Ho*: There is no significant association within species between partial colony mortality and size of transplanted and control corals (all sites pooled).

6. *Ho*: There is no significant difference in transplanted coral percent colony mortality between injury event efforts, impact minimization efforts, and nursery efforts.

2.1 Limitations

As mentioned, this study examined stony corals which were part of previously implemented monitoring efforts associated with several completed reef injury, impact minimization and nursery activities. Prior limited data collection on each colony created boundaries for statistical analysis on each colony's success. Additionally, the gap of years between some projects final monitoring event and this study resulted in an incomplete data set for each project. On average, 10 years had passed between the previous monitoring efforts and this study. This factor and natural environmental conditions increased the chance for corals and tags marking the corals to be missing and/or unidentifiable. Another limitation was the lack of or inaccurate transplantation site information and project maps to find the transplanted corals. These issues made it challenging to find the transplantation sites and the appropriately tagged coral colonies.

The biggest challenge was locating the initial and final project reports for the various transplantation efforts. The reports were extremely difficult to find and due to their age, and limited information was contained within them. Various resources were contacted in order to attempt to locate several reports, however, a few of them were never found. This limited my study such that desired transplantation sites were unable to be visited for this long-term monitoring thesis project.

3.0 Materials and Methods

This study assessed stony corals which were transplanted as part of completed reef injury restoration, impact minimization, or nursery projects (experimental sites) (Table 1) (Figure 2). No new corals were transplanted during this study. I used official project reports to locate each site and to choose and relocate tagged and un-tagged transplanted colonies assessed. Section 3.1 provides details on all the projects included in this study. Because a number of these projects were completed more than 10 years ago, some colonies were difficult to relocate. In 2012, divers carried a brush/knife as a means to clean off/scrape tags, if found, in order to accurately identify each coral. All corals were photographed to assist with identification and data management and were assessed for attachment (attached (alive), loose, or missing). In addition, colony length, width, height, percent tissue mortality, presence/absence of bleaching, disease, and/or *Cliona delitrix* (a boring sponge), and overgrowth of tissue on attachment material was collected for each colony. Partial tissue mortality was estimated in situ based on the 'ideal' colony having 100% living tissue. All sites were visited once in 2012 as a means to collect the aforementioned data. Survival of each coral species was based on the percent of colonies that remained attached (alive) by 2012.

I also assessed control (natural) colonies as part of this study. Control colonies were only included in two (Table 2) of the transplantation projects examined. In order to increase the number of control colonies, I utilized data collected at Broward County Annual Monitoring sites (Gilliam *et al*., 2012) (Figure 3) (section 3.2 includes more information on this project). At the two injury areas which had control colonies (*M/V Firat* and *C/V Hind*) mapped and tagged as part of the relocation effort, the procedures for locating and measuring these coral was the same as for the transplanted colonies.

Once all field and archival data was collected, statistical analysis was completed with Microsoft Excel®, JMP 10.0 and STATA 13.0 software. The analysis included basic multivariate statistics by grouping corals into categories based on species, size classes, date of transplantation, fragment or whole colony, treatment and health condition (partial mortality and presence and absence of bleaching, disease, and/or *Cliona delitrix*). Hypothesis testing was conducted by the use of generalized estimating equations (GEE) which is basically an ANOVA test. Generalized estimating equations (GEE) are used to analyze correlated (clustered) data, especially when they are binary or in the form of counts (Burton *et al*, 1998).

Table 1: The available data for the experimental coral colonies: type of injury event, date of injury, transplantation date, number of years since transplantation to this study, number of transplanted colonies, number of reattached and tagged colonies, and the number of colonies found during this thesis. Asterisk denotes a higher number of coral found due to additional transplants that were added post reports.

Experimental Sites							
Site	**Event**	**Injury Date (if applicable)**	**Trans. Date**	**Number of Years Since Trans.**	**Number of Colonies Trans.**	**Number of Reattached Colonies Tagged**	**Number of Colonies Found**
M/V Firat	Injury	November 15, 1994	February 7 – March 25, 1995	17	588	133	100
C/V Hind	Injury	March 18, 1998	May 2-23, 1998	14	385	157	163
M/V Spar Orion	Injury	May 17, 2006	June 22 – September 8, 2006	6	278	171	133
Clipper Lasco	Injury	September 14, 2006	October 17 – November 10, 2006	6	122	45	41
Broward County Mitigation Boulders	Impact Min.	2005-2006	2005-2006	6	169	169	169
Warren Modules	Nursery	N/A	June 2001 – December 2002	10	60	60	62*
DERM Modules	Nursery	N/A	June 2001 – December 2002	10	193	193	296*
Hillsboro Cable Drag	Injury	November 2002	Spring 2003	9	200	171	182
Study Total					**1995**	**1099**	**1146**

Table 2: The available data for the control coral colonies: date of first monitoring and the number of tagged colonies.

Control Sites		
Site	**Date of First Monitoring**	**Number of Colonies Monitored**
Broward Annual Monitoring	1998-2003	76
M/V Firat	1998	102
C/V Hind	2001	30
Total		**208**

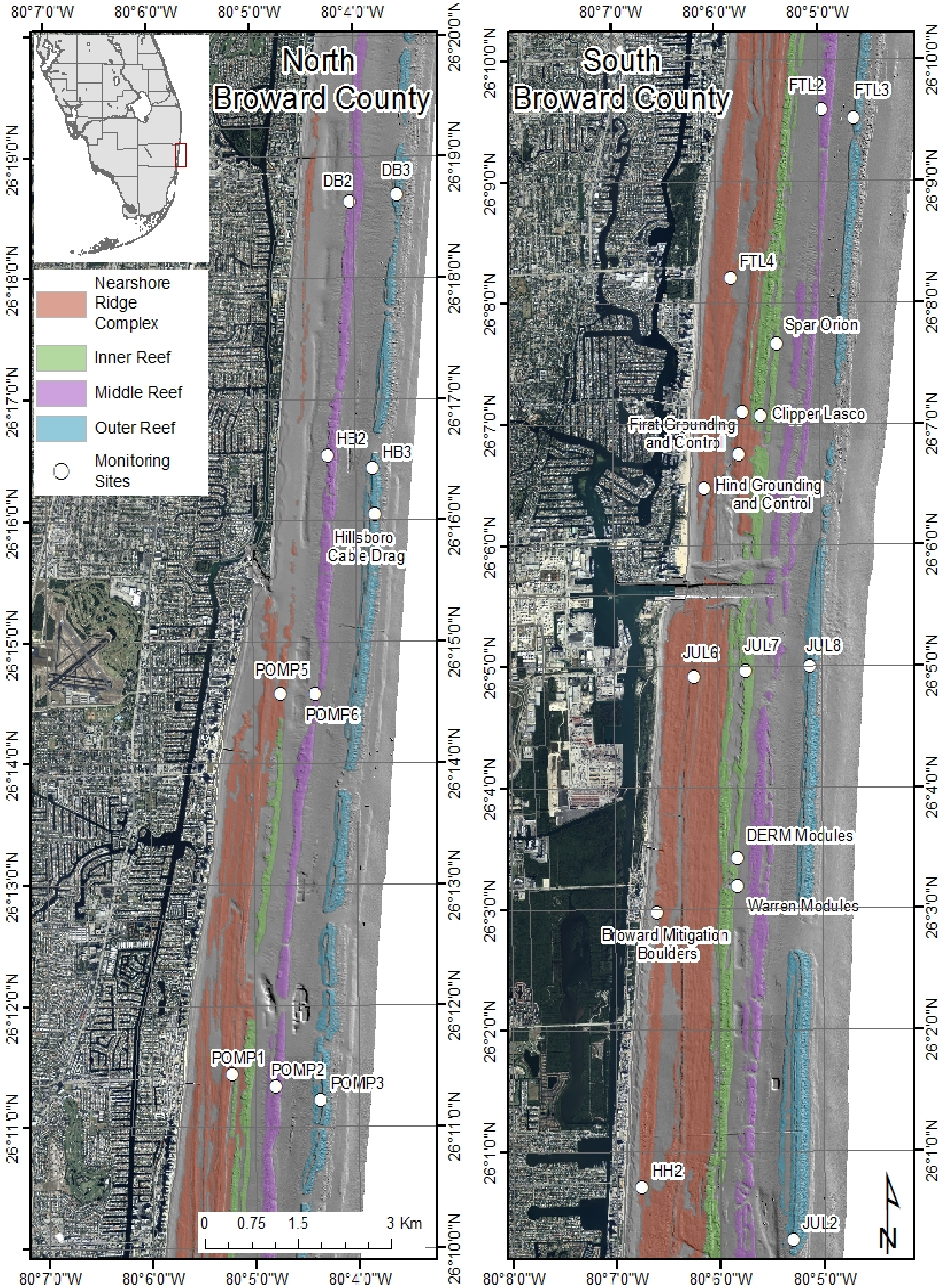

Figure 2: Map containing the location of all control and experimental sites visited.

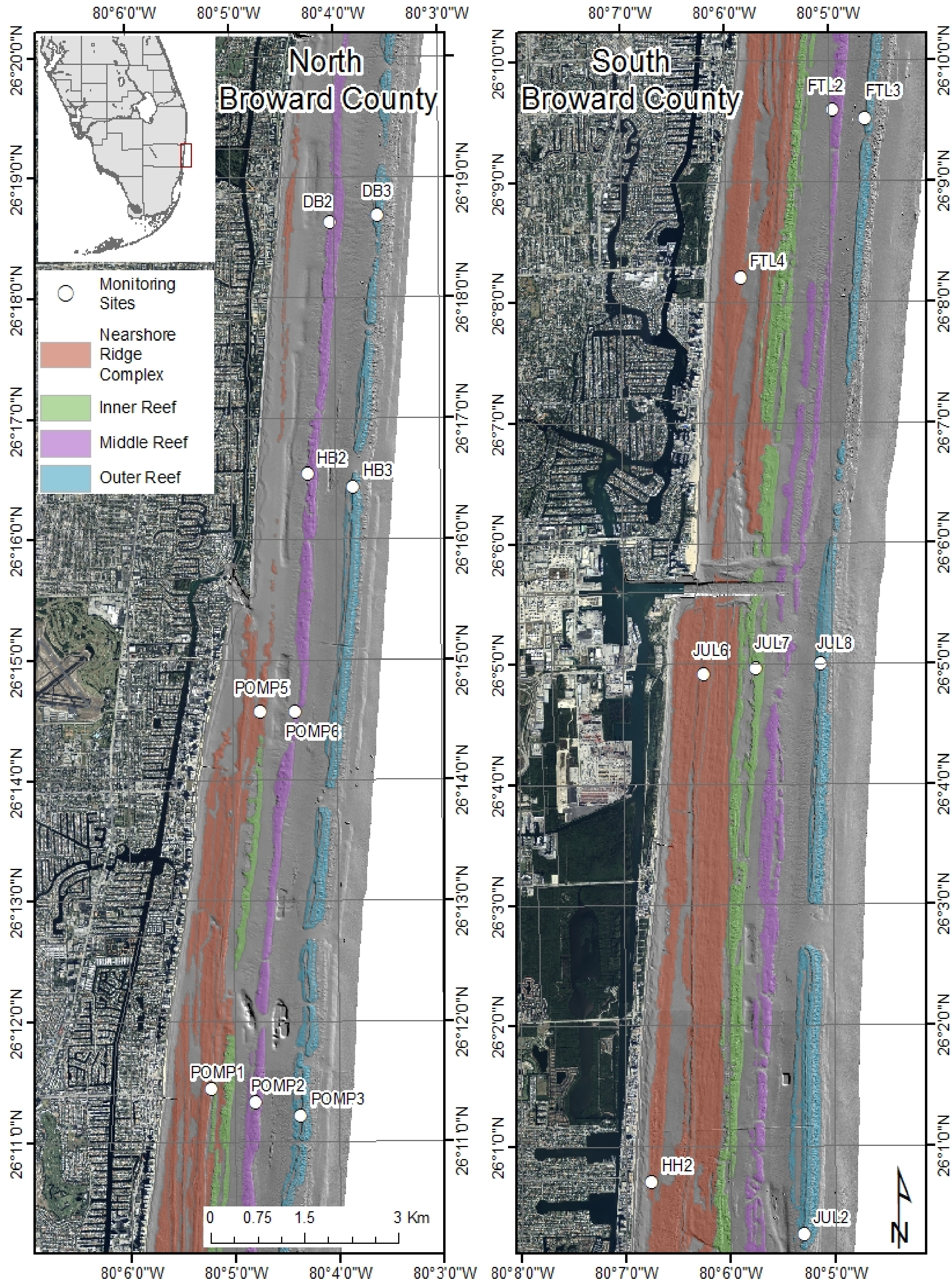

Figure 3: The Broward County Annual Monitoring sites that were utilized for control coral colonies.

Generalized Estimating Equations (GEE) were developed by Liang and Zegar (1986) as a means of testing hypotheses regarding the influence of correlated variables measured over time. GEE's are an extension of the generalized linear models and provide similar estimates as those found using Ordinary Least Squares Regression (OLS) when the dependent variable is normally distributed and no correlation within response is assumed (Ballinger, 2004). GEE's use maximum-likelihood estimation of the regression parameters and the variance calculated uses a link function, which is a transformation function that allows the dependent variable to be expresses as a vector of parameter estimates ($y= \beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3,...$) in the form of an additive model (Ballinger, 2004).

Two main types of data analyses were utilized and included: mixed nested general linear models and Tukey HSD (Honest Significant Difference) multiple comparison tests with Bonferroni Adjustments. The mixed nested general linear model was utilized to find variability in the data. This type of model is used to represent fixed effects when data sets have multiple dependent variables. This thesis had several variables that needed to be nested in order to accurately analyze the data. The Turkey HSD multiple comparison tests were utilized to determine a mean that is different from a set of means. This test is needed when an ANOVA analysis concludes that there is a difference in groups' mean. The Tukey HSD multiple comparison test assumes that each group has a normal distribution and standard deviation. The final analysis utilized was the Bonferroni Adjustments which is needed when dealing with a variety of independent and dependent tests with a single data set; this adjustment is made to the p-values. In other words, the Bonferroni Adjustment is crucial in reducing the likelihood of obtaining false-positive results (Sall *et al.*, 2007).

3.1 Experimental Locations

3.1.1 Injury Sites

M/V Firat

On November 15, 1994, the Turkish freighter *M/V Firat* (154 m in length) was grounded off the coast of Fort Lauderdale, Florida for 11 days. It came to rest in the nearshore hardbottom in approximately 2 to 10 m water depth (Figure 2). After assessing the grounding location, the total damage area was estimated to be 310 m^2. Continental

Shelf Associates, Inc. (CSA) was hired to complete the area's emergency stabilization once the vessel was removed following the event. A five man dive team reattached 588 stony corals consisting of 12 species at 16 sites within the damaged area. The corals were reattached with epoxy. Of the 588 corals, 133 were tagged and mapped. This work was completed from February 7 to March 25, 1995 (Graham and Shroeder, 1996; Continental Shelf Associates, Inc., 2004). Additionally, in 1998 CSA conducted a five year monitoring study on the success of the reattached corals. This information was not utilized in this thesis project.

C/V Hind

On March 18, 1998, the vessel *C/V Hind* (106 m) grounded on the nearshore hardbottom off the coast of Ft. Lauderdale, Florida. It came to rest a half mile north of Port Everglades Inlet, in approximately three meters of water (Figure 2). As a means to stop the vessel, the captain deployed the anchor which also impacted the reef. After assessing the grounding locations, the estimated injury area was over 5,200 m^2. During May 2-23, 1998, 385 injured corals were reattached via hydraulic cement and underwater epoxy in 12 Coral Reattachment Zones (Sea Byte Inc. and SSR Inc., 1998, Gilliam *et al.*, 2000).

In 2000, NSUOC (Gilliam *et al.*, 2000) reassessed the area and located 333 of the 385 reattached corals. Of these corals, 74% of them were secured to the seabed and living. Of these 333 colonies, 157 were tagged and mapped along with 30 naturally attached (control) corals for future monitoring efforts. During tagging and mapping, corals were assessed for attachment, size, health and condition (Gilliam *et al.*, 2000).

M/V Spar Orion

On May 17, 2006, the vessel *M/V Spar Orion* (180 m) was grounded on the inner reef off the coast of Fort Lauderdale, Florida for one day. It came to rest in approximately 10 m of water (Figure 2). Even though the grounding lasted a short period of time, 545.6 m^2 of damage still occurred. This included an estimated 431 scraped and fractured stony coral colonies. After emergency stabilization took place on June 22 to September 8, 2006, a total of 278 corals were reattached to the substrate in six transplantation stations via Portland cement and silica. All transplanted corals were marked with a masonry nail; 171 were tagged and mapped for future monitoring. No control colonies were mapped, and no monitoring efforts have taken place on these reattached corals (Continental Shelf Associates, Inc., 2006a; Continental Shelf Associates, Inc., 2006b; Jordan, 2007).

Clipper Lasco

On September 14, 2006, the vessel *Clipper Lasco* (169 m) was grounded on the nearshore hardbottom off the coast of Fort Lauderdale, Florida for 6 days. It came to rest in approximately 10 m of water (Figure 2). Unfortunately, the bow of this ship plowed through the previously damaged area of the *M/V Eastwind*. In total, a 564 m^2 area was affected by this grounding. Transplanted corals were secured via Portland Number 6 cement. Forty-five corals were tagged and mapped, however their condition and health was not recorded. No control colonies were mapped. Since restoration efforts, no monitoring has taken place (Jordan, 2007; Polaris Applied Sciences, Inc., 2006).

Hillsboro Cable Drag

The offshore transportation of dredge material associated with the Hillsboro Inlet Improvement Project in November 2002 caused injury to the middle and outer reef when cables between a tugboat and barge were slackened and dragged across the reefs' surface. The damage happened at depths ranging from 10 to 21 m off the coast of Hillsboro, Florida (Figure 2). Emergency stabilization efforts established ten zones where eight species of stony corals were reattached with Portland Type II cement without plaster and mapped in spring 2003. In 2005, NSUOC was contracted to monitor and assess the injury areas once the corals were reattached. Unfortunately, when NSUOC returned to the area many corals were not located due to the 3+ years that passed between the initial reattachment and the contract. In 2007, 191 colony locations were found of the 200 that were reattached within the 10 zones. However, of these 191 some colonies were missing, loose, and dead. In total, 171 colonies were tagged for the four year contracted monitoring efforts (Gilliam *et al*., 2007; Gilliam *et al*., 2010). No control colonies were mapped.

3.1.2 Other Experimental Sites

Broward County Mitigation Boulders for Beach Erosion Control Project

Broward County renourished 11 km of beaches along Hallandale and Dania Beach during 2005 and 2006. The Beach Erosion Control Project widened some beaches to approximately 60 meters by placing 1.37 million m^3 of sand on them from borrow areas along north Broward's coast (Broward County Beach Renourishment, 2012). It was estimated that 30,750 m^2 of hardbottom habitat may be buried during this renourishment effort. The mitigation required flat, limestone boulders approximately two meters in diameter to be placed in sand pockets nearshore and offshore Dania Beach in five meters of water (Figure 2) (Gilliam, 2006; Stephens, 2007).

In addition to boulder placement, project permits required stony corals from expected impact areas to be transplanted to the boulders in order to assist in minimizing the beach renourishment impacts. Transplanted corals were selected if they had 15 centimeters (cm) diameter or greater of live tissue and were free of disease or the boring sponge, *Cliona delitrix*. Once chosen, they were removed, transported, attached to the boulders with Portland Type II cement, and tagged. All corals were identified to species and mapped for future monitoring. In total, 169 colonies were monitored for 18 months (Stephens, 2007). No control colonies were mapped.

Warren and DERM Modules

In 2001, two sites of modules termed "Warren" and Miami-Dade County Department of Environmental Resources Management "DERM Modules" were deployed as mitigation in response to offshore cable construction activities in Broward County, Florida. These two sites are located on sand approximately 350 m apart. The modules lay offshore of the inner reef in 13 m of water offshore Dania Beach (Figure 2). The Warren Modules are concrete blocks (55 cm x 55 cm x 15 cm) composed of Type II Portland cement and limestone stacked in the shape of a pyramid (Figure 4). The DERM Modules (2.59 m x 1.52 m x 1.52 m) are composed of concrete and limestone slabs, culverts, and boulders (Figure 5). They are elevated 0.5 m off the sand substrate via concrete pedestals (Post Buckley Schuh & Jernigan, Inc., 1999; Post Buckley Schuh & Jernigan, Inc. 2000;

Monty, 2006; Monty *et al*., 2006). These modules were utilized as a stony coral nursery by Jamie Monty for her 2006 Master's Thesis at NSUOC (Monty, 2006).

Figure 4: Warren Module utilized as artificial reef (Monty, 2006).

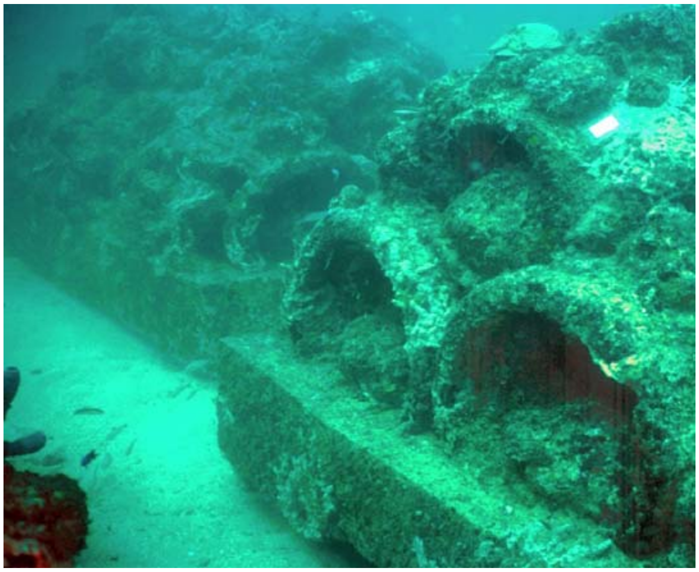

Figure 5: DERM Module utilized as artificial reef (Monty, 2006).

Monty (2006) utilized "corals of opportunity" which she defined as coral colonies that become loose and/or detached from the reef due to various events, such as storms, bioerosion, and/or unpermitted and unreported human impacts. The corals of opportunity were transplanted to the modules via Type II Portland cement and tagged. Of the 253 corals comprising 16 species, 60 were secured to the Warren Modules and 193 to the DERM Modules. Monty monitored the corals for 13 – 31 months because corals were transplanted monthly between June 2001 and December 2002 (Monty, 2006; Monty *et al.*, 2006). All colonies secured to the modules were photographed to assist with identification and data management and were assessed for attachment (attached (alive), loose, or missing) in 2012. In addition, colony length, width, height, percent tissue mortality, presence/absence of bleaching, disease, and/or *Cliona delitrix*, and overgrowth of tissue on attachment material was collected for each colony in 2012.

3.2 Control Sites

Shoreline Protection Project Broward County Annual Monitoring

NSUOC was awarded a contract (*Shoreline Protection Project Broward County Yearly Monitoring*) to annually monitor the coral reefs of Broward County beginning in 2000. This agreement was set up in order to establish baseline pre-injury monitoring for the Beach Renourishment Project that would take place in 2005, as mentioned above. The project has 25 permanent monitoring locations, 17 of which were utilized during my thesis project, that are contracted to be visited annually (Figure 3). Seventeen of the 25 sites were utilized because coral colonies from the subset had reliable in situ measurement data. From these sites, stony coral data, such as size and condition, is collected on the same colonies annually due to stainless steel pins permanently marking the fixed locations at each site (Gilliam *et al.,* 2012).

The data was collected via scrutinizing in situ data collection sheets and images from Dr. Gilliam's computer data base at NSUOC. Each annual monitoring site consists of one 30 m^2 belt transect. These transects were documented by taking 40 non-overlapping 0.75 m^2 quadrat images every year of monitoring. I used colonies within these site transect images as controls for natural colony condition (colony percent mortality). Colonies within these sites were selected if they were completely in the image quadrat. By using corals completely in each image it allowed for a more standard analysis of each colony. If only part of the colony was in each image quadrat, it would have been difficult to determine accurate size and percent tissue mortality measurements from the in situ data collection sheets. If the colony was in two different quadrats that meant that two different people would have measurements for the same coral colony based on how much of the coral was located in each quadrat. The coral colony measurements were located by scrutinizing the in situ data collection sheets from each year of surveying. Examining each year of data was required in order to determine if and when the colony died or went missing, if applicable.

M/V Firat

Compensatory mitigation for the grounding of the *M/V Firat* included a five year monitoring study that was conducted by CSA. This study began in 1998 and it assessed the transplanted corals and selected (102) control scleractinian colonies. The control corals' selection criterion was based on if they remained attached and unharmed during and after the grounding event. Each coral was scrutinized for its health, attachment status and growth rate. All control corals were tagged and mapped for future analysis (Graham and Shroeder, 1996; Continental Shelf Associates, Inc., 2004).

C/V Hind

After initial restoration efforts were completed, Dr. Gilliam from NSUOC reassessed the grounding location of the *C/V Hind* in 2001. One hundred fifty-seven of the reattached scleractinians were located, tagged and mapped along with 30 naturally attached colonies for reference (control). At this time, these corals were examined for attachment, size, health and condition (Gilliam *et al*., 2000).

4.0 Results

According to the records available from contractor written restoration reports and data collected in Dr. Gilliam's Coral Reef Restoration and Monitoring Lab at Nova Southeastern University, 1,307 coral colonies or fragments were targeted to be surveyed during this study (Tables 1 and 2). Of these coral colonies, 1,099 were experimental from various transplantation efforts and 208 were controls (Tables 1 and 2). After visiting all project sites 1,146 coral colonies were actually located, some colonies not initially targeted were found and added to the study. If the coral colony was not located and the tag was located, the colony was defined as missing; however, during analysis the colony was termed dead. Of these experimental colonies, 703 were found attached (alive) to the substrate (61%). In addition, 423 were dead and 20 were alive but loose from the substrate. On the other hand, all of the tagged control colonies were found; 139 were found attached (alive) to the substrate (67%) while 67 were found dead. Additionally, two live colonies were found loose and no longer secured to the substrate (Tables 1 and 2). In total, 1,354 stony coral colonies of 21 species were surveyed (Table 3).

Table 3: Number of control and experimental colonies for each species surveyed for this project.

Species	Number of Control Colonies	Number of Experimental Colonies
Agaricia agaricites	0	6
Agaricia species	0	1
Colpophyllia natans	2	12
Dichocoenia stokesii	18	77
Diploria species	60	153
Eusmilia fastigiata	0	3
Madracis decactis	1	8
Meandrina meandrites	19	100
Montastraea annularis complex	3	50
Montastrea cavernosa	57	280
Mussa angulosa	0	1
Mycetophyllia aliciae	1	2
Oculina diffusa	0	5
Porites astreoides	16	63
Siderastrea siderea	5	150
Solenastrea bournoni	26	148
Stephanocoenia intersepta	0	85
Unidentified species	0	2
Total	**208**	**1146**

The number of corals found for each species was not always of sufficient number for separate analysis; a desired number of colonies was approximately 40 individuals. As a means to analyze the rarer species, some were grouped based on their genus and/or their rarity off Broward County, Florida. The individual coral species analyzed during this project were as follows: *Dichocoenia stokesii, Meandrina meandrites, Montastraea cavernosa, Porites astreoides*, *Siderastrea siderea*, *Solenastrea bournoni*, and *Stephanocoenia intersepta*. The coral species groupings analyzed during this project were as follows: *Diploria* species which consists of *Diploria clivosa*, *Diploria labyrinthiformis*, and *Diploria strigosa*, *Montastraea annularis* complex which consists of *Montastraea annularis* and *Montastraea faveolata*, Other species which consists of *Colpophyllia natans*, *Agaricia agaricites*, *Agaricia* species, *Eusmilia fastigiata*, *Mussa angulosa*, *Madracis decactis*, *Oculina diffusa*, *Mycetophyllia aliciae* and unidentified species. Colony size metrics for each species are summarized in Tables 4 – 13.

Table 4: The average length, width, and height (cm) for the living experimental and control *Dichocoenia stokesii* colonies.

Dichocoenia stokesii			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	14.66	9.82	16.57
Std Dev	5.03	9.00	5.49
Std Err Mean	0.67	1.203	0.73
Upper 95% Mean	16.01	12.23	18.04
Lower 95% Mean	13.31	7.41	15.10
N	56	56	56

Table 5: The average length, width, and height (cm) for the living experimental and control *Diploria* species colonies.

***Diploria* species**			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	25.44	10.26	31.80
Std Dev	11.76	6.02	13.30
Std Err Mean	1.07	0.55	1.21
Upper 95% Mean	27.56	11.34	34.20
Lower 95% Mean	23.32	9.17	29.41
N	121	121	121

Table 6: The average length, width, and height (cm) for the living experimental and control *Meandrina meandrites* colonies.

Meandrina meandrites			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	20.56	9.66	24.62
Std Dev	8.42	6.28	9.90
Std Err Mean	0.96	0.72	1.13
Upper 95% Mean	22.47	11.09	26.87
Lower 95% Mean	18.65	8.24	22.38
N	77	77	77

Table 7: The average length, width, and height (cm) for the living experimental and control *Montastraea annularis* complex colonies.

Montastraea annularis complex			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	31.31	24.64	41.64
Std Dev	16.93	13.23	20.11
Std Err Mean	2.61	2.04	3.10
Upper 95% Mean	36.59	28.76	47.913
Lower 95% Mean	26.03	20.52	35.38
N	42	42	42

Table 8: The average length, width, and height (cm) for the living experimental and control *Montastraea cavernosa* colonies.

Montastrea cavernosa			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	21.12	14.91	26.29
Std Dev	9.13	7.30	11.70
Std Err Mean	0.58	0.46	0.74
Upper 95% Mean	22.26	15.82	27.75
Lower 95% Mean	19.98	14.00	24.82
N	248	248	248

Table 9: The average length, width, and height (cm) for the living experimental and control Other species colonies.

Other species			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	21.00	13.27	25.20
Std Dev	7.63	5.38	10.60
Std Err Mean	1.97	1.39	2.73
Upper 95% Mean	25.23	16.24	31.07
Lower 95% Mean	16.77	10.29	19.33
N	15	15	15

Table 10: The average length, width, and height (cm) for the living experimental and control *Porites astreoides* colonies.

Porites astreoides			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	14.45	8.12	16.93
Std Dev	4.90	3.22	5.25
Std Err Mean	0.76	0.450	0.81
Upper 95% Mean	15.98	9.12	18.57
Lower 95% Mean	12.92	7.12	15.29
N	42	42	42

Table 11: The average length, width, and height (cm) for the living experimental and control *Siderastrea siderea* colonies.

Siderastrea siderea			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	14.04	8.30	17.15
Std Dev	4.87	4.05	5.92
Std Err Mean	0.55	0.46	0.67
Upper 95% Mean	15.13	9.21	18.48
Lower 95% Mean	12.95	7.40	15.83
N	79	79	79

Table 12: The average length, width, and height (cm) for the living experimental and control *Solenastrea bournoni* colonies.

Solenastrea bournoni			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	22.15	19.16	26.45
Std Dev	8.21	7.31	9.09
Std Err Mean	0.70	0.62	0.78
Upper 95% Mean	23.53	20.40	27.98
Lower 95% Mean	20.76	17.93	24.91
N	137	137	137

Table 13: The average length, width, and height (cm) for the living experimental and control *Stephanocoenia intersepta* colonies.

Stephanocoenia intersepta			
	Height (cm)	**Length (cm)**	**Width (cm)**
Mean	11.43	7.00	13.23
Std Dev	4.43	3.41	4.88
Std Err Mean	0.65	0.50	0.71
Upper 95% Mean	12.73	8.00	14.67
Lower 95% Mean	10.13	6.00	11.80
N	47	47	47

4.1 Hypothesis 1

Ho: There is no significant difference in partial colony mortality between transplanted and control stony coral colonies (all sites and species pooled) or within species between transplanted and control coral colonies (species within each treatment pooled).

All experimental and control colony data collected in 2012 was pooled together in one data set and analyzed with JMP, a statistical software from the business unit of SAS. A mixed nested general linear model analysis was completed with the data set (Table 14 and 15). The data set included: treatment (control or experimental), coral species, and percent mortality for each colony analyzed. Tables 14 (control) and 15 (experimental) and Figures 6 (control) and 7 (experimental) show the averages of percent mortality for each species or species grouping. Each event type (injury, impact minimization, or nursery) was nested within each site of the event. All sites were considered a random effect; the fixed effects were the treatment (control or experimental) and coral species. Nineteen percent variability in mortality was due to site and 81% variability was due to the fixed effects. In other words, 19% of the variability was due to the event location and 81% of the data variability was due to colonies being either a control or experimental and colony species. This variability shows how spread out data distribution is.

Table 14: The average percent mortality, standard deviation, standard error mean, upper 95% mean, lower 95% mean, and number of control colony's species.

Average Percent Mortality - Controls						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	57.50	44.47	10.48	79.61	35.39	18
Diploria species	65.93	39.74	5.13	76.20	55.67	60
Meandrina meandrites	36.95	45.47	10.43	58.86	15.03	19
Montastraea annularis complex	63.33	32.15	18.56	143.19	-16.52	3
Montastraea cavernosa	33.10	39.85	5.28	43.68	22.53	57
Other species	62.50	45.00	22.50	134.11	-9.11	4
Porites astreoides	70.38	35.58	8.89	89.33	51.42	16
Siderastrea siderea	66.00	32.86	14.70	106.81	25.19	5
Solenastrea bournoni	32.65	39.12	7.67	48.45	16.85	26

Table 15: The average percent mortality, standard deviation, standard error mean, upper 95% mean, lower 95% mean, and number of experimental colony's species.

Average Percent Mortality - Experimental						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	61.27	42.16	4.80	70.84	51.70	77
Diploria species	56.78	43.17	3.50	63.67	49.88	153
Meandrina meandrites	46.10	45.24	4.52	55.08	37.12	100
Montastraea annularis complex	46.92	38.51	5.45	57.87	35.97	50
Montastraea cavernosa	51.43	40.50	2.42	56.19	46.66	280
Other species	79.48	36.37	5.75	91.11	67.84	40
Porites astreoides	72.14	36.13	4.55	81.24	63.04	63
Siderastrea siderea	74.75	35.32	2.88	80.45	69.05	150
Solenastrea bournoni	32.95	40.66	3.34	39.56	26.35	148
Stephanocoenia intersepta	62.69	40.93	4.44	71.52	53.87	85

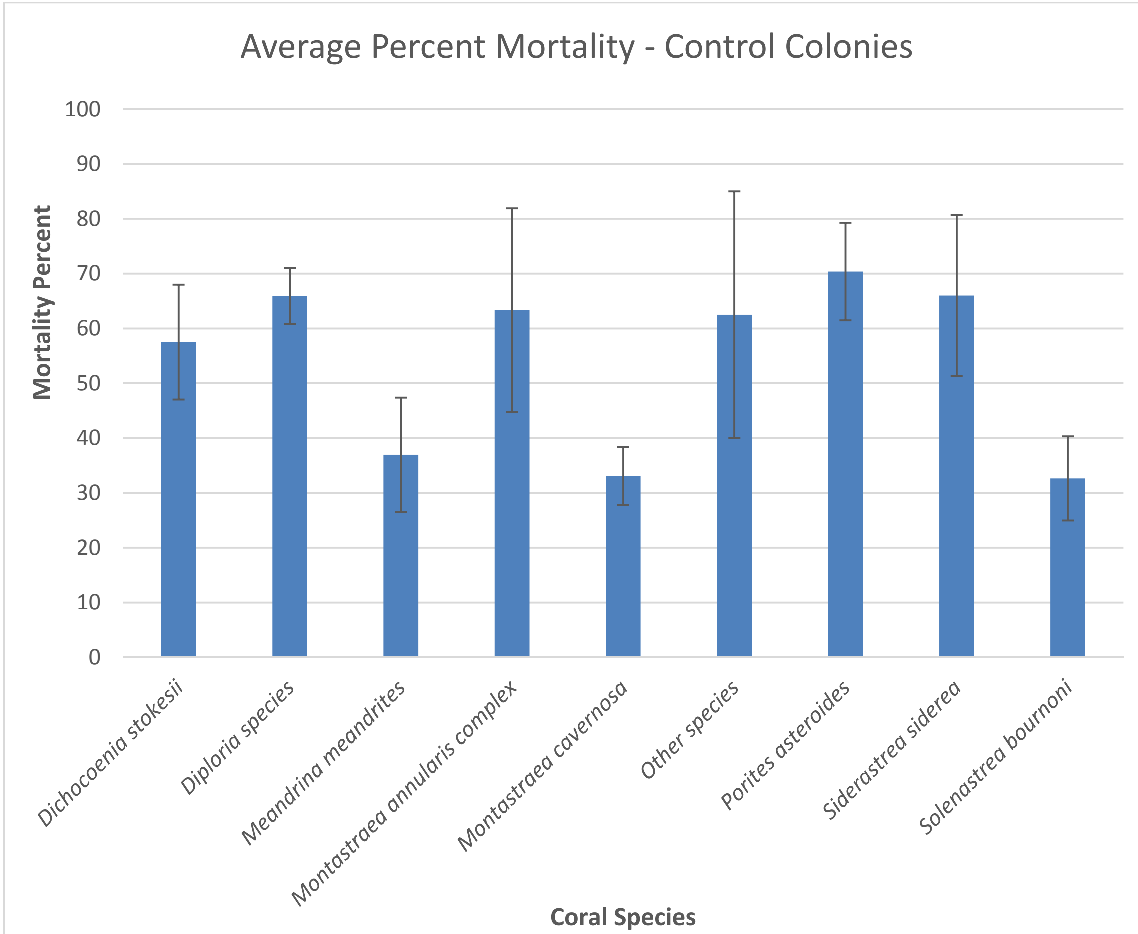

Figure 6: Average (±SE) percent mortality for the control coral species.

No statistical difference in percent mortality was found between the control colonies pooled and experimental colonies pooled (F (1, 1,607.4) = 0.0305, p = 0.8614); however, a statistical difference was found between coral species (F (9, 1344) = 15.7, p = <0.0001). Once no statistical difference was found between the control and experimental groups, only the experimental groups were utilized for between species analysis. To determine the difference by experimental coral species, a Tukey HSD multiple comparison test was used (Table 16).

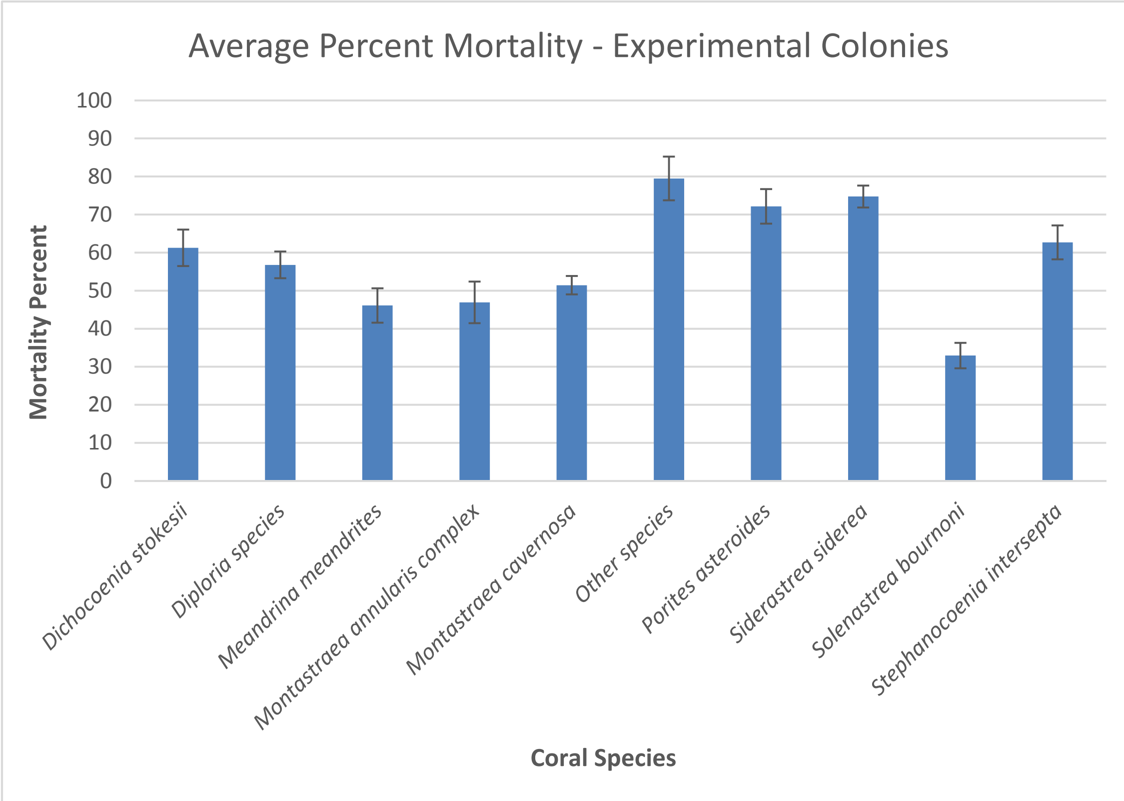

Figure 7: Average (±SE) percent mortality for the experimental coral species.

4.1.1 Dichocoenia stokesii

In total, 77 experimental colonies were located of which 44 were alive and attached to the substrate, 32 were dead, and one was found alive but loose. As for the control colonies, 18 were surveyed, 10 of which were alive and attached to the substrate, 7 were found dead and one was loose from the substrate (Tables 17 and 18 and Figures 8 and 9). The overall percent survival for *D. stokesii* was 61.11% for the control colonies and 58.44% for the experimental colonies (Table 19 and Figure 10). Significant differences in partial mortality was found between the experimental colonies of *D. stokesii* and *S. bournoni* (CI 95%: 6.67, 40.28) and *M. meandrites* (CI 95%: 3.39, 37.62). Mean differences determined that *D. stokesii* partial mortality was 23.48% more than *S. bournoni* and 20.51% than *M. meandrites* (Table 16).

Table 16: LSMeans differences Tukey HSD analysis to determine experimental coral species with significant differences including the upper and lower confidence intervals (CI). The asterisk located in the p-Value column signify a significant difference between the two coral species listed in level 1 and level 2.

Level 1	Level 2	Percent Diff.	Lower 95% CI	Upper 95% CI	p-Value
Other species	*S. bournoni*	37.00	15.44	58.57	<.0001*
Other species	*M. meandrites*	34.03	12.51	55.56	<.0001*
Other species	*M. annularis* complex	31.21	4.76	57.65	0.0073*
P. astreoides	*S. bournoni*	30.63	12.87	48.39	<.0001*
S. siderea	*S. bournoni*	29.42	14.53	44.32	<.0001*
P. astreoides	*M. meandrites*	27.66	9.45	45.87	<.0001*
S. siderea	*M. meandrites*	26.45	11.34	41.57	<.0001*
Other species	*M. cavernosa*	25.60	5.45	45.76	0.0024*
P. astreoides	*M. annularis* complex	24.83	1.40	48.26	0.0277*
S. intersepta	*S. bournoni*	24.71	7.15	42.27	0.0004*
S. siderea	*M. annularis* complex	23.62	2.15	45.09	0.0181*
D. stokesii	*S. bournoni*	23.48	6.67	40.29	0.0004*
Diploria species	*S. bournoni*	22.19	8.01	36.36	<.0001*
S. intersepta	*M. meandrites*	21.74	4.14	39.35	0.0038*
D. stokesii	*M. meandrites*	20.51	3.39	37.62	0.0059*
P. astreoides	*M. cavernosa*	19.23	3.70	34.76	0.0036*
Diploria species	*M. meandrites*	19.22	4.38	34.05	0.0018*
S. intersepta	*M. annularis* complex	18.91	-4.48	42.31	0.2370
S. siderea	*M. cavernosa*	18.02	5.19	30.86	0.0004*
D. stokesii	*M. annularis* complex	17.68	-5.13	40.49	0.2935
Diploria species	*M. annularis* complex	16.39	-4.29	37.07	0.2630
Other species	*Diploria* species	14.82	-6.34	35.97	0.4435
Other species	*D. stokesii*	13.53	-9.23	36.28	0.6802
S. intersepta	*M. cavernosa*	13.31	-2.43	29.05	0.1829
Other species	*S. intersepta*	12.29	-10.62	35.21	0.7955
D. stokesii	*M. cavernosa*	12.08	-2.68	26.84	0.2215
M. cavernosa	*S. bournoni*	11.40	-1.66	24.45	0.1487
Diploria species	*M. cavernosa*	10.79	-1.44	23.01	0.1384
P. astreoides	*Diploria* species	8.44	-8.50	25.38	0.8583
M. cavernosa	*M. meandrites*	8.43	-4.97	21.83	0.6041
Other species	*S. siderea*	7.58	-13.64	28.81	0.9814
S. siderea	*Diploria* species	7.23	-7.37	21.84	0.8624
Porites astreoides	*D. stokesii*	7.15	-12.02	26.32	0.9751
Other species	*P. astreoides*	6.38	-17.21	29.96	0.9976
S. siderea	*D. stokesii*	5.94	-10.84	22.72	0.9825
P. astreoides	*S. intersepta*	5.92	-14.11	25.94	0.9953
M. annularis complex	*S. bournoni*	5.80	-15.76	27.36	0.9977
M. cavernosa	*M. annularis* complex	5.60	-14.23	25.43	0.9966
S. siderea	*S. intersepta*	4.71	-12.13	21.55	0.9969
M. meandrites	*S. bournoni*	2.97	-12.60	18.54	0.9999
M. annularis complex	*M. meandrites*	2.83	-19.19	24.85	1.0000
S. intersepta	*Diploria* species	2.52	-14.57	19.62	1.0000
D. stokesii	*Diploria* species	1.29	-14.34	16.92	1.0000
S. intersepta	*D. stokesii*	1.23	-17.85	20.31	1.0000
P. astreoides	*S. siderea*	1.21	-16.37	18.78	1.0000

Table 17: Number of experimental colonies found, attached (alive), loose, and dead during this project.

Experimental Colonies – Attached (alive), Loose, Dead				
Species	**Number of Colonies**	**Number Attached**	**Number Loose**	**Number Dead**
Dichocoenia stokesii	77	44	1	32
Diploria species	153	85	2	66
Meandrina meandrites	100	60	1	36
Montastraea annularis complex	50	39	1	10
Montastraea cavernosa	280	198	5	77
Other species	40	13	0	27
Porites astreoides	63	31	1	31
Siderastrea siderea	150	74	2	74
Solenastrea bournoni	148	114	2	32
Stephanocoenia intersepta	85	45	2	38

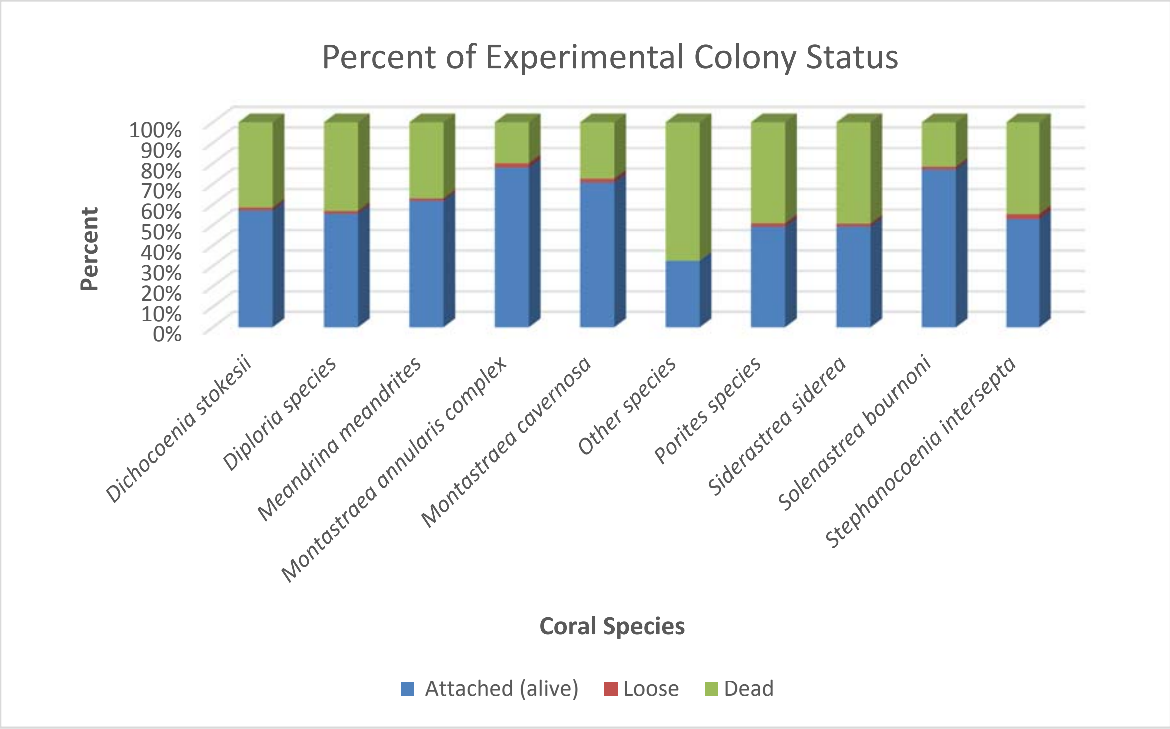

Figure 8: Graph displaying the percent of attached (alive), loose, and dead experimental coral colonies of each coral species observed.

Table 18: Number of control colonies found, attached (alive), loose, and dead during this project.

Control Colonies – Number Attached (alive), Loose, Dead				
Species	**Number of Colonies**	**Number Attached**	**Number Loose**	**Number Dead**
Dichocoenia stokesii	18	10	1	7
Diploria species	60	34	0	26
Meandrina meandrites	19	13	0	6
Montastraea annularis complex	3	2	0	1
Montastraea cavernosa	57	44	1	12
Other species	4	2	0	2
Porites astreoides	16	10	0	6
Siderastrea siderea	5	3	0	2
Solenastrea bournoni	26	21	0	5
Stephanocoenia intersepta	0	0	0	0

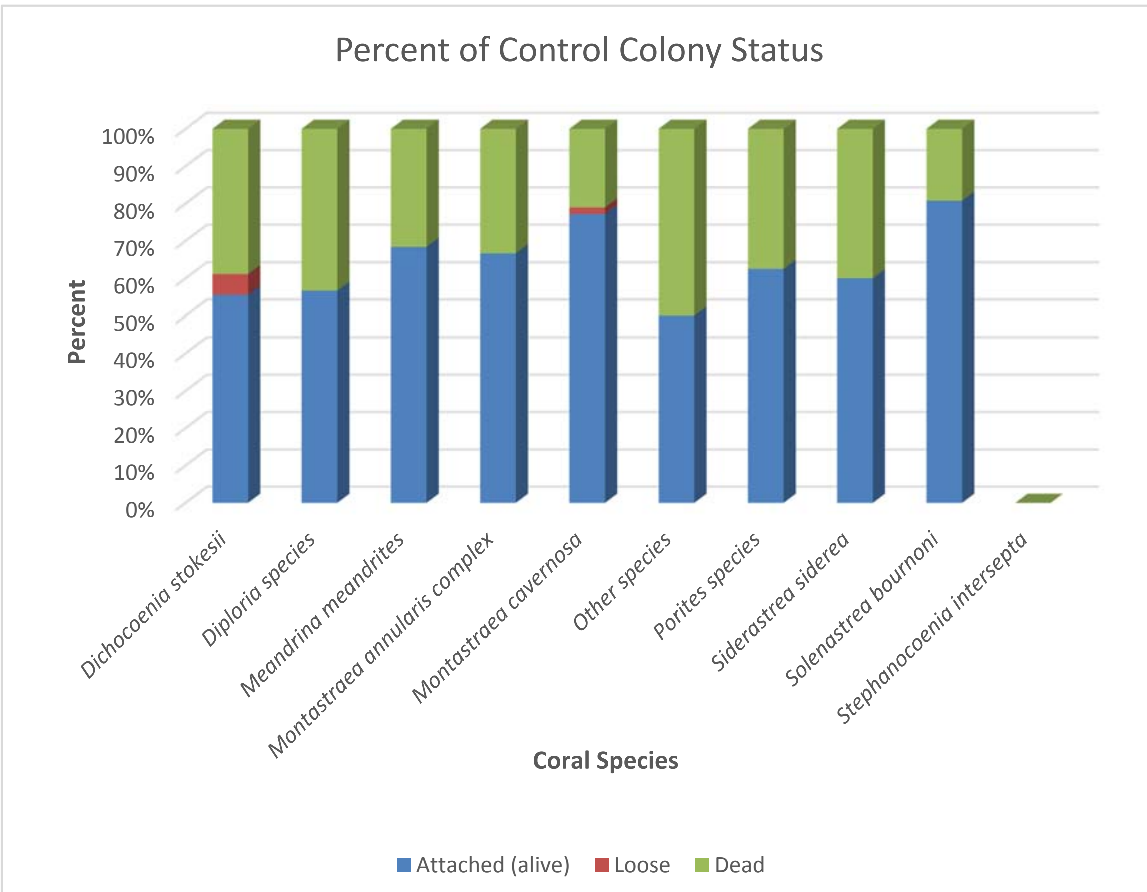

Figure 9: Graph displaying the percent of attached (alive), loose, and dead control coral colonies of each coral species observed.

Table 19: Percent survival for the control and experimental coral species.

Percent Survival		
Species	**Control Colonies**	**Experimental Colonies**
Dichocoenia stokesii	61.11	58.44
Diploria species	56.67	56.86
Meandrina meandrites	68.42	61.00
Montastraea annularis complex	66.67	80.00
Montastraea cavernosa	78.95	70.71
Other species	50.00	32.50
Porites astreoides	62.50	50.79
Siderastrea siderea	60.00	50.67
Solenastrea bournoni	80.77	78.38
Stephanocoenia intersepta	NA	55.29

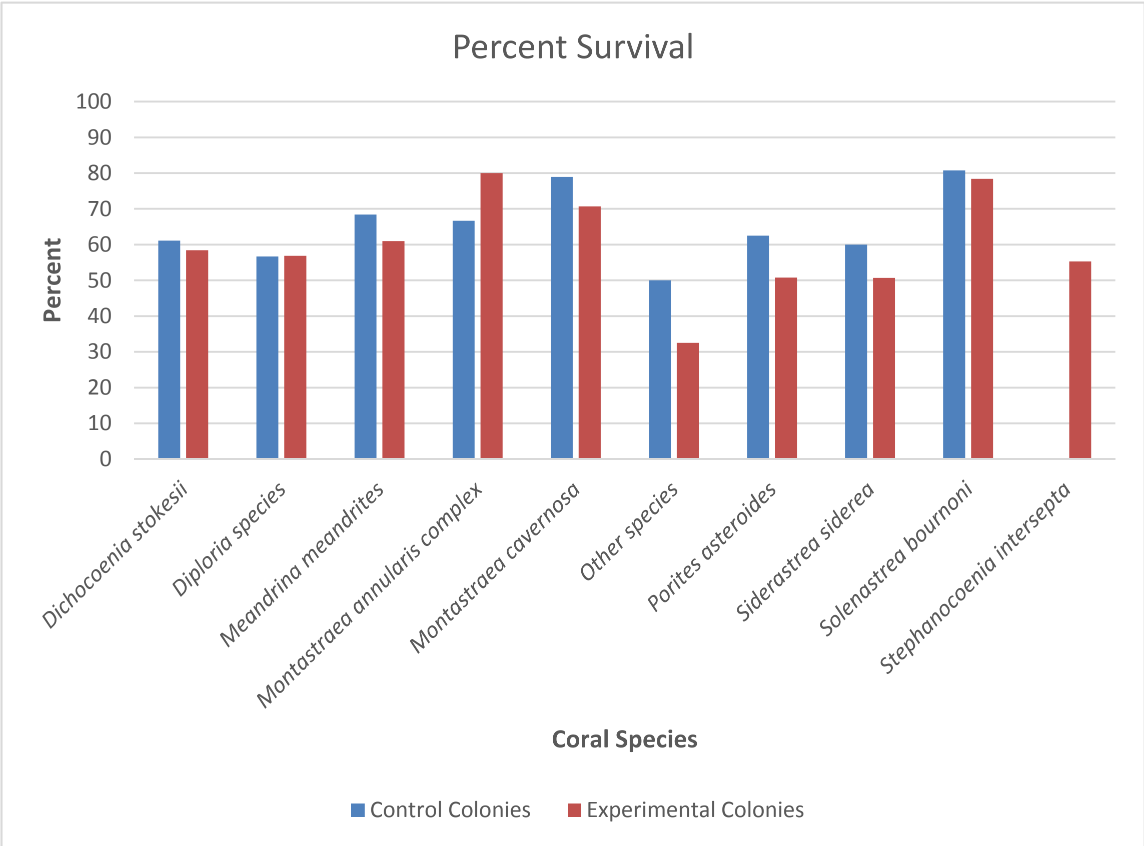

Figure 10: Graph of overall percent survival for the control and experimental coral species.

4.1.2 *Diploria* species

The *Diploria* species consists of *D. clivosa* (166), *D. labyrinthiformis* (10), and *D. strigosa* (37) species. In total, 153 experimental colonies were located of which 85 were alive and attached to the substrate, 66 were dead, and two were found alive but loose. As for the control colonies, 60 were surveyed, 34 were living attached to the substrate and 26 were found dead (Tables 17 and 18 and Figures 8 and 9). The overall percent survival for *Diploria* species was 56.67% for the control colonies and 56.86% for the experimental colonies (Table 19 and Figure 10). A significant difference in partial mortality was found between *Diploria* species and *M. meandrites* (CI 95%: 4.38, 34.05) and *S. bournoni* (CI 95%: 8.01, 36.36). Mean differences determined that *Diploria* species partial mortality was 19.22% more than *M. meandrites* and 22.19% than *S. bournoni* (Table 16).

4.1.3 *Meandrina meandrites*

In total, 100 experimental colonies were located of which 60 were alive and attached to the substrate, 36 were dead, and one was found alive but loose. As for the control colonies, 19 were surveyed, 13 were living attached to the substrate and six were found dead (Table 17 and 18 and Figure 8 and 9). The overall percent survival for *M. meandrites* was 68.42% for the control colonies and 61.00% for the experimental colonies (Table 19 and Figure 10). *M. meandrites* was not found to have significantly greater partial mortality than any other experimental species.

4.1.4 *Montastraea annularis* complex

The *Montastraea annularis* complex consists of *M. annularis* (2) and *M. faveolata* (51) species. In total, 50 experimental colonies were located of which 39 were alive and attached to the substrate, 10 were dead, and one found alive but loose. Additionally, both *M. annularis* colonies survived. As for the control colonies, three were surveyed, two were living attached to the substrate and one was found dead (Table 17 and 18 and Figure 8 and 9). The overall percent survival for *Montastraea annularis* complex was 66.67% for the control colonies and 80% for the experimental colonies (Table 19 and

Figure 10). No significant differences were found between the experimental colonies of *Montastraea annularis* complex and any other experimental species.

4.1.5 Montastraea cavernosa

In total, 280 experimental colonies were located of which 198 were alive and attached to the substrate, 77 were found dead, and five were found alive but loose. As for the control colonies, 57 were surveyed, 44 were living attached to the substrate, 12 were found dead, and one was loose from the substrate (Tables 17 and 18 and Figures 8 and 9). The overall percent survival for *M. cavernosa* was 78.95% for the control colonies and 70.71% for the experimental colonies (Table 19 and Figure 10).*M. cavernosa* was not found to have significantly greater partial mortality than any other experimental species.

4.1.6 Other species

The category of other species consists of *C. natans* (14), *A. agaricites* (6), *Agaricia* species (1), *E. fastigiata* (3), *M. angulosa* (1), *M. decactis* (9), *O. diffusa* (5), *M. aliciae* (3) and unidentified species (2). In total, 40 experimental colonies were located of which 13 were alive and attached to the substrate and 27 were dead. As for the control colonies, four were surveyed (Tables 17 and 18 and Figures 8 and 9), two were living attached to the substrate and two were found dead. The two corals found living were both *C. natans*, while the two dead corals were *M. aliciae* and *M. decactis*. The overall percent survival for Other species was 50% for the control colonies and 32.50% for the experimental colonies (Table 19 and Figure 10). Significant differences were found in partial mortality between Other species and *S. bournoni* (CI 95%: 15.43, 58.57), *M. meandrites* (CI 95%: 12.51, 55.55), *Montastrea annularis* complex (CI 95%: 4.75, 57.65), and *M. cavernosa* (CI 95%: 5.45, 45.75). Mean differences determined that Other species partial mortality was 37% more than *S. bournoni*, 34.03% than *M. meandrites*, 31.21% than *Montastrea annularis* complex, and 25.6% than *M. cavernosa* (Table 16).

4.1.7 Porites astreoides

In total, 63 experimental colonies were located of which 31 were alive and attached to the substrate, 31 were dead, and one was found alive but loose. As for the control colonies, 16 were surveyed, 10 were living attached to the substrate and six were found dead (Tables 17 and 18 and Figures 8 and 9). The overall percent survival for *P. astreoides* was 62.50% for the control colonies and 50.79% for the experimental colonies (Table 19 and Figure 10). Significant differences were found in partial mortality between *P. astreoides* and *S. bournoni* (CI 95%: 12.86, 48.39), *M. meandrites* (CI 95%: 9.44, 45.86), *Montastrea annularis* complex (CI 95%: 1.40, 48.26), and *M. cavernosa* (CI 95%: 3.70, 34.75). Mean differences determined that *P. astreoides* partial mortality was 30.63% more than *S. bournoni*, 27.66% than *M. meandrites*, 24.83% than *Montastrea annularis* complex, and 19.23% than *M. cavernosa* (Table 16).

4.1.8 Siderastrea siderea

In total, 150 experimental colonies were located of which 74 were alive and attached to the substrate, 74 were dead, and two were found alive but loose. As for the control colonies, five were surveyed, three were living attached to the substrate and two were found dead (Table 17 and 18 and Figure 8 and 9). The overall percent survival for *S. siderea* was 60% for the control colonies and 50.67% for the experimental colonies (Table 19 and Figure 10). Significant differences were found in partial mortality between *S. siderea* and *S. bournoni* (CI 95%: 14.52, 44.31), *M. meandrites* (CI 95%: 11.36, 41.56), *Montastrea annularis* complex, (CI 95%: 2.15, 45.09) and *M. cavernosa* (CI 95%: 5.18, 30.85). Mean differences determined that *S. siderea* partial morality was 29.42% more than *S. bournoni*, 26.45% than *M. meandrites*, 23.62% than *Montastrea annularis* complex, and 18.02% than *M. cavernosa* (Table 16).

4.1.9 Solenastrea bournoni

In total, 148 experimental colonies were located of which 114 were alive and attached to the substrate, 32 were dead, and two were found alive but loose. As for the control colonies, 26 were surveyed, 21 were living attached to the substrate and five were found dead (Table 17 and 18 and Figure 8 and 9). The overall percent survival for *S. bournoni* was 80.77% for the control colonies and 78.38% for the experimental colonies (Table 19 and Figure 10). *S. bournoni* was not found to have significantly greater partial mortality than any other experimental species.

4.1.10 Stephanocoenia intersepta

In total, 85 experimental colonies were located of which 45 were alive and attached to the substrate, 38 were dead, and two were found alive but loose. However, there were no control colony data available for this particular species therefore; the treatments could not be statistically compared (Table 17 and 18 and Figure 8 and 9). The overall percent survival for the experimental *S. intersepta* colonies was 55.29% (Table 19 and Figure 10). However, significant differences between partial mortality was found between *S. intersepta* and *S. bournoni* (CI 95%: 7.15, 42.26), *M. meandrites* (CI 95%: 4.13, 39.34), and *Montastrea annularis* complex (CI 95%: -4.48, 42.30). Mean differences determined that *S. intersepta* partial morality was 24.71% more than *S. bournoni*, 21.74% than *M. meandrites* and 18.91% than *Montastrea annularis* complex (Table 16).

4.2 Hypothesis 2

Ho: There is no significant difference in the presence of boring sponge, Cliona delitrix, bleaching, and disease, between transplanted and control coral species (all sites pooled).

A qualitative (descriptive) count of the control and experimental coral species and the sublethal effect data from 2012 was performed due to a limited number of colonies with sublethal effects (Table 20 and 21). The sublethal effects included the presence and/or absence of bleaching, disease, and boring sponge, *Cliona delitrix*. Of the control colonies, one was bleached, zero were diseased, and 6 were present with boring sponge, *C. delitrix* (Table 22). The experimental colonies had 23 with bleaching, 12 with disease, and 59 with boring sponge, *C. delitrix* (Table 22).

When combining the experimental and control colony data, *S. siderea* and *S. bournoni* had the most colonies with bleaching present. Additionally, disease was highest in the *S. siderea* colonies located. Finally, *C. delitrix* was found in higher numbers on *Diploria* species, *M. cavernosa*, and *S. bournoni* colonies (Tables 20 and 21).

Table 20: Number and percent of control species with sublethal effects.

Sublethal Effects – Control Species				
Species	**Number of Colonies Surveyed**	**Bleaching**	**Disease**	**Boring Sponge**
Dichocoenia stokesii	18	0 (0%)	0 (0%)	0 (0%)
Diploria species	60	0 (0%)	0 (0%)	4 (7%)
Meandrina meandrites	19	0 (0%)	0 (0%)	0 (0%)
Montastraea annularis complex	3	0 (0%)	0 (0%)	1 (34%)
Montastraea cavernosa	57	0 (0%)	0 (0%)	0 (0%)
Other species	4	0 (0%)	0 (0%)	1 (25%)
Porites astreoides	16	0 (0%)	0 (0%)	0 (0%)
Siderastrea siderea	5	0 (0%)	0 (0%)	0 (0%)
Solenastrea bournoni	26	1 (4%)	0 (0%)	0 (0%)
Stephanocoenia intersepta	0	0 (0%)	0 (0%)	0 (0%)
Total	**208**	**1 (1%)**	**0 (0%)**	**6 (3%)**

Table 21: Number and percent of experimental species with sublethal effects.

Sublethal Effects - Experimental Species				
Species	**Number of Colonies Surveyed**	**Bleaching**	**Disease**	**Boring Sponge**
Dichocoenia stokesii	77	2 (3%)	0 (0%)	0 (0%)
Diploria species	153	0 (0%)	1 (1%)	12 (8%)
Meandrina meandrites	100	2 (2%)	0 (0%)	3 (3%)
Montastraea annularis complex	50	0 (0%)	0 (0%)	5 (10%)
Montastraea cavernosa	280	2 (1%)	0 (0%)	16 (6%)
Other species	40	0 (0%)	1 (3%)	2 (5%)
Porites astreoides	63	0 (0%)	0 (0%)	2 (3%)
Siderastrea siderea	150	8 (5%)	10 (7%)	8 (5%)
Solenastrea bournoni	148	8 (5%)	0 (0%)	10 (7%)
Stephanocoenia intersepta	85	1 (1%)	0 (0%)	1 (1%)
Total	**1146**	**23 (2%)**	**12 (1%)**	**59 (5%)**

Table 22: Treatment, number, and percent of coral colonies with sublethal effects.

Treatment	**Total Number of Colonies**	**Bleaching**	**Disease**	***Cliona delitrix***
Control	208	1 (1%)	0 (0%)	6 (3%)
Experimental	1146	23 (2%)	12 (1%)	59 (5%)

4.3 Hypothesis 3

Ho: There is no significant difference in partial colony mortality between transplanted and control stony coral species between study sites.

All data collected in 2012 was pooled and analyzed with JMP, a statistical software business from SAS. A mixed nested general linear model analysis was completed with the data set. Tables 23 – 33 summarize the species data for each site. The data set included: treatment (control or experimental), study site, coral species, and percent mortality for each colony analyzed. Each event (injury event, impact minimization, or nursery) was nested within each site (where the data was collected) of the event. The random effect was the site (where the data was collected) nested in treatment (control or experimental) of coral colony; the fixed effects were the treatment (control or experimental), coral species, and event (injury event, impact minimization, or nursery). Fourteen percent variability in mortality was due to site when the event was included and 86% variability was due to the fixed effects. In other words, 14% of the variability in the data set was due to each site in each event and 86% of the variability in the data was due to the colonies either being a control or experimental coral, the species that each colony was, and which event the coral was from. The variability shows data distribution spread.

No statistical difference was found between the control and experimental groups (F (1, 136) = 2.83, p = <0.0946); however a statistical difference was found by coral species (F (9, 1,317) = 10.33, p = <0.0001) and event (F (8, 104) = 7.48, p = <0.0001). Once no statistical difference was found between the control and experimental groups, only the experimental group species were analyzed further. To determine species and event differences, a Tukey HSD multiple comparison test was used (Tables 34 and 35).

Table 23: Control species average percent mortality for *C/V Hind*.

***C/V Hind* - Control Species Average Percent Mortality**						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	50.00	57.74	28.87	141.87	-41.87	4
Diploria species	56.50	40.74	14.40	90.56	22.44	8
Montastraea cavernosa	33.45	38.80	10.76	56.91	10.01	13
Solenastrea bournoni	48.40	45.53	20.36	104.93	-8.13	5

Table 24: Control species average percent mortality for *M/V Firat*.

M/V Firat - Control Species Average Percent Mortality						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	56.54	42.40	11.76	82.16	30.92	13
Diploria species	68.45	39.47	5.63	79.79	57.11	49
Meandrina meandrites	0.83	2.04	0.83	2.98	-1.31	6
Montastraea cavernosa	30.31	42.73	10.68	53.08	7.55	16
Porites astreoides	70.11	32.52	10.84	95.11	45.11	9
Solenastrea bournoni	18.00	34.80	11.60	44.75	-8.75	9

Table 25: Control species average percent mortality for Broward County Yearly Monitoring.

Broward County Yearly Monitoring - Control Species Average Percent Mortality						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	100.00	N/A	N/A	N/A	N/A	1
Diploria species	50.00	50.00	28.87	174.21	-74.21	3
Meandrina meandrites	53.62	46.33	12.85	81.61	25.62	13
Montastraea annularis complex	63.33	32.15	18.56	143.19	-16.52	3
Montastraea cavernosa	34.54	40.04	7.57	50.06	19.01	28
Other species	62.50	45.00	22.50	134.11	-9.11	4
Porites astreoides	70.71	41.88	15.83	109.44	31.99	7
Siderastrea siderea	66.00	32.86	14.70	106.81	25.19	5
Solenastrea bournoni	37.08	39.17	11.31	61.97	12.20	12

Table 26: Experimental species average percent mortality for *C/V Hind*.

C/V Hind - Experimental Species Average Percent Mortality						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	79.58	31.51	9.10	99.60	59.56	12
Diploria species	64.26	42.13	6.83	78.11	50.42	38
Meandrina meandrites	73.43	45.06	17.03	115.10	31.75	7
Montastraea annularis complex	34.82	34.67	7.39	50.19	19.45	22
Montastraea cavernosa	75.08	34.09	4.40	83.89	66.28	60
Other species	100.00	N/A	N/A	N/A	N/A	1
Porites astreoides	81.00	34.35	15.36	123.65	38.35	5
Siderastrea siderea	98.33	2.89	1.67	105.50	91.16	3
Solenastrea bournoni	25.00	38.18	13.50	56.91	-6.91	8
Stephanocoenia intersepta	42.86	41.62	15.73	81.35	4.36	7

Table 27: Experimental species average percent mortality for *Clipper Lasco*.

Clipper Lasco - Experimental Species Average Percent Mortality						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	11.67	12.58	7.26	42.92	-19.59	3
Diploria species	70.00	41.23	18.44	121.20	18.80	5
Meandrina meandrites	35.00	43.16	14.39	68.17	1.83	9
Montastraea annularis complex	90.00	N/A	N/A	N/A	N/A	1
Montastraea cavernosa	40.00	35.57	10.42	63.22	16.78	11
Other species	85.00	21.21	15.00	275.59	-105.59	2
Siderastrea siderea	50.00	43.78	21.89	119.67	-19.67	4
Solenastrea bournoni	40.00	51.97	30.00	169.08	-89.08	3
Stephanocoenia intersepta	68.33	54.85	31.67	204.58	-67.92	3

Table 28: Experimental species average percent mortality for DERM Modules.

DERM Modules - Experimental Species Average Percent Mortality						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	80.00	34.32	7.87	96.54	63.46	19
Diploria species	35.00	50.50	20.62	87.99	-17.99	6
Meandrina meandrites	51.00	46.54	7.87	66.99	35.01	35
Montastraea annularis complex	40.00	46.58	19.02	88.89	-8.89	6
Montastraea cavernosa	44.09	42.49	5.23	54.54	33.65	66
Other species	71.79	43.48	11.62	96.90	46.68	14
Porites astreoides	75.31	34.62	8.65	93.76	56.87	16
Siderastrea siderea	77.50	34.39	3.67	84.79	70.21	88
Solenastrea bournoni	89.79	23.09	4.81	99.77	79.80	23
Stephanocoenia intersepta	67.17	41.61	8.68	85.17	49.18	23

Table 29: Experimental species average percent mortality for Hillsboro Cable Drag.

Hillsboro Cable Drag - Experimental Species Average Percent Mortality						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	55.00	51.96	25.98	137.68	-27.68	4
Meandrina meandrites	27.85	39.39	10.92	51.65	4.04	13
Montastraea annularis complex	58.94	37.55	8.61	77.05	40.85	19
Montastraea cavernosa	46.03	38.90	3.80	53.56	38.50	105
Other species	100.00	0.00	0.00	100.00	100.00	2
Porites astreoides	71.92	35.05	6.87	86.08	57.77	26
Siderastrea siderea	70.00	37.00	12.33	98.44	41.56	9
Stephanocoenia intersepta	56.25	50.56	25.28	136.70	-24.20	4

Table 30: Experimental species average percent mortality for *M/V Firat*.

M/V Firat **- Experimental Species Average Percent Mortality**						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	49.62	45.15	12.52	76.90	22.33	13
Diploria species	68.34	40.21	6.06	80.56	56.12	44
Meandrina meandrites	30.00	46.28	17.49	72.80	-12.80	7
Montastraea cavernosa	48.88	44.11	10.70	71.56	26.20	17
Other species	100.00	N/A	N/A	N/A	N/A	1
Porites astreoides	71.67	43.01	14.34	104.73	38.61	9
Solenastrea bournoni	51.67	47.30	15.77	88.03	15.31	9

Table 31: Experimental species average percent mortality for *M/V Spar Orion*.

M/V Spar Orion**- Experimental Species Average Percent Mortality**						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	69.60	44.39	19.85	124.72	14.48	5
Diploria species	62.11	40.46	9.28	81.61	42.60	19
Meandrina meandrites	39.68	43.96	10.08	60.87	18.50	19
Montastraea annularis complex	30.00	N/A	N/A	N/A	N/A	1
Montastraea cavernosa	41.36	38.61	11.64	67.30	15.42	11
Other species	86.56	28.23	9.41	108.25	64.86	9
Porites astreoides	66.67	57.74	33.33	210.09	-76.76	3
Siderastrea siderea	74.78	35.81	6.43	87.81	61.64	31
Solenastrea bournoni	53.18	45.29	13.66	83.61	22.76	11
Stephanocoenia intersepta	55.63	39.76	8.12	72.42	38.83	24

Table 32: Experimental species average percent mortality for Mitigation Boulders.

Mitigation Boulders- Experimental Species Average Percent Mortality						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	40.28	42.58	10.04	61.45	19.10	18
Diploria species	35.85	41.24	6.60	49.21	22.48	39
Montastraea cavernosa	30.00	N/A	N/A	N/A	N/A	1
Other species	60.71	46.59	17.61	103.80	17.63	7
Porites astreoides	52.50	24.75	17.50	274.86	-169.86	2
Siderastrea siderea	15.00	N/A	N/A	N/A	N/A	1
Solenastrea bournoni	13.97	25.10	2.65	19.22	8.71	90
Stephanocoenia intersepta	39.09	37.47	11.30	64.26	13.92	11

Table 33: Experimental species average percent mortality for Warren Modules.

Warren Modules- Experimental Species Average Percent Mortality						
Species	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Dichocoenia stokesii	90.00	17.32	10.00	133.03	46.97	3
Diploria species	50.00	70.71	50.00	685.31	-585.31	2
Meandrina meandrites	67.00	43.73	13.83	98.28	35.72	10
Montastraea annularis complex	100.00	N/A	N/A	N/A	N/A	1
Montastraea cavernosa	43.89	39.75	13.25	74.44	13.34	9
Other species	100.00	0.00	0.00	100.00	100.00	4
Porites astreoides	57.50	60.10	42.50	597.51	-482.51	2
Siderastrea siderea	66.79	37.60	10.05	88.50	45.08	14
Solenastrea bournoni	46.25	42.69	21.35	114.19	-21.69	4
Stephanocoenia intersepta	99.15	1.86	0.52	100.28	98.03	13

4.3.1. Coral Species

The partial mortality analysis of coral species in hypothesis 3 is different from the partial morality analysis of coral species in hypothesis 1 because of the differences in the random and fixed effects for each data analysis. In other words, the data set for each hypothesizes were grouped differently to account for the multiple dependent variables (mixed nested general linear model) and the variability in means (Tukey HSD multiple comparison test). In hypothesis 1, all sites (where the data was collected) were considered a random effect where as in hypothesis 3 the random effect was the site (where the data was collected) which was nested with the treatment (control or experimental). Also, in hypothesis 1 the fixed effects were the treatment (control or experimental) and coral species where as in hypothesis 3 the fixed effects were treatment (control or experimental), coral species, and event (injury event, impact minimization, or nursery). These differences in random and fixed effects allow for varying results based on how the data set is grouped for each analysis.

Table 34: LSMeans differences Tukey HSD analysis to determine experimental coral species with significant differences including the upper and lower confidence intervals. The asterisk located in the p-Value column signify a significant difference between the two coral species listed in level 1 and level 2.

Level 1	Level 2	Percent Diff.	Lower 95% CI	Upper 95% CI	p-Value
Other species	*M. meandrites*	36.50	15.21	57.79	<.0001*
Other species	*M. annularis* complex	35.98	9.49	62.48	0.0008*
Other species	*M. cavernosa*	29.14	9.14	49.14	0.0002*
Other species	*S. bournoni*	28.74	7.20	50.27	0.0010*
P. astreoides	*M. meandrites*	28.19	10.16	46.21	<.0001*
P. astreoides	*M. annularis* complex	27.67	4.31	51.03	0.0070*
S. siderea	*M. meandrites*	26.41	11.41	41.41	<.0001*
S. siderea	*M. annularis* complex	25.89	4.22	47.56	0.0062*
D. stokesii	*M. meandrites*	23.98	6.86	41.10	0.0004*
Diploria species	*M. meandrites*	23.85	8.68	39.02	<.0001*
D. stokesii	*M. annularis* complex	23.46	0.40	46.52	0.0422*
S. intersepta	*M. meandrites*	23.36	5.92	40.81	0.0010*
Diploria species	*M. annularis* complex	23.33	1.95	44.71	0.0199*
S. intersepta	*M. annularis* complex	22.85	-0.67	46.36	0.0652
P. astreoides	*M. cavernosa*	20.83	5.48	36.18	0.0008*
P. astreoides	*S. bournoni*	20.42	2.26	38.59	0.0139*
S. siderea	*M. cavernosa*	19.05	6.18	31.92	0.0001*
S. siderea	*S. bournoni*	18.65	3.12	34.18	0.0057*
D. stokesii	*M. cavernosa*	16.62	1.79	31.45	0.0145*
Diploria species	*M. cavernosa*	16.49	3.85	29.13	0.0015*
D. stokesii	*S. bournoni*	16.22	-0.54	32.98	0.0675
Diploria species	*S. bournoni*	16.09	1.85	30.32	0.0131*
S. intersepta	*M. cavernosa*	16.00	0.32	31.69	0.0411*
S. intersepta	*S. bournoni*	15.60	-2.09	33.29	0.1392
Other species	*S. intersepta*	13.14	-9.46	35.73	0.7078
Other species	*Diploria* species	12.65	-8.50	33.80	0.6721
Other species	*D. stokesii*	12.52	-10.02	35.05	0.7600
Other species	*S. siderea*	10.09	-10.88	31.05	0.8822
Other species	*P. astreoides*	8.31	-15.04	31.66	0.9819
S. bournoni	*M. meandrites*	7.76	-8.38	23.90	0.8825
M. cavernosa	*M. meandrites*	7.36	-5.98	20.70	0.7675
S. bournoni	*M. annularis* complex	7.25	-15.13	29.63	0.9907
M. cavernosa	*M. annularis* complex	6.84	-12.85	26.54	0.9846
P. astreoides	*S. intersepta*	4.82	-15.05	24.70	0.9990
P. astreoides	*Diploria* species	4.34	-12.68	21.35	0.9985
P. astreoides	*D. stokesii*	4.21	-14.87	23.28	0.9995
S. siderea	*S. intersepta*	3.05	-13.61	19.70	0.9999
S. siderea	*Diploria* species	2.56	-12.45	17.57	0.9999
S. siderea	*D. stokesii*	2.43	-14.38	19.24	1.0000
P. astreoides	*S. siderea*	1.78	-15.73	19.28	1.0000
D. stokesii	*S. intersepta*	0.62	-18.28	19.52	.
M. annularis complex	*M. meandrites*	0.52	-21.57	22.61	.
Diploria species	*S. intersepta*	0.49	-16.65	17.63	.
S. bournoni	*M. cavernosa*	0.40	-13.49	14.30	.
D. stokesii	*Diploria* species	0.13	-15.33	15.59	.

Table 35: LSMeans differences Tukey HSD analysis to determine events with significant differences including the upper and lower confidence intervals. The asterisk located in the p-Value column signify a significant difference between the two events listed in level 1 and level 2.

Level 1	Level 2	Percent Difference	Lower 95% CI	Upper 95% CI	p-Value
Warren Modules	Mitigation Boulders	42.26	7.69	76.84	0.0059*
SPP - Yearly Monitoring	Mitigation Boulders	38.91	10.01	67.81	0.0012*
C/V Hind	Mitigation Boulders	38.70	18.97	58.42	<.0001*
DERM Modules	Mitigation Boulders	36.57	17.35	55.79	<.0001*
Hillsboro Cable Drag	Mitigation Boulders	32.21	10.01	54.40	0.0004*
M/V Firat	Mitigation Boulders	31.43	12.05	50.81	<.0001*
M/VSpar Orion	Mitigation Boulders	29.13	3.71	54.54	0.0128*
Clipper Lasco	Mitigation Boulders	24.73	-6.55	56.00	0.2453
Warren Modules	*Clipper Lasco*	17.53	-25.58	60.65	0.9303
SPP - Yearly Monitoring	*Clipper Lasco*	14.18	-24.47	52.83	0.9642
C/V Hind	*Clipper Lasco*	13.97	-18.64	46.57	0.9115
Warren Modules	*M/V Spar Orion*	13.13	-25.99	52.25	0.9756
DERM Modules	*Clipper Lasco*	11.84	-20.33	44.01	0.9616
Warren Modules	*M/V Firat*	10.83	-25.11	46.77	0.9883
Warren Modules	Hillsboro Cable Drag	10.06	-26.82	46.93	0.9937
SPP - Yearly Monitoring	*M/V Spar Orion*	9.78	-24.45	44.01	0.9924
C/V Hind	*M/V Spar Orion*	9.57	-17.77	36.90	0.9695
Hillsboro Cable Drag	*Clipper Lasco*	7.48	-26.30	41.25	0.9987
SPP - Yearly Monitoring	*M/V Firat*	7.48	-16.08	31.03	0.9861
DERM Modules	*M/V Spar Orion*	7.44	-19.15	34.03	0.9923
C/V Hind	*M/V Firat*	7.27	-12.55	27.08	0.9634
M/V Firat	*Clipper Lasco*	6.70	-25.94	39.35	0.9993
SPP - Yearly Monitoring	Hillsboro Cable Drag	6.70	-24.46	37.87	0.9990
C/V Hind	Hillsboro Cable Drag	6.49	-16.85	29.83	0.9930
Warren Modules	DERM Modules	5.69	-29.55	40.94	0.9999
DERM Modules	*M/V Firat*	5.14	-16.39	26.66	0.9978
M/V Spar Orion	*Clipper Lasco*	4.40	-31.95	40.75	1.0000
DERM Modules	Hillsboro Cable Drag	4.36	-18.66	27.38	0.9995
Warren Modules	*C/V Hind*	3.57	-32.31	39.45	1.0000
Warren Modules	SPP - Yearly Monitoring	3.35	-37.94	44.64	1.0000
Hillsboro Cable Drag	*M/V Spar Orion*	3.08	-25.70	31.85	1.0000
SPP - Yearly Monitoring	DERM Modules	2.34	-27.30	31.98	1.0000
M/V Firat	*M/V Spar Orion*	2.30	-24.99	29.59	1.0000
C/V Hind	DERM Modules	2.13	-19.29	23.55	1.0000
Hillsboro Cable Drag	*M/V Firat*	0.78	-22.97	24.52	1.0000
SPP - Yearly Monitoring	*C/V Hind*	0.21	-27.09	27.52	.

Dichocoenia stokesii

In total, 77 experimental colonies were located of which 44 were alive and attached to the substrate, 32 were dead, and one was found alive but loose. As for the control colonies, 18 were surveyed, 10 of which were alive and attached to the substrate, seven were found dead, and one was loose from the substrate. Significant differences in partial mortality was found between *D. stokesii* and *M. meandrites* (CI 95%: 6.86, 41.10), *Montastraea annularis* complex (CI 95%: 0.40, 46.52) and *M. cavernosa* (CI 95%: 1.79, 31.45). Mean differences determined that *D. stokesii* partial mortality was 23.98% more than *M. meandrites,* 23.46% than *Montastraea annularis* complex and 16.62% than *M. cavernosa* (Table 34).

Diploria species

The *Diploria* species consists of *D. clivosa* (166), *D. labyrinthiformis* (10), and *D. strigosa* (37) species. In total, 153 experimental colonies were located of which 85 were alive and attached to the substrate, 66 were dead, and two were found alive but loose. As for the control colonies, 60 were surveyed, 34 were living attached to the substrate and 26 were found dead. Significant differences in partial mortality was found between *Diploria* species and *M. meandrites* (CI 95%: 8.68, 39.02), *Montastrea annularis* complex (CI 95%: 1.95, 44.71), *M. cavernosa* (CI 95%: 3.85, 29.13) and *S. bournoni* (CI 95%: 1.85, 30.32). Mean differences determined that *Diploria* species partial mortality was 23.85% more than *M. meandrites,* 23.33% than *Montastrea annularis* complex, 16.49% than *M. cavernosa* and 16.09% than *S. bournoni* (Table 34).

Meandrina meandrites

In total, 100 experimental colonies were located of which 60 were alive and attached to the substrate, 36 were dead, and one was found alive but loose. As for the control colonies, 19 were surveyed, 13 were living attached to the substrate and six were found dead. *M. meandrites* partial morality was not found to be significantly greater than any other coral species.

Montastraea annularis complex

The *Montastraea annularis* complex consists of *M. annularis* (2) and *M. faveolata* (51) species. In total, 50 experimental colonies were located of which 39 were alive and attached to the substrate, 10 were dead, and one was found alive but loose. Additionally, both *M. annularis* colonies survived. As for the control colonies, three were surveyed, two were living attached to the substrate and one was found dead. *M. annularis* complex partial morality was not found to be significantly greater than any other coral species.

Montastraea cavernosa

In total, 280 experimental colonies were located of which 198 were alive and attached to the substrate, 77 were found dead, and five were alive but loose. As for the control colonies, 57 were surveyed, 44 were living attached to the substrate, 12 were found dead, and one was loose from the substrate. *M. cavernosa* partial morality was not found to be significantly greater than any other coral species.

Other species

The category of other species consists of *C. natans* (14), *A. agaricites* (6), *Agaricia* species (1), *E. fastigiata* (3), *M. angulosa* (1), *M. decactis* (9), *O. diffusa* (5), *M. aliciae* (3) and unidentified species (2). In total, 40 experimental colonies were located of which 13 were alive and attached to the substrate and 27 were found dead. As for the control colonies, four were surveyed, two were living attached to the substrate and two were found dead. The two corals found living were both *C. natans*, while the two dead corals were *M. aliciae* and *M. decactis*. Significant differences in partial mortality was found between Other species and *M. meandrites* (CI 95%: 15.21, 57.79), *Montastrea annularis* complex (CI 95%: 9.49, 62.48), *M. cavernosa* (CI 95%: 9.14, 49.14) and *S. bournoni* (CI 95%: 7.20, 50.27). Mean differences determined that Other species partial mortality was 36.50% more than *M. meandrites,* 35.98% than *Montastrea annularis* complex, 29.14% than *M. cavernosa* and 28.74% than *S. bournoni* (Table 34).

Porites astreoides

In total, 63 experimental colonies were located of which 31 were alive and attached to the substrate, 31 were dead, and one was found alive but loose. As for the control colonies, 16 were surveyed, 10 were living attached to the substrate and six were found dead. Significant differences in partial mortality was found between *P. astreoides* and *M. meandrites* (CI 95%: 10.16, 46.21), *Montastrea annularis* complex (CI 95%:

4.31, 51.03), *M. cavernosa* (CI 95%: 5.48, 36.18) and *S. bournoni* (CI 95%: 2.26, 38.59). Mean differences determined that *P. astreoides* partial mortality was 28.19% more than *M. meandrites,* 27.67% than *Montastrea annularis* complex, 20.83% than *M. cavernosa* and 20.42% than *S. bournoni* (Table 34).

Siderastrea siderea

In total, 150 experimental colonies were located of which 74 were alive and attached to the substrate, 74 were dead, and two were found alive but loose. As for the control colonies, five were surveyed, three were living attached to the substrate and two were found dead. Significant differences in partial mortality was found between *S. siderea* and *M. meandrites* (CI 95%: 11.41, 41.41), *Montastrea annularis* complex (CI 95%: 4.22, 47.56), *M. cavernosa* (CI 95%: 6.18, 31.92) and *S. bournoni* (CI 95%: 3.12, 34.18). Mean differences determined that *S. siderea* partial morality was 26.41% more than *M. meandrites,* 25.89% than *Montastrea annularis* complex, 19.05% than *M. cavernosa* and 18.65% than *S. bournoni* (Table 34).

Solenastrea bournoni

In total, 148 experimental colonies were located of which 114 were alive and attached to the substrate, 32 were dead, and two were found alive but loose. As for the control colonies, 26 were surveyed, 21 were living attached to the substrate and five were found dead. *S. bournoni* partial morality was not found to be significantly greater than any other coral species.

Stephanocoenia intersepta

In total, 85 experimental colonies were located of which 45 were alive and attached to the substrate, 38 were dead, and two were found alive but loose. However, there were no control colony data available for this particular species therefore, the treatments could not be statistically compared. However, significant differences in partial mortality was found between *S. intersepta* and *M. meandrites* (CI 95%: 5.92, 40.81) and *M. cavernosa* (CI 95%: 0.32, 31.69). Mean differences determined that *S. intersepta* partial morality was 23.36% more than *M. meandrites* and 16% than *M. cavernosa* (Table 34).

4.3.2. Sites/Events

M/V Firat

Project records included the location of 100 transplanted coral colonies and most were located during surveying. While locating the corals, one site was composed of rubble and the corals were unable to be found; these corals were deemed to be dead. Of the 100 colonies, 52 were found alive and attached to the substrate, 45 were found dead, and three were loose and no longer attached to the substrate (Table 38 and Figure 11). The average percent mortality for the experimental colonies was 59.03% (Table 36).

Project records also included the location of 102 control coral colonies. Of the 102 colonies, 69 were found alive and attached to the substrate, 32 were found dead, and one was loose and no longer attached to the substrate (Table 39 and Figure 12). The average percent mortality for the control colonies was 52.67% (Table 37).

A significant difference in partial mortality of the experimental colonies (all species pooled) was found between *M/V Firat* and the Mitigation Boulder sites (CI 95%: 12.05, 50.80). Mean differences determined that *M/V Firat* had 31.43% more partial mortality than the Mitigation Boulders (Table 35).

Table 36: Average percent mortality for each experimental site.

Experimental Percent Mortality						
Event	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
C/V Hind	64.31	40.00	3.13	70.49	58.12	163
Clipper Lasco	46.95	40.65	6.35	59.78	34.12	41
DERM Modules	65.22	41.60	2.42	69.98	60.46	296
Hillsboro Cable Drag	51.98	39.96	2.96	57.82	46.13	182
M/V Firat	59.03	43.45	4.35	67.65	50.41	100
M/V Spar Orion	60.03	41.08	3.56	67.08	52.98	133
Mitigation Boulders	25.95	35.49	2.73	31.34	20.56	169
Warren Modules	71.92	38.24	4.86	81.63	62.21	62

Table 37: Average percent mortality for each control site.

Control Percent Mortality						
Event	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
C/V Hind	44.30	41.90	7.65	59.95	28.65	30
M/V Firat	52.67	43.60	4.32	61.23	44.10	102
Yearly Monitoring	47.68	41.68	4.78	57.21	38.16	76

Table 38: Experimental colony status (attached (alive), dead, or loose) at each study location.

Experimental Colony Status				
Event	**Attached**	**Dead**	**Loose**	**N**
C/V Hind	91	68	4	163
Clipper Lasco	33	8	0	41
DERM Modules	145	150	1	296
Hillsboro Cable Drag	127	50	5	182
M/V Firat	52	45	3	100
M/V Spar Orion	83	50	0	133
Mitigation Boulders	150	19	0	169
Warren Modules	22	33	7	62

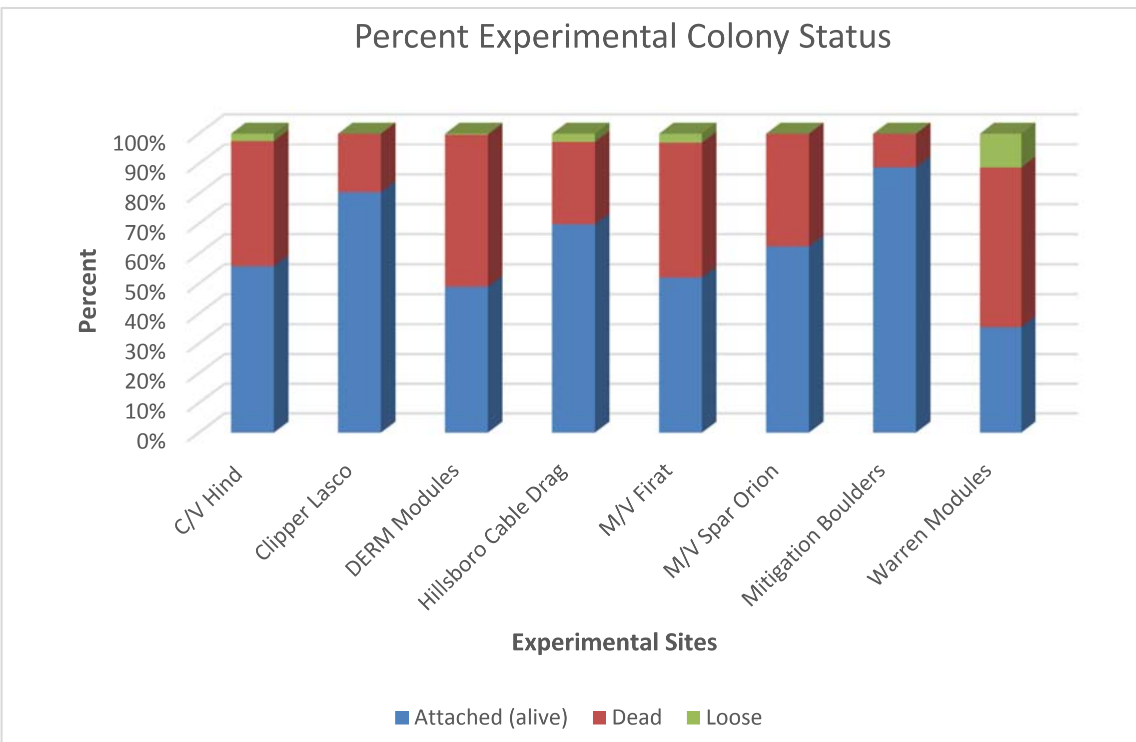

Figure 11: Graph displaying the percent of the total number of experimental corals that were attached (alive), dead, and loose at each of the experimental sites.

Table 39: Control colony status (attached (alive), dead, or loose) at each study location.

Control Colony Status				
Event	**Attached**	**Dead**	**Loose**	**N**
C/V Hind	22	8	0	30
M/V Firat	69	32	1	102
Yearly Monitoring	48	27	1	76

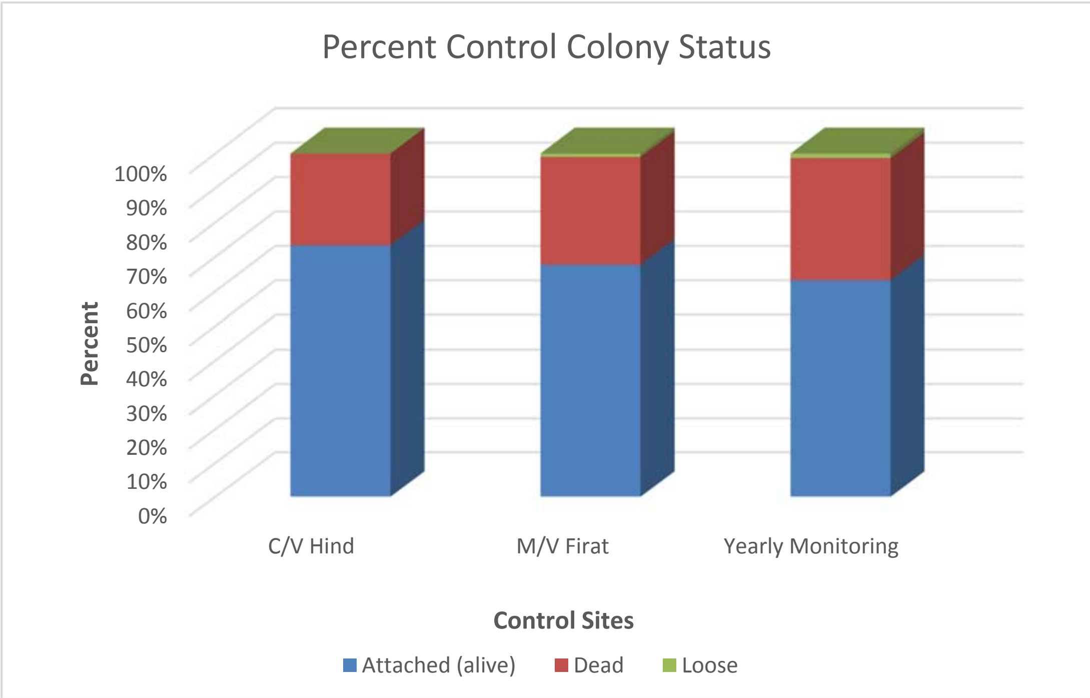

Figure 12: Graph displaying the percent of the total number of control corals that were attached (alive), dead, and loose at each of the control sites.

C/V Hind

Project records included the location of 163 transplanted coral colonies. Of the 163 colonies, 91 were found alive and attached to the substrate, 68 were found dead, and four were loose and no longer attached to the substrate (Table 38 and Figure 11). The average percent mortality for the experimental colonies was 64.31% (Table 36).

Project records included the location of 30 control coral colonies. Of the 30 colonies, 22 were found alive and attached to the substrate and 8 were found dead (Table 39 and Figure 12). The average percent mortality for the control colonies was 44.30% (Table 37).

A significant difference in partial colony mortality was found between *C/V Hind* and the Mitigation Boulder sites (CI 95%: 18.96, 58.42). Mean differences determined that *C/V Hind* had 38.70% more partial mortality of corals than the Mitigation Boulders (Table 35).

M/V Spar Orion

Project records included the location of 133 transplanted coral colonies. Of the 133 colonies, 83 were found alive and attached to the substrate and 50 were found dead (Table 38 and Figure 11). The average percent mortality for the experimental colonies was 60.03% (Table 36).

A significant difference in partial colony mortality was found between *M/V Spar Orion* and the Mitigation Boulder sites (CI 95%: 3.71, 54.54). Mean differences determined that *M/V Spar Orion* had 29.13% more partial mortality of corals than the Mitigation Boulders (Table 35).

Clipper Lasco

Project records included the location of 41 transplanted coral colonies. Of the 41 colonies, 33 were found alive and attached to the substrate and 8 were found dead (Table 38 and Figure 11). The average percent mortality for the experimental colonies was 46.95% (Table 36). No significant differences in partial mortality were found between the *Clipper Lasco* and any other site.

Broward County Mitigation Boulders

Project records included the location of 169 transplanted coral colonies. Of the 169 colonies, 150 were found alive and attached to the substrate and 19 were found dead (Table 38 and Figure 11). The average percent mortality for the experimental colonies was 25.95% (Table 36). No significant differences in partial mortality was found between the Broward County Mitigation Boulders and any other site.

Warren Modules

Project records included the location of 62 transplanted coral colonies. Of the 62 colonies, 22 were found alive and attached to the substrate, 33 were found dead, and seven were loose and no longer attached to the substrate (Table 38 and Figure 11). The average percent mortality for the experimental colonies was 71.92% (Table 36).

A significant difference in health condition of scleractinian species was found between Warren Modules and the Mitigation Boulder sites (CI 95%: 7.68, 76.83). Mean differences determined that Warren Modules had 42.26% more partial mortality of corals than the Mitigation Boulders (Table 35).

DERM Modules

Project records included the location of 296 transplanted coral colonies. Of the 296 colonies, 145 were found alive and attached to the substrate, 150 were found dead, and one was loose and no longer attached to the substrate (Table 38 and Figure 11). The average percent mortality for the experimental colonies was 65.22% (Table 36).

A significant difference in partial colony mortality was found between DERM Modules and the Mitigation Boulder sites (CI 95%: 17.34, 55.78). Mean differences determined that DERM Modules had 36.57% more partial mortality of corals than the Mitigation Boulders (Table 35).

Hillsboro Cable Drag

Project records included the location of 182 transplanted coral colonies. Of the 182 colonies, 127 were found alive and attached to the substrate, 50 were found dead, and five were loose and no longer attached to the substrate (Table 38 and Figure 11). The average percent mortality for the experimental colonies was 51.98% (Table 36).

A significant difference in partial colony mortality was found between Hillsboro Cable Drag and the Mitigation Boulder sites (CI 95%: 10.01, 54.39). Mean differences determined that Hillsboro Cable Drag had 32.21% more partial mortality of corals than the Mitigation Boulders (Table 35).

Yearly Monitoring

Project records included the location of 76 control coral colonies. Of the 76 colonies, 48 were found alive and attached to the substrate, 27 were found dead, and one was loose and no longer attached to the substrate (Table 39 and Figure 12). The average percent mortality for the control colonies was 47.68% (Table 37). No significant differences in partial mortality were found between Yearly Monitoring and any other site.

4.4 Hypothesis 4

Ho: There is no significant difference in partial colony mortality between whole and fragmented transplanted coral species (all sites pooled).

All 2012 experimental data was pooled and analyzed with JMP, a statistical software from the business unit of SAS. A mixed nested general linear model analysis was completed with the data set. The data set included: study site, coral species, percent mortality for each colony analyzed, and data based on if the colony was whole or fragmented at the time of transplantation. Each event (injury event, impact minimization, or nursery) was nested within each site (where the data was collected) of the event and with whole (N, 920) or fragmented (N, 157) colony data. All sites were considered the random effect; the fixed effects were the coral species and whole/fragment data. Twenty three percent variability in mortality was due to the random effect (site) and 77% variability was due to the fixed effects (coral species and fragment data). In other words, 23% of the partial mortality was due to where the colony was located at each event (injury event, impact minimization, or nursery) and 77% of the variability was due to the coral species and if the colony was or was not fragmented. The variability shows how spread out the distribution of the data set is.

A statistical difference was found between coral species ($F(9, 1{,}111) = 8.98$, $p = <0.0001$), and whole/fragment data ($F(1, 195) = 17.15$, $p = <0.0001$). To determine the difference by coral species and whole/fragment data, a Tukey HSD multiple comparison test was used (Table 40). Overall, more mortality was seen in the fragmented corals (64.11%) than the whole coral colonies (51.02%) (Table 41).

Table 40: LSMeans differences Tukey HSD analysis to determine coral species significant differences in fragment data with upper and lower confidence intervals. The p-Values with asterisks signify significant differences between listed.

Level 1	Level 2	Percent Diff.	Lower 95% CI	Upper 95% CI	p-Value
Other species	*S. bournoni*	33.99	12.42	55.56	<.0001*
Other species	*M. annularis* complex	33.45	6.81	60.09	0.0029*
Other species	*M. meandrites*	32.04	10.72	53.35	<.0001*
S. siderea	*S. bournoni*	27.39	12.27	42.51	<.0001*
S. siderea	*M. annularis* complex	26.85	4.96	48.75	0.0042*
Other species	*M. cavernosa*	25.74	5.82	45.66	0.0018*
S. siderea	*M. meandrites*	25.44	10.32	40.55	<.0001*
P. asteroides	*S. bournoni*	25.08	5.92	44.24	0.0015*
P. asteroides	*M. annularis* complex	24.55	-0.09	49.18	0.0517
D. stokesii	*S. bournoni*	23.57	5.28	41.86	0.0019*
P. asteroides	*M. meandrites*	23.13	3.81	42.44	0.0060*
D. stokesii	*M. annularis* complex	23.03	-1.12	47.18	0.0764
Other species	*Diploria* species	22.61	0.75	44.47	0.0359*
D. stokesii	*M. meandrites*	21.61	3.39	39.84	0.0069*
S. intersepta	*S. bournoni*	21.33	3.40	39.27	0.0066*
S. intersepta	*M. annularis* complex	20.80	-3.20	44.79	0.1561
S. intersepta	*M. meandrites*	19.38	1.58	37.19	0.0205*
S. siderea	*M. cavernosa*	19.14	6.38	31.90	<.0001*
P. asteroides	*M. cavernosa*	16.83	0.15	33.52	0.0458*
S. siderea	*Diploria* species	16.01	0.09	31.93	0.0473*
D. stokesii	*M. cavernosa*	15.32	-0.85	31.50	0.0810
P. asteroides	*Diploria* species	13.70	-5.58	32.99	0.4213
S. intersepta	*M. cavernosa*	13.09	-2.75	28.93	0.2098
Other species	*S. intersepta*	12.65	-10.12	35.42	0.7592
D. stokesii	*Diploria* species	12.19	-6.33	30.71	0.5376
Diploria species	*S. bournoni*	11.38	-4.76	27.52	0.4326
Diploria species	*M. annularis* complex	10.84	-11.83	33.52	0.8856
Other species	*D. stokesii*	10.42	-12.85	33.69	0.9212
S. intersepta	*Diploria* species	9.96	-8.35	28.26	0.7819
Diploria species	*M. meandrites*	9.43	-7.16	26.01	0.7344
Other species	*P. asteroides*	8.91	-15.11	32.92	0.9759
M. cavernosa	*S. bournoni*	8.25	-5.59	22.08	0.6751
M. cavernosa	*M. annularis* complex	7.71	-12.76	28.18	0.9732
Other species	*S. siderea*	6.60	-14.26	27.46	0.9921
M. cavernosa	*M. meandrites*	6.29	-7.45	20.04	0.9103
S. siderea	*S. intersepta*	6.05	-10.73	22.84	0.9801
S. siderea	*D. stokesii*	3.82	-13.84	21.48	0.9996
P. asteroides	*S. intersepta*	3.75	-17.18	24.67	0.9999
D. species	*M. cavernosa*	3.13	-11.06	17.33	0.9995
S. siderea	*P. asteroides*	2.31	-16.08	20.69	1.0000
D. stokesii	*S. intersepta*	2.23	-17.80	22.27	1.0000
M. meandrites	*S. bournoni*	1.95	-14.17	18.07	1.0000
P. asteroides	*D. stokesii*	1.51	-19.63	22.66	1.0000
M. meandrites	*M. annularis* complex	1.42	-21.22	24.06	1.0000
M. annularis complex	*S. bournoni*	0.54	-21.93	23.00	.

Table 41: Average percent mortality of the whole and fragmented experimental colonies. Due to missing colonies, the N only equals 1,077.

Average Percent Mortality						
	Mean	Std Dev	Std Err Mean	Upper 95% Mean	Lower 95% Mean	N
Whole Colony	51.02	42.25	1.39	53.75	48.28	920
Fragment Colony	64.11	39.38	3.14	70.32	57.91	157

4.4.1 Dichocoenia stokesii

In total, four fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). A significant difference was found between fragments of *D. stokesii* and *S. bournoni* and *M. meandrites* colonies. Mean differences determined that *D. stokesii* fragment partial mortality was 23.57% more than *S. bournoni* and 21.61% than *M. meandrites* (Table 40).

Table 42: Descriptive statistics including the number of whole and fragmented experimental colonies located.

Species	Number of Whole Colonies	Number of Fragments	Total
Dichocoenia stokesii	70	4	74
Diploria species	84	61	145
Meandrina meandrites	101	6	107
Montastraea annularis complex	43	6	49
Montastrea cavernosa	253	34	287
Other species	36	6	42
Porites asteroides	55	8	63
Siderastrea siderea	138	11	149
Solenastrea bournoni	150	8	158
Stephanocoenia intersepta	66	13	79

4.4.2 Diploria species

In total, 61 fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). No significant differences were found between fragments of *Diploria* species and any other species studied in this experiment.

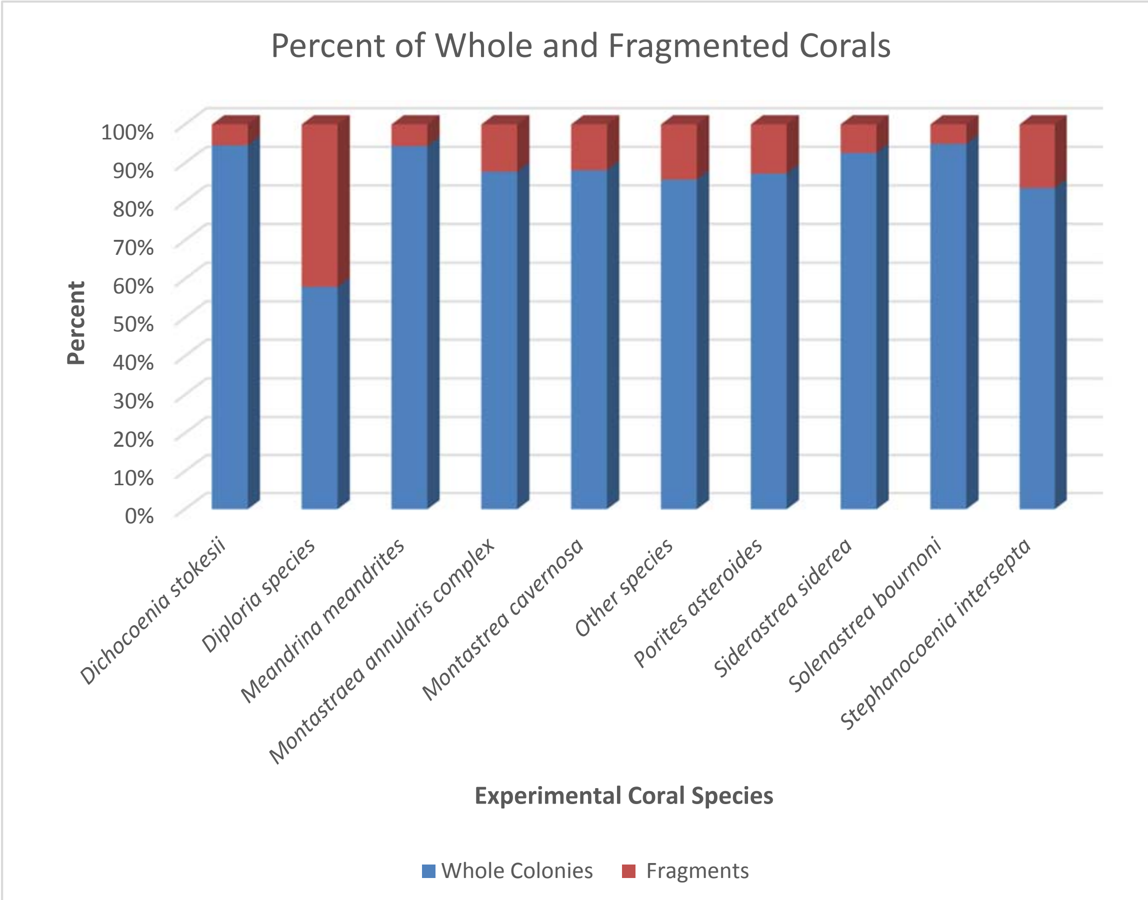

Figure 13: Graph of the percent of whole and fragmented colonies for each experimental species overall.

4.4.3 Meandrina meandrites

In total, six fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). No significant differences were found between fragments of *M. meandrites* and any other species studied in this experiment.

4.4.4 Montastraea annularis complex

In total, six fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). No significant differences were found between fragments of *Montastraea annularis* complex and any other species studied in this experiment.

4.4.5 Montastraea cavernosa

In total, 34 fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). No significant differences were found between fragments of *M. cavernosa* and any other species studied in this experiment.

4.4.6 Other species

The category of other species consists of *C. natans* (14), *A. agaricites* (6), *Agaricia* species (1), *E. fastigiata* (3), *M. angulosa* (1), *M. decactis* (9), *O. diffusa* (5), *M. aliciae* (3) and unidentified species (2). In total, six fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). Significant differences were found between fragments of Other species and *S. bournoni*, *Montastraea annularis* complex, *M. meandrites*, *M. cavernosa*, and *Diploria* species colonies. Mean differences determined that Other species partial mortality was 33.99% more than *S. bournoni*, 33.45% than *Montastraea annularis* complex, 32.04% than *M. meandrites*, 25.74% than *M. cavernosa* and 22.61% than *Diploria* species (Table 40).

4.4.7 Porites astreoides

In total, 11 fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). Significant differences were found between fragments of *P. astreoides* and *S. bournoni*, *M. meandrites* and *M. cavernosa* colonies. Mean differences determined that *P. astreoides* partial mortality was 25.08% more than *S. bournoni*, 23.13% than *M. meandrites* and 16.83% than *M. cavernosa* (Table 40).

4.4.8 Siderastrea siderea

In total, eight fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). Significant differences were found between fragments of *S. siderea* and *S. bournoni*, *Montastraea annularis* complex, *M. meandrites*, *M. cavernosa* and *Diploria* species colonies. Mean differences determined that *S. siderea* partial mortality was 27.39% more than *S. bournoni*, 26.85% than *Montastraea annularis* complex, 25.44% than *M. meandrites*, 19.14% than *M. cavernosa* and 16.01% than *Diploria* species (Table 40).

4.4.9 Solenastrea bournoni

In total, eight fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). No significant differences were found between fragments of *S. bournoni* and any other species studied in this experiment.

4.4.10 Stephanocoenia intersepta

In total, 13 fragmented colonies were found throughout all experimental sites (Table 42 and Figure 13). Significant differences were found between fragments of *S. intersepta* and *S. bournoni* and *M. meandrites* colonies. Mean differences determined that *S. intersepta* partial mortality was 21.33% more than *S. bournoni* and 19.38% than *M. meandrites* (Table 40).

4.5 Hypothesis 5

Ho: There is no significant association within species between partial colony mortality and size of transplanted and control corals (all sites pooled).

All 2012 data was pooled analyzed with JMP, a statistical software from the business unit of SAS. Pairwise correlations using a Bonferroni Adjustment was completed between height, length, and width and percent mortality for each species within the treatment (control or experimental). The data set included: treatment (experimental or control), colony percent mortality, and colony height, length, and width. Mathematically, correlation is expressed as a coefficient; the coefficient ranges from one to zero. The likelihood that two variables always occur together gives a coefficient of one, coefficients between one and zero indicate a rage of dependence, and a coefficient of zero means the two variables are independent of each other. No correlation was found between the 2012 data of partial colony mortality and size of transplanted and control coral species. Also, no correlation was found between control and experimental partial mortality for *S. intersepta* due to no control data for *S. intersepta*. Tables 43 – 52 summarize the correlation data for each species.

Table 43: Bonferroni Adjustment Pairwise correlations for *Dichocoenia stokesii.*

Dichocoenia stokesii			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	0.99	0.94
Whole Colony Height (cm)	Whole Colony Length (cm)	0.15	0.59
Whole Colony Height (cm)	Whole Colony Width (cm)	0.13	0.64
Percent Mortality	Whole Colony Length (cm)	0.40	-0.07
Percent Mortality	Whole Colony Width (cm)	0.38	-0.01
Percent Mortality	Whole Colony Height (cm)	0.27	-0.02

Table 44: Bonferroni Adjustment Pairwise correlations for *Diploria* species.

***Diploria* species**			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	0.78	0.93
Whole Colony Height (cm)	Whole Colony Length (cm)	0.46	0.46
Whole Colony Height (cm)	Whole Colony Width (cm)	0.45	0.38
Percent Mortality	Whole Colony Length (cm)	0.06	0.09
Percent Mortality	Whole Colony Width (cm)	-0.13	-0.02
Percent Mortality	Whole Colony Height (cm)	-0.07	0.14

Table 45: Bonferroni Adjustment Pairwise correlations for *Meandrina meandrites.*

Meandrina meandrites			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	0.98	0.92
Whole Colony Height (cm)	Whole Colony Length (cm)	0.73	0.63
Whole Colony Height (cm)	Whole Colony Width (cm)	0.73	0.64
Percent Mortality	Whole Colony Length (cm)	0.10	0.16
Percent Mortality	Whole Colony Width (cm)	0.17	0.11
Percent Mortality	Whole Colony Height (cm)	-0.19	0.28

Table 46: Bonferroni Adjustment Pairwise correlations for *Montastraea annularis* complex.

***Montastraea annularis* complex**			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	-1.00	0.94
Whole Colony Height (cm)	Whole Colony Length (cm)	1.00	0.61
Whole Colony Height (cm)	Whole Colony Width (cm)	-1.00	0.66
Percent Mortality	Whole Colony Length (cm)	-1.00	0.54
Percent Mortality	Whole Colony Width (cm)	1.00	0.46
Percent Mortality	Whole Colony Height (cm)	-1.00	0.11

Table 47: Bonferroni Adjustment Pairwise correlations for *Montastraea cavernosa.*

Montastrea cavernosa			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	0.93	0.89
Whole Colony Height (cm)	Whole Colony Length (cm)	0.69	0.71
Whole Colony Height (cm)	Whole Colony Width (cm)	0.75	0.74
Percent Mortality	Whole Colony Length (cm)	-0.05	0.19
Percent Mortality	Whole Colony Width (cm)	-0.14	0.15
Percent Mortality	Whole Colony Height (cm)	-0.10	0.13

Table 48: Bonferroni Adjustment Pairwise correlations for Other species.

Other species			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	1.00	0.89
Whole Colony Height (cm)	Whole Colony Length (cm)	1.00	0.46
Whole Colony Height (cm)	Whole Colony Width (cm)	1.00	0.61
Percent Mortality	Whole Colony Length (cm)	-1.00	0.35
Percent Mortality	Whole Colony Width (cm)	-1.00	0.43
Percent Mortality	Whole Colony Height (cm)	-1.00	0.23

Table 49: Bonferroni Adjustment Pairwise correlations for *Porites astreoides.*

Porites astreoides			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	0.97	0.84
Whole Colony Height (cm)	Whole Colony Length (cm)	0.61	0.62
Whole Colony Height (cm)	Whole Colony Width (cm)	0.56	0.52
Percent Mortality	Whole Colony Length (cm)	-0.52	0.10
Percent Mortality	Whole Colony Width (cm)	-0.47	0.13
Percent Mortality	Whole Colony Height (cm)	-0.44	0.17

Table 50: Bonferroni Adjustment Pairwise correlations for *Siderastrea siderea.*

Siderastrea siderea			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	0.77	0.87
Whole Colony Height (cm)	Whole Colony Length (cm)	-0.12	0.68
Whole Colony Height (cm)	Whole Colony Width (cm)	-0.72	0.70
Percent Mortality	Whole Colony Length (cm)	-0.74	-0.10
Percent Mortality	Whole Colony Width (cm)	-1.00	-0.04
Percent Mortality	Whole Colony Height (cm)	0.76	-0.04

Table 51: Bonferroni Adjustment Pairwise correlations for *Solenastrea bournoni.*

Solenastrea bournoni			
Variable 1	**Variable 2**	**Control Pairwise Correlation**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	0.91	0.92
Whole Colony Height (cm)	Whole Colony Length (cm)	0.64	0.61
Whole Colony Height (cm)	Whole Colony Width (cm)	0.55	0.60
Percent Mortality	Whole Colony Length (cm)	0.30	-0.24
Percent Mortality	Whole Colony Width (cm)	0.20	-0.30
Percent Mortality	Whole Colony Height (cm)	0.44	-0.30

Table 52: Bonferroni Adjustment Pairwise correlations for *Stephanocoenia intersepta.*

Stephanocoenia intersepta		
Variable 1	**Variable 2**	**Experimental Pairwise Correlation**
Whole Colony Width (cm)	Whole Colony Length (cm)	0.95
Whole Colony Height (cm)	Whole Colony Length (cm)	0.82
Whole Colony Height (cm)	Whole Colony Width (cm)	0.80
Percent Mortality	Whole Colony Length (cm)	-0.05
Percent Mortality	Whole Colony Width (cm)	-0.11
Percent Mortality	Whole Colony Height (cm)	0.02

4.6 Hypothesis 6

Ho: There is no significant difference in transplanted coral percent colony mortality between injury event efforts, impact minimization efforts, and nursery efforts.

All experimental, 2012 data was pooled and analyzed with JMP, a statistical software from the business unit of SAS. A mixed nested general linear model analysis was completed with the data set. The data set included: experimental colonies, percent mortality, and type of event (injury event, impact minimization, or nursery) (Table 53). The injury events included*: M/V Firat*, *C/V Hind*, *M/V Spar Orion, Clipper Lasco*, and Hillsboro Cable Drag. The impact minimization event included the Broward County Mitigation Boulders only. The nursery events included both Warren and DERM Modules. Each site (*M/V Firat*, *C/V Hind*, *M/V Spar Orion, Clipper Lasco*, Hillsboro Cable Drag, Broward County Mitigation Boulders, and Warren and DERM Modules) was nested within each type of event (injury event, impact minimization, or nursery). The average percent mortality for each type of event (injury event, impact minimization, or nursery) shows that the impact minimization event had the least mortality (25.94%) while the most mortality was seen at the nursery events (66.37%) (Table 53 and Figure

14). The Tukey HSD multiple comparison test was utilized to determine significant differences between the injury events, impact minimization, and nursery events. The nursery events were found to have 37.79% more partial mortality than the impact minimization event and 8.17% more partial mortality than the injury events. Also, the injury events were found to have 29.62% more partial mortality than the impact minimization event (Table 54).

Table 53: Average percent mortality for experimental colonies in impact minimization and injury events.

Average Percent Mortality						
Type of Event	**Mean**	**Std Dev**	**Std Err Mean**	**Upper 95% Mean**	**Lower 95% Mean**	**N**
Impact Minimization	25.94	35.49	2.73	31.34	20.56	169
Injury Event	57.76	41.07	1.65	61.00	54.52	619
Nursery	66.37	41.07	2.17	70.65	62.11	358

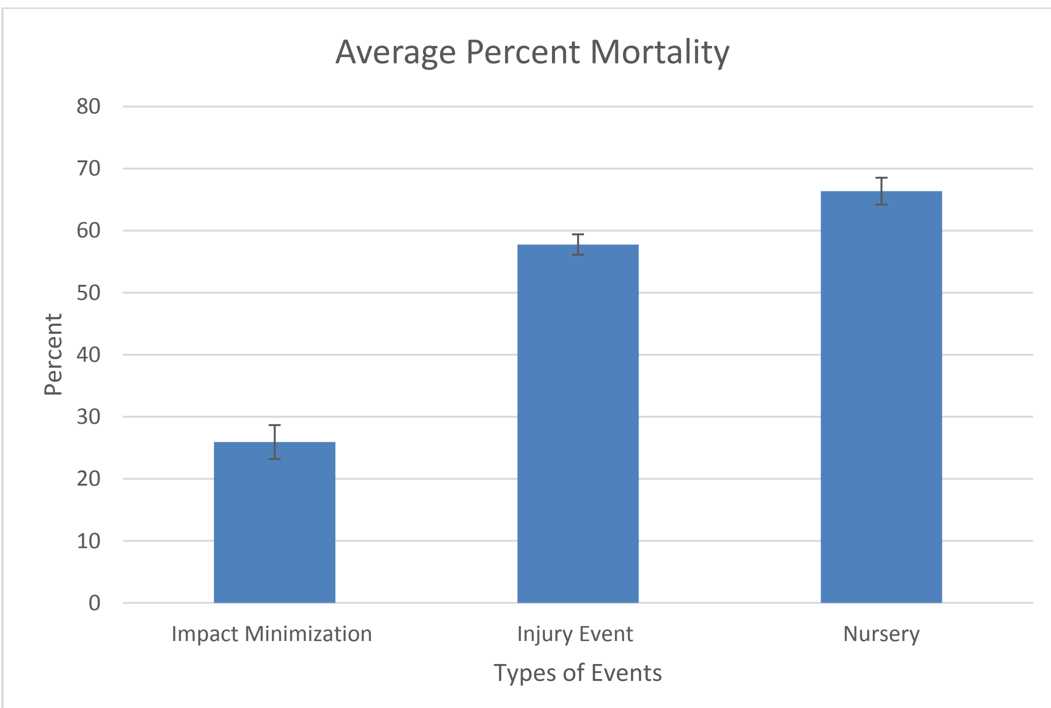

Figure 14: Graph displaying average percent mortality for each type of event (injury, impact minimization, and nursery).

Table 54: LSMeans differences Tukey HSD analysis to determine significant differences between injury events, impact minimization events, and nursery events. The asterisk denotes significant differences in the p-values.

Level 1	Level 2	Percent Diff.	Lower 95% CI	Upper 95% CI	p-Value
Nursery	Impact Minimization	37.79	29.08	46.50	<.0001*
Injury Event	Impact Minimization	29.62	21.54	37.70	<.0001*
Nursery	Injury Event	8.17	1.82	14.52	0.0073*

5.0 Discussion

5.1 Hypothesis 1

Ho: There is no significant difference in partial colony mortality between transplanted and control stony coral colonies (all site and species pooled) or within species between transplanted and control coral colonies (species within each treatment pooled).

No significant differences in percent mortality were found between the control and experimental colonies throughout this experiment. The pooled, 2012 data collected found that only 19% of variability was due to mortality showing that the majority of the colonies had relatively similar percent mortality. The pooled, 2012 data collected also found that 81% of the variability was due to the fixed effects. The fixed effects were treatment (control or experimental) and coral species. This is expected since all coral species have different growth rates and ability to withstand altering environmental conditions. Overall, this experiment showed that once injured colonies were reattached to the substrate and given time to recover, they tend grow and act like natural colonies.

When the 2012, pooled data was analyzed for average percent mortality for each coral species. The most mortality in the control corals was found in *P. astreoides*, *S. siderea*, *Montastraea annularis* complex, and Other species. Of the experimental colonies, Other species, *S. siderea*, and *P. astreoides* had the most mortality. The least mortality of the control corals were found in *M. cavernosa*, *S. bournoni*, and *M. meandrites*. Of the experimental colonies, *S. bournoni*, *M. meandrites*, and *Montastraea annularis* complex had the least mortality. These species comparisons further show the similarities in mortality between the experimental and control colonies.

Even though there were no significant differences in mortality found between control and experimental coral colonies, significant differences in mortality were found between experimental coral species once reattached. These differences were mostly likely due to individual species characteristics, such as growth rates and/or adaption to changing water conditions. In an experiment done by Torres and Morelock (2002), *M. cavernosa* was found limited in areas of high sediment influx. Sedimentation via storms and hurricanes have occurred during the 6-17 years that has passed since the initial coral injury took place. Additionally, an experiment has shown that *S. bournoni* colonies are not greatly affected by altering environmental conditions (Hudson *et al*., 1989). These may have been factors that contributed to the significant differences in mortality found between *S. siderea* and *S. bournoni*, *M. meandrites*, *Montastraea annularis* complex, and *M. cavernosa* all of which are common southeast Florida corals.

The two coral species with the best overall survival for both control and experimental colonies were *M. cavernosa* and *S. bournoni.* As mentioned earlier, in a study done by Torres and Morelock (2002), *M. cavernosa* was found in lower abundance in areas with high sedimentation. This factor can be related since most areas visited during this study were of hardbottom substrate therefore the factor of sedimentation would not play a major role. As for the *S. bournoni* colonies, a study completed in 1989 by Hudson *et al*., found that storms, changes in water temperature, hurricanes, construction, and dredging did not affect the growth rate of *S. bournoni*. All of the aforementioned factors have occurred in southeast Florida during the 6-17 year time period that has elapsed for this project and may have had a greater impact of other species in this study.

The control coral species with the worst overall survival were Other species and *Diploria* species. The experimental coral species with the worst overall survival were Other species, *P. astreoides*, and *S. siderea*. The Other species category consisted of *C. natans* (14), *A. agaricites* (6), *Agaricia* species (1), *E. fastigiata* (3), *M. angulosa* (1), *M. decactis* (9), *O. diffusa* (5), *M. aliciae* (3) and unidentified species (2) all of which are rare off the southeast coast of Florida. Due to their rarity, their predicted percent survival would be small. This can be predicted because in order for them to survive they need relativity specific water conditions just like any other coral species. If Other species are not found in abundance, this could hint that ideal water conditions for these corals are not found often in south Florida waters. As for the *Diploria* species, a study completed on *D. labyrinthiformis* in 2004, showed the coral skeletal density was temperature sensitive and declined rapidly with decreased water temperatures (Cohen *et al*., 2004). Since most sites were shallow, water temperatures may have altered during hurricanes and/or colder than average winters; however, this is just a speculation. Another study completed by Smith (1992), found that *Diploria* species struggled with recruitment survival on a damaged reef in Bermuda. Perhaps *Diploria* species may not survive well in injury locations. In regards to the experimental *P. astreoides* colonies, an experiment completed in 1980 by

Bak and Steward-Van Es showed that when *P. astreoides* is damaged due to an artificial injury that is bigger than 5 cm^2 the colonies were unable to recover; injury, besides dislodgement, to the experimental corals is highly likely due to the events that were studied for this project. Since the corals in this project were small (average height: 14.45 cm, average width: 8.12 cm, and average length: 16.93 cm) a 5 cm^2 injury could possibly kill that colony. Decreased survival of *S. siderea* may have been due, in the past, to the fact that these sites were damaged and greatly impacted by humans. When a ship grounds, sedimentation may increase initially, diesel fuel and other fluids may leak, and/or other pollution may enter the water causing the reef to become 'unhealthy.' Unhealthy reefs have been shown to be home to *S. siderea* with increased partial mortality as colony size increases (Lewis, 1997). Also, *S. siderea* has been found in areas with high sediment influx. This seems unusual for a coral however, *S. siderea* may rely on that sediment for nutrition via food particles in the sand. Since these injury events mostly occurred on hard substrate, sedimentation would be limited therefore, *S. siderea* colonies would find it difficult to obtain food and survive (Foster, 1980).

5.2 Hypothesis 2

Ho: There is no significant difference in the presence of boring sponge, Cliona delitrix, bleaching, and disease, between transplanted and control coral species (all sites pooled).

A limited number of coral colonies with sublethal effects required a qualitative count of the control and experimental coral species with sublethal effects. The sublethal effects included the presence and/or absence of bleaching, disease, and infestation of the boring sponge, *Cliona delitrix.* The control species with the highest number of bleached colonies was *S. bournoni* and no control colonies had disease. The control species with the highest number of *C. delitrix* was *Diploria* species. Of the experimental colonies, the species with the highest number of bleached colonies was *S. siderea* and *S. bournoni*. The species with the highest number of diseased colonies was *S. siderea* and the species with the highest number of *C. delitrix* colonies was *M. cavernosa*, *Diploria* species, and *S. bournoni*. Overall, 8% of the experimental colonies had sublethal effects and 3% of the control colonies had sublethal effects.

Even with sublethal effects, the experimental colonies showed repair and growth similar to the control colonies. As discussed in Sabater and Yap (2002), once an injured coral colony is reattached to the substrate, it can repair itself and continue growing due to limited energy spent on reattaching itself to the ocean floor. Also, growth rates would have had time to recover due to the number of years that have passed since the initial injury took place. By 2012, the corals had already acclimated to their environment subsequent to their reattachment and in turn their growth rates presumably would have recovered (Sabater and Yap, 2002). The results of my study and Sabater and Yap (2002) further show that once injured corals are transplanted, they exhibit similar growth and survival to natural coral colonies in southeast Florida, USA.

5.3 Hypothesis 3

Ho: There is no significant difference in partial colony mortality between transplanted and control stony coral species between study sites.

Once again, no significant differences were found in percent morality between the control and experimental corals. However, significant differences in percent mortality were found between study sites and coral species. The data set included: percent mortality, site, and coral species. The random effect was site and treatment (control or experimental); this accounted for 14% variability in mortality in the pooled, 2012 data set. This shows that majority of the colonies at each site had relatively similar percent mortality. The fixed effects were treatment (control or experimental), coral species, and event; this accounted for 86% variability in mortality in the pooled, 2012 data set. This is an expected result since each environment in which each event took place was different. All the locations had varying depths, bottom substrate (hard bottom and/or rubble etc.), temperature, wave action, storms that passed through, and/or varying amount of damage to each coral colony. All of these factors influence the percent mortality for each coral colony at each site. Also, all of these events occurred on different years, days, and times which may affect coral recovery due to altering environmental conditions over the years, such as storms, hurricanes, and/or sediment influx due to coastal erosion. Furthermore, varying coastal construction and/or beach renourishment activities near the site may have impacted certain marine areas more than other marine locations which could have impacted coral recovery.

At the site of the *C/V Hind*, the control coral species with the highest average percent mortality was *Diploria* species and *D. stokesii* and the experimental coral species with the highest average percent mortality was Other species (only one colony was analyzed), *P. astreoides* and *S. siderea*. At the site of the *M/V Firat*, the control coral species with the highest average percent mortality was *P. astreoides* and *Diploria* species and the experimental coral species with the highest average percent mortality was Other species (only one colony was analyzed) and *P. astreoides*. At the site of the Broward County Yearly Monitoring, the control coral species with the highest average percent mortality was *D. stokesii* (only one colony was analyzed), *P. astreoides* and *S. siderea*. At the site of the *Clipper Lasco*, the experimental coral species with the highest average percent mortality was *Montastrea annularis* complex and Other species. At the site of the DERM Modules, the experimental coral species with the highest percent mortality was *S. bournoni* and *D. stokesii.* At the site of the Hillsboro Cable Drag, the experimental coral species with the highest average percent morality was Other species and *P. astreoides*. At the site of the *M/V Spar Orion*, the experimental coral species with the highest average percent mortality was Other species and *S. siderea.* At the site of the Mitigation Boulders, the experimental coral species with the highest average percent mortality was Other species and *P. astreoides* At the site of the Warren Modules, the experimental coral species with the highest average percent mortality was *Montastrea annularis* complex (only one colony was analyzed), Other species, and *D. stokesii*.

Of the coral species studied during this analysis, *P. astreoides* was one of the coral species with highest mortality at most of the study locations/events. A study completed in 2002 by Torres and Morelock on *P. astreoides* show that these species can withstand short increments of sediment influx, however these studies were completed on massive coral colonies and not small coral colonies as studied in this experiment. On the other hand, another experiment completed in 1980 by Bak and Steward-Van Es showed that when *P. astreoides* is damaged due to a lesion that is bigger than 5 cm^2 most colonies were unable to recover. Since the corals in this thesis were fairly small (average height:

14.45 cm, average width: 8.12 cm, and average length: 16.93 cm) a 5 cm^2 injury could possibly increase the chances that the coral colony will not survive.

The second coral species with the greatest percent mortality was Other species. Due to the limited number of specific coral colonies off the coast of southeast Florida, coral species that were deemed as "Other species" I will discuss further as analysis of them was hard to determine via JMP 10. The corals in the category includes: *C. natans*, *A. agaricites*, *Agaricia* species, *E. fastigiata*, *M. angulosa*, *M. decactis*, *O. diffusa*, *M. aliciae* and unidentified species. Fourteen colonies of *C. natans* were located and of these colonies the two controls were living while of the 12 experimental colonies, five were attached (alive) and seven were dead. This species is most likely worth reattaching if found due to having a 71% percent survival. The same is true for *M. decactis* which had an 80% percent survival. No control colonies were found of *A. agaricite*s, however, dependent upon the goal of transplantation, the 0% percent survival in the six experiential colonies, this species does not seem to be worth the reattachment efforts. The same is true for *Agaricia* species, *E. fastigiata, M. angulosa* and *M. aliciae* colonies. Finally, *O. diffusa* had one attached experimental colony located and four dead colonies. This gives *O. diffusa* a 20% chance at survival and therefore is most likely not worth the effort to reattach it. Overall, all of these species are not common on the coast of southeastern Florida, USA and therefore the environmental conditions located here may not be optimal for these species in general.

When analyzing the coral species at each site, the biggest influences to the differences in mortality may have been due to the depth at which each event took place and the type of substrate structure located at the injury event site. With increased depth, limited light is available, temperature decreases and more sedimentation may take place (Fricke and Meischner, 1985). These factors can contribute to the species distribution and the health condition of the coral colony. Specifically, of the sites in the injury event of the *M/V Firat*, one site was unusable. This was due to the site being of a rubble substrate. Once divers descended on the site, no site marker was located and no coral colonies with tags were located. According to my study, corals at this particular site were deemed missing and therefore dead.

Additionally, most significant differences between events were found with the Broward County Mitigation Boulders. This is possibly due to the depth, temperature and bottom substrate of the site. The Mitigation Boulder site was in a depth of 5 m of water which is shallow comparing to the other event sites. With these corals being in shallower water than the other experimental locations observed during this experiment, more light is available for photosynthesis and water temperature increases; two conditions good for coral growth and survival. Also, the boulders were relativity high off the sand substrate which made them further away from sand sedimentation that could have washed over them, in turn causing increased partial mortality. The Mitigation Boulders seem to be the best of all the sites for coral reattachment and recovery.

5.4 Hypothesis 4

Ho: There is no significant difference in partial colony mortality between whole and fragmented transplanted coral species (all sites pooled).

When analyzing the scleractinians based on whole colonies versus fragmented colonies, there was no significant differences found in the pooled, 2012 data set. However, differences were determined between coral species. The random effects were each site; this accounted for 23% variability in mortality. This result is expected since each site occurred in different locations, depth, and/or bottom substrates. The fixed effects were coral species and whole or fragmented coral colony data; this accounted for 77% variability in mortality. Once again, this result would be expected since each fragmented coral had varying degrees of fragmentation. If coral fragmentation was extreme, the coral colony would have a harder time repairing itself verses a coral with minor scratches and scrapes. As for differences in coral species partial mortality, *S. siderea* was deemed to have more partial mortality than *S. bournoni*, *Montastrea annularis* complex, *M. meandrites*, *M. cavernosa* and *Diploria* species, Other species had more partial mortality than *S. bournoni*, *Montastrea annularis* complex, *M. meandrites*, *M. cavernosa*, and *Diploria* species, *P. astreoides* had more partial mortality than *S. bournoni*, *M. meandrites*, and *M. cavernosa*, and *S. intersepta* had more partial mortality than *S. bournoni* and *M. meandrites*. These differences could be contributed to the aforementioned reasons dealing with reproduction mode, growth rates, and response to stress by each species.

5.5 Hypothesis 5

Ho: There is no significant association within species between partial colony mortality and size of transplanted and control corals (all sites pooled).

No correlation was found in the pooled, 2012 data in percent mortality when comparing size classes of transplanted and control coral species. The data set included: treatment (experimental or control), percent mortality, height, length, and width. This analysis suggests that size of the colony was not a factor when analyzing partial colony mortality. In other words, no matter size of the coral colony, mortality remained the same. If mortality was great enough, the colony would most likely die and if mortality was small enough, the colony would most likely survive unless impacted by sublethal effects; this remained true for the control and experimental coral species.

5.6 Hypothesis 6

Ho: There is no significant difference in transplanted coral percent colony mortality between injury event efforts, impact minimization efforts, and nursery efforts.

The pooled, 2012 experimental data found significant differences in percent mortality when analyzing injury events, impact minimization, and nursery events. The data set included: experimental colonies, percent mortality, and type of event (injury event, impact minimization, and nursery events). The injury events included: *M/V Firat*, *C/V Hind*, *M/V Spar Orion*, *Clipper Lasco*, and Hillsboro Cable Drag. The impact minimization event included the Broward County Mitigation Boulders only. The nursery events included both Warren and DERM Modules. Of all the types of events, the impact minimization event had the least partial mortality. This result is most likely due to the fact that these corals experienced the least amount of stress during transplantation. The impact minimization corals were hand selected and carefully removed from the substrate to be reattached onto the boulders. Minimal stress was put on these corals during removal in hopes that they would attach successfully. The impact minimization event is unlike the nursery and injury transplanted corals. The nursery corals were chosen based on the colonies already being unattached from the substrate. With the corals already unattached, it is hard to determine how long the corals were rolling along the bottom of the sea floor; this type of injury is termed chronic injury. Every time a coral moves along the substrate it is repeatedly being injured increasing the corals stress level. As for the injury event corals, these colonies received an intense level of stress from being scraped, scared, and/or fractured due to being hit, this type of injury is termed acute injury. The immediate damage the colonies faced may have been detrimental, however, transplantation was still completed on the coral colonies.

The discussion of hypothesis 3 analyzes additional reasons the impact minimization event was the best of all circumstances for reattachment and recovery. One main difference between the nursery events and the impact minimization event was the height at which the structures were from the sandy bottom substrate. The donated modules (nursery) lay directly in the sand on a 0.5 m pedestal which makes these corals vulnerable to sediment influx from the sandy substrate. On the other hand, the Mitigation Boulders (impact minimization) were approximately 2 m in diameter and sat higher off the sand possibly decreasing the sediment influx from the substrate.

The injury events were found to have more partial morality than the impact minimization event. This could be due to the fact that these corals could have been significantly damaged when injured. They could have been scraped, scarred, and/or fractured whereas the impact minimization corals were living with 15 cm or greater of live tissue area; this amount of live tissue may not have been true for the injury coral colonies. Once again, the Mitigation Boulders (impact minimization) seem to be the best of all circumstances for coral reattachment and recovery.

6.0 Conclusion

After reviewing the data and analysis, some major points about coral transplantation and recovery offshore southeast Florida can be determined:

- Once corals are transplanted and reattached to the substrate, they behave and act like control corals.
- Within my study, size did not correlate with mortality.
- The greatest transplantation success occurs during impact minimization events when corals are carefully selected, removed, and transplanted.
- Large mound/boulder and brain corals, such as, *Montastrea cavernosa*, *Solenastrea bournoni*, *Meandrina meandrites*, and *Montastrea annularis* complex transplant and recover the best.
- Individual species characteristics can impact coral success.
- The worst common species to transplant in southeast Florida are colonies that grow low to the substrate and do not have a high profile, such as, *Siderastrea siderea* and *Porites astreoides*.
- Sublethal effects found in transplant and control colonies are relativity similar showing that transplantation may not play a role in a corals likelihood of obtaining a sublethal health effect.
- If coral fragmentation is extreme, the coral colony will have a harder time repairing itself verses a coral with minor scrapes and scratches.

In most real world situations, resource managers should consider the following when allocating transplantation efforts during injury events, impact minimization events, and/or nursery events:

- Focus on the most common naturally growing coral species at that particular events location for transplantation.
- Use minimal effort on species that do not have a good survival rate based on this study, such as *Porites astreoides*.
- Although this study did not examine sediment influx, an observation is to beware of transplanting corals in areas with high sediment influx.

- The type of material used for reattachment did not seem to make any difference on survival success.
- Focus transplantation efforts on areas with a solid hard substrate and limited substrate motion.
- Include accurately mapped and tagged control colonies for future analysis.
- When documenting transplantation efforts, be sure to:
  - Identify each colony to a species level for future analysis.
  - Obtain accurate GPS locations of the sites created within each event.
  - Accurately map each coral colony with tag number within each site of the event for future analysis.

7.0 Literature Cited

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