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Distribution, Growth, and Impact of the Coral-Excavating Sponge, Cliona delitrix, on the Stony Coral Communities Offshore Southeast Florida

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DISTRIBUTION, GROWTH, AND IMPACT OF THE CORAL-EXCAVATING SPONGE, *CLIONA DELITRIX*, ON THE STONY CORAL COMMUNITIES OFFSHORE SOUTHEAST FLORIDA

Master’s Thesis

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Submitted to the Faculty of Nova Southeastern University Oceanographic Center in partial fulfillment of the requirements for the degree of Master of Science with specialties in:

Marine Biology
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Marine Biology

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I. Abstract

Bioerosion is a major process that affects the carbonate balance on coral reefs, and excavating sponges from the genus *Cliona* are some of the most important bioeroders on Caribbean reefs. The orange boring sponge, *Cliona delitrix*, is an abundant excavating sponge offshore southeast Florida that frequently colonizes dead portions of live stony corals, killing live coral tissue as it grows. With the recent decline in coral cover attributed to combined environmental and anthropogenic stressors, the increasing abundance of excavating sponges poses yet another threat to the persistence of Caribbean coral reefs.

In the first part of this study, I explored distributional patterns of *C. delitrix* offshore southeast Florida and compared yearly sponge growth/corresponding coral tissue loss rates across habitats of different depths. *C. delitrix* densities and growth rates were significantly higher on the outer reef, where coral colonies also showed some of the fastest tissue retreat rates. More sponge individuals were found on sites with higher coral densities, likely resulting from the higher availability of preferred coral skeleton substrate. *C. delitrix* showed a clear preference for boulder stony coral species, which could alter the coral community composition in the future and allow an increase in branching and foliose species. The growth rates of *C. delitrix* offshore southeast Florida are slower compared to rates from other locations, likely a result of intense fouling of the coral-sponge interface by other spatial reef competitors. These results suggest that outer reef sites with high boulder coral density offshore southeast Florida are most vulnerable to *C. delitrix* colonization and may continue to suffer the greatest impacts of coral bioerosion.

Excavating sponges are also strong competitors for space on coral reefs; able to colonize, excavate, and kill entire live stony corals. Despite the known negative effects of excavating sponges on stony corals very few studies have experimentally tested the competitive nature of this interaction. In the second part of this study, I examined the effect of manual removal of the excavating sponge, *Cliona delitrix* (Pang 1973), on tissue loss of the stony coral *Montastrea cavernosa* (Linnaeus 1767), and its possibility as a
A total of 33 *M. cavernosa* colonies colonized by small *C. delitrix* sponges (up to 10 cm in diameter) were examined. Sponges were removed using a hammer and chisel from 22 of the affected colonies, and 11 colonies were left alone as controls. After sponge removal, the resultant cavities in the coral skeletons were filled to minimize future colonization by other bioeroders and promote coral tissue growth over the excavation. Cement was used as fill material on 11 of the colonies, and the remaining 11 cavities were filled with epoxy. Standardized photos of each colony were taken immediately, at 6 months and 12 months after sponge removal. Results show a significant reduction in coral tissue loss in colonies where sponge was removed, and both fill materials performed similarly reducing coral tissue loss. I also found that a majority of experimental corals showed no return of *C. delitrix* to the colony surface a year after removal. This study demonstrates that eliminating the bioeroding sponge competitor may promote recovery of the affected stony coral. Additionally, the sponge removal technique can be applied to any stony coral colonized by *C. delitrix* to preserve, or at least slow the loss of, remaining live tissue.

**Keywords:** *Cliona delitrix, excavating sponges, bioerosion, sponge growth, sponge distribution, coral tissue loss, sponge-coral competition*
II. Dedication and Acknowledgements

Thank you to my advisor, boss, and friend, Dr. David S. Gilliam, for being the best mentor I could ask for and for taking me under your wing four years ago when you accepted me into your lab. I am grateful for the experiences I have had while working in your lab as they have helped prepare me for a career in the field and provided countless memories that will always make me smile. Thank you to my dear friend and sponge master herself, Dr. Andia Chaves-Fonnegra, for your irreplaceable advice, guidance, and support throughout the development, writing, and presentation of this master’s thesis research. To my committee members, Dr. Bernhard Riegl and Dr. Jose Lopez, thank you for stimulating a sense of curiosity and excitement about coral reefs and marine sponges in the classes you taught and the conversations we shared. Thank you to my parents and my Sabba Sam who provided endless love, support, and encouragement to allow me to pursue my dreams to become a marine biologist. Thank you to the various members of the CRRAM lab who helped with fieldwork for this project including C. Walton, M. Lopez-Padierna, L. Larson, C. Bliss, J. Mellein, S. Bush, Z. Ostroff, P. Espitia, N. D’Antonio, L. Kabay, K. Correia, and K. Cucinotta. A special thanks to Daniel Fahy for assistance in the field and helping to devise this research idea, and the same for Dr. Brian Walker who assisted in the image standardization technique. Finally, a HUGE thank you to all of my friends, the faculty, and the staff at the Oceanographic Center who helped make graduate school such a memorable and wonderful experience, and some of the best years of my life.

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III. Preface

This thesis consists of four chapters. Chapter 1 is an overall introduction to the topics discussed in Chapters 2 and 3. Chapter 2 examines the distribution and growth of the excavating sponge *Cliona delitrix* across the coral reef communities offshore southeast Florida. This information is useful in creating baseline measurements of the local abundance of this sponge and will help to focus management efforts on specific reef habitats or coral species that are suffering the greatest impacts from *C. delitrix*. This study also determines the growth rate of *C. delitrix* on different reef habitats at different depths, along with the associated coral tissue loss rates. Chapter 3 details a study in which small *C. delitrix* sponges were removed from affected *Montastraea cavernosa* colonies to explore the competitive interaction between these two organisms and to evaluate the viability of manually removing small sponge individuals as a mechanism to preserve live stony coral tissue in colonies currently colonized by this sponge. Chapter 4 presents the overall summary and conclusions of the research contained in Chapters 2 and 3.
IV. Table of Contents

I. Abstract .......................................................................................................................... I
II. Dedication and Acknowledgements ...........................................................................III
III. Preface ........................................................................................................................ IV
IV. Table of Contents ......................................................................................................... V
V. List of Figures ................................................................................................................ VII
VI. List of Tables ................................................................................................................ VIII

CHAPTER 1: Introduction ...............................................................................................1

1.1 Sponges as Major Reef Components ........................................................................2
1.2 Sponge Bioerosion .....................................................................................................2
1.3 Competitive Interactions Between Sponges and Stony Corals ...............................3
1.4 Species Profile: *Cliona delitrix* ...............................................................................3
1.5 Characterization of South Florida Reefs ...............................................................5
1.6 Excavating Sponges as a Concern for Modern Coral Reefs ....................................5
1.7 Literature Cited .........................................................................................................7

CHAPTER 2: Distribution and growth of the coral-excavating sponge, *Cliona delitrix*, on the coral reef communities offshore Broward County, southeast Florida ..........................................................12

2.1 Abstract ....................................................................................................................13
2.2 Introduction ...............................................................................................................14
2.3 Study Area ................................................................................................................16
2.4 Methods ....................................................................................................................17
   2.4.1 Habitat Preferences of *C. delitrix* .................................................................17
   2.4.2 Lateral Growth of *C. delitrix* across Three Reef Habitats ..........................20
   2.4.3 Coral Tissue Loss in Relation to Dead Zone Width ......................................22
2.5 Results ......................................................................................................................22
   2.5.1 Habitat Preferences .....................................................................................22
   2.5.2 Lateral Growth Between Habitats .................................................................27
   2.5.3 Coral Tissue Loss Between Habitats .........................................................27
   2.5.4 Coral Tissue Loss in Relation to Dead Zone Width ....................................28
2.6 Discussion ................................................................................................................30
2.7 Conclusions .............................................................................................................34
2.8 Literature Cited .......................................................................................................35

CHAPTER 3: Determining the effect of excavating sponge, *Cliona delitrix*, removal on stony coral tissue loss offshore southeast Florida .........................................................41

3.1 Abstract ....................................................................................................................42
3.2 Introduction ..............................................................................................................43
3.3 Methods ....................................................................................................................44
3.3.1 Sponge Removal and Cavity Filling .............................................................44
3.3.2 Coral Tissue Loss Monitoring and Analysis .................................................45
3.4 Results .............................................................................................................46
  3.4.1 Percent Change in Dead Area between Treatments .....................................46
  3.4.2 Percent Change in Dead Area between Fill Materials .............................47
  3.4.3 Presence of *C. delitrix* after Removal ......................................................48
3.5 Discussion ....................................................................................................49
  3.5.1 Management Considerations .................................................................51
  3.5.2 Conclusions .............................................................................................52
3.6 Literature Cited ..........................................................................................53

CHAPTER 4: Summary and Conclusions ..............................................................57

4.1 Summary ......................................................................................................58
4.2 Conclusion ..................................................................................................59

APPENDIX ..........................................................................................................60

Appendix 1. Dead area measurements and percent change in dead area values for
  individual colonies by treatment group (6 months) ............................................61
Appendix 2. Dead area measurements and percent change in dead area values for
  individual colonies by treatment group (12 months) .........................................62
Appendix 3. Frequency of coral colonies in each treatment group showing the presence of
  *C. delitrix* at each monitoring period. Initial sponge size is also indicated ......63
V. List of Figures

Figure 2.1. Habitat preference study area offshore southeast Florida ..........................19
Figure 2.2. Sponge growth study area offshore southeast Florida..............................20
Figure 2.3. Schematic drawing of initial setup for sponge growth and coral tissue loss measurements........................................................................................................21
Figure 2.4. Cliona delitrix density by site coral density..............................................23
Figure 2.5. Cliona delitrix density by site depth.........................................................23
Figure 2.6. Cliona delitrix density by distance to nearest inlet .................................24
Figure 2.7. Cliona delitrix density by distance to nearest outfall ..............................24
Figure 2.8. Yearly average C. delitrix growth rates between sites ............................27
Figure 2.9. Yearly average coral tissue loss rates by reef habitat ..............................28
Figure 2.10. Linear regression of coral tissue loss rates by C. delitrix growth rates for dead zone widths < 0.5 cm.................................................................29
Figure 2.11. Linear regression of coral tissue loss rates by C. delitrix growth rates for dead zone widths < 1.00 cm.................................................................29
Figure 3.1. Mean percent change in dead area by treatment group .........................47
Figure 3.2. Mean percent change in dead area by fill material .................................48
VI. List of Tables

Table 2.1. Frequency of stony coral colonization by *C. delitrix* in relation to availability of individual species .................................................................25

Table 2.2. *Cliona delitrix* colonization frequency and density by habitat .................26

Table 2.3. *Cliona delitrix* densities measured across the tropical W. Atlantic ..........30

Table 2.4. Growth rates of various *Cliona* spp. of the Caribbean ..........................32

Table 2.5. Known *Cliona delitrix* growth rates from the tropical W. Atlantic ..........33

Table 3.1. Percentage of *M. cavernosa* colonies showing visual presence of *C. delitrix* after removal ..................................................................................................................49
CHAPTER 1

INTRODUCTION
1.1 Sponges as Major Reef Components

Second only to stony corals, sponges are among the most common benthic organisms in coral reef communities (Wulff, 2006). On Caribbean coral reefs, sponges compose the highest portion of reef biomass, and they can exceed stony corals in both bottom cover and density values (Zea, 1993; Diaz & Rützler, 2001). Schmahl (1991) recorded 84 sponge species on four Southeast Florida reefs compared to only 36 species of coral. Marine sponges are an important link between the benthic community and overlying ocean waters as they harvest nutrients from the water column through filter feeding and incorporate them into the benthos (Van Soest et al., 2012). Other functional roles of sponges on coral reefs include water filtration that removes excess nutrients, plankton, and bacteria (Wilkinson, 1983; Van Soest et al., 2012), consolidation of reef framework by binding coral rubble to the substrate (Diaz & Rützler, 2001), and providing habitat and food for a variety of reef dwellers (Wulff, 2001). Although not fundamental reef builders, some recent groups of sponges are capable of constructing large reef formations that add relief to the seafloor (Van Soest et al., 2012). It is evident that sponges play many roles in coral reef dynamics and energetics (De Goeji et al., 2013); however some of the largest contributions are through the bioerosion of the reef framework and competition with corals for space (Rützler, 1975; Lopez-Victoria et al., 2006; Bell, 2008).

1.2 Sponge Bioerosion

Bioerosion is a major biological process that erodes reef substrate and produces fine grained carbonate silts and contributes to coral reef structure (Risk et al., 1995). Numerous vertebrate and invertebrate groups play a role in eroding the reef substratum including bivalves, sea urchins, parrotfishes, and sponges, but bioerosion by excavating sponges is the most abundant (Scoffin et al., 1980; Tribollet & Golubic, 2005). Of the 9,000 different Caribbean reef sponges, at least 36 species are known bioeroders; 20 from the genus *Cliona* (Diaz & Rutzler, 2001; Zea & Weil, 2003). Excavating sponges erode and then inhabit a wide variety of carbonate reef structures such as coral skeletons, mollusk shells, and polychaete tubes (MacGeachy & Stearn, 1976; Stearn & Scoffin, 1977; Callahan et al., 2007). In a process known as cellular etching, these sponges send
out excavating tissue filaments that remove silt-sized carbonate particles that are expelled into the surrounding water column through the oscula (Rützler & Rieger, 1973; Pomponi, 1979; Sammarco & Risk, 1990). Sponge bioerosion rates fall within the range of typical coral reef calcification rates (Andersson & Gledhill, 2013), thus sponge bioerosion is capable of negating current levels of stony coral growth or reef accretion on the larger-scale. Bioerosion by excavating sponges is responsible for up to 90% of the total carbonate removal on coral reefs (Scoffin et al., 1980; Risk et al., 1995), up to 30 kg of CaCO$_3$/m$^2$ yr$^{-1}$ (Calcinai et al., 2007). Consequently, sponge bioerosion weakens the reef structure and framework, primarily in the form of individual coral skeletons, making them more susceptible to storm damage and eventual collapse (Bromley, 1978; Macdonald & Perry, 2003).

1.3 Competitive Interactions Between Sponges and Stony Corals

Because sponge biomass, abundance, and diversity can match or even exceed that of stony corals on many reefs, competitive interactions between these two groups is common (Rützler, 1978). Up to 12 coral-sponge interactions have been noted in just one square meter of reef, and in 80% of these instances, the sponges have been found to eventually overgrow the coral colony (Suchanek et al., 1983; Vicente, 1990). In another study (Aerts, 1998), 128 sponge species were witnessed interacting with corals, and 30 of these species were involved in coral overgrowth. Boring sponges that simultaneously encrust and excavate carbonate substratum are also strong competitors for space (Rützler, 1975; Vicente, 1978; Chaves-Fonnegra & Zea, 2007). These types of sponges are extremely successful competitors due to their mechanical and chemical etching capabilities that directly excavate nearby organisms, and in some cases, the allelopathic chemicals contained in their mucus (Sullivan et al. 1983, Sullivan et al., 1986). Various boring sponges from the genus *Aka* have been documented effectively killing live tissue of neighboring stony corals (Sullivan et al. 1983, Sullivan et al., 1986).

1.4 Species Profile: Cliona delitrix

The orange boring sponge, *Cliona delitrix* (Pang 1973), is one excavating species that is abundant within the coral reef communities offshore southeast Florida. *Cliona*
*Cliona delitrix* has very bright orange tissue whose surface is tightly packed with inhalant ostial papillae and scattered large oscules that aid in pumping and waste removal. The sponge grows by first colonizing and encrusting a carbonate structure (frequently coral skeletons or reef framework), then boring into the substratum where it infills eroded spaces with tissue, penetrating depths of 12 cm or more (Chaves-Fonnegra & Zea, 2007). Most of the tissue in *C. delitrix* lies below the substratum surface with only the papillae and oscula directly exposed to seawater, making it difficult to determine the exact extent of bioerosion within a substrate (Chaves-Fonnegra & Zea, 2007). Bioerosion in this species is both a chemical and physical process using acidic dissolution of the substrate and mechanical etching of carbonate chips through excavating tissue filaments (Pomponi, 1977).

A recent study by Chaves-Fonnegra (2014) found that *C. delitrix* preferentially settles on recently dead coral skeletons when compared to old dead coral or reef substrate, frequently inhabiting dead portions of live stony corals. After colonizing live stony corals, *C. delitrix* regularly produces a bright white ‘dead zone’ of bare coral skeleton surrounding the sponge, resulting from recently killed coral tissue due to excavating and allelopathic activities (Rose & Risk, 1985; Chaves-Fonnegra *et al.*, 2008). Capable of growing both across the surface and into the skeleton of a coral, *C. delitrix* commonly overgrows entire colonies up to 1 meter in diameter (Rose & Risk, 1985; Ward-Paige *et al.*, 2005).

This species is a gonochoric broadcast spawner with a sex ratio of 1:1 that has the potential for long distance dispersal at distances up to 700 km (Chaves-Fonnegra, 2014). *Cliona delitrix* has multiple reproductive events during the warm summer months offshore southeast Florida (Chaves-Fonnegra, 2014). The timing of spawning in *C. delitrix* enhances its’ ability to colonize stony corals as the warmer months are also when bleaching mortality in corals is most likely, providing recently dead coral skeleton for the newly released larvae to settle on (Chaves-Fonnegra, 2014). Recruitment of this species has increased on Colombian coral reefs as a result of extensive coral mortality, and on southeast Florida reefs from 2003-2007, cover of this sponge has increased at rates of (8 cm²/m²) yr⁻¹ (Chaves-Fonnegra, 2014). Because of the recent increases and aggressive
excavating nature of *C. delitrix*, this species along with other bioeroding sponges have been classified as modern threats to coral reefs that need to be understood further (Williams *et al.*, 1999).

### 1.5 Characterization of Southeast Florida Reefs

Located at the northern latitudinal limit of coral growth on the Florida Reef Tract and within 3 km of the Florida mainland, the coral reef communities offshore southeast Florida are heavily impacted by both natural and anthropogenic stressors. Major storms and hurricanes frequent the area dislodging benthic organisms and impacting the reef framework (Jaap, 2000; Wulff, 2006; Collier *et al.*, 2008), while coral diseases have also played a role in coral decline over the last three decades (Richardson *et al.*, 1998). Temperature anomalies also occur locally causing large-scale bleaching events (similar to that of early 2010) that result in large amounts of coral mortality along the Florida Reef Tract (Lirman *et al.*, 2011). In addition to natural threats, a number of anthropogenic stressors are also present on southeast Florida coral reefs. Careless boat anchoring, physical contact from snorkelers/divers, and ‘ghost’ fishing gear causes great amounts of physical damage to the ecosystem (Chiappone *et al.*, 2005). Commercial activities such as shipping and the cruise industry can also result in extensive reef damage due to the close proximity of anchorage zones to local reefs and occasional groundings of these huge ships (Rubin *et al.*, 2008; Walker *et al.*, 2012). The booming south Florida tourism industry and increasing population also leads to large amounts of coastal development, beach renourishment activities, and marine construction operations that increase sedimentation and cause physical reef damage from dredging (Marszalek, 1981). Finally, various sources of land based pollution flow over these reefs every day in the form of nutrient runoff, canal discharges, and sewage outfalls that further stress the marine environment.

### 1.6 Excavating Sponges as a Concern for Modern Coral Reefs

Recent studies have noted major increases in the abundance of excavating sponges on coral reefs across the Caribbean and tropical Western Atlantic (Cortes & Risk, 1985; Rose & Risk, 1985; Holmes, 2000; Rützler, 2002; Ward-Paige *et al.*, 2005).
The rise in density and cover of these sponges is a result of the sponges’ superior competitiveness for space, further stimulated by environmental stressors that are damaging to stony corals yet beneficial for sponge growth, such as rises in temperature and nutrient levels (Schönberg, 2006; Schönberg & Ortiz, 2009). With the recent sharp decline in coral cover attributed to combined environmental and anthropogenic stressors, the increasing abundance of excavating sponges poses yet another threat to the persistence of Caribbean reefs (Glynn, 1997; Williams et al., 1999; Rützler, 2002). With these processes and stressors to stony corals likely to continue, coral reefs will become more susceptible to boring sponge colonization and the impact of excavating sponges will be exacerbated; raising the need to understand *Cliona delitrix* and this group of organisms further.

In Chapter 2 of this thesis, I examine the distribution and growth of the excavating sponge *Cliona delitrix* across the coral reef communities offshore southeast Florida. I also determine the growth rate of *C. delitrix* on three different local reef habitats at different depths, along with the associated coral tissue loss rates in these habitats. Together, this information is useful in creating baseline measurements of the local abundance of this sponge and will help to focus management efforts on specific reef habitats or coral species that are suffering the greatest impacts from *C. delitrix*. Chapter 3 details a study in which small *C. delitrix* sponges were removed from affected *Montastraea cavernosa* colonies to explore the competitive interaction between these two organisms and to evaluate the viability of manually removing small sponge individuals as a mechanism to preserve live stony coral tissue in colonies currently colonized by this sponge. Chapter 4 presents the overall summary and conclusions of the research contained in Chapters 2 and 3.
1.7 Literature Cited


CHAPTER 2

DISTRIBUTION AND GROWTH OF THE CORAL-EXCAVATING SPONGE, _CLIONA DELITRIX_, ON THE CORAL REEF COMMUNITIES OFFSHORE SOUTHEAST FLORIDA
2.1 Abstract

Bioerosion is a major process that affects the carbonate balance on coral reefs, and excavating sponges from the genus *Cliona* are some of the most important bioeroders on Caribbean reefs. The orange boring sponge, *Cliona delitrix*, is an abundant excavating sponge offshore southeast Florida that frequently colonizes dead portions of live stony corals, killing live coral tissue as it grows. With the recent decline in coral cover attributed to combined environmental and anthropogenic stressors, the increasing abundance of excavating sponges poses yet another threat to the health of Caribbean coral reefs. In this study, I explored distributional patterns of *C. delitrix* offshore southeast Florida and compared yearly sponge growth/corresponding coral tissue loss rates across habitats of different depths. *C. delitrix* densities and growth rates were significantly higher on the deepest habitat, the outer reef, where coral colonies affected by *C. delitrix* also showed some of the fastest tissue retreat rates. More sponge individuals were found on sites with higher coral densities, likely resulting from the higher availability of preferred coral skeleton substrate. *C. delitrix* showed a clear preference for boulder stony coral species over branching or foliose ones, which could alter the coral community composition in the future and allow for an increase in branching and foliose species. The growth rates of *C. delitrix* offshore southeast Florida are slower compared to rates from other locations, likely a result of intense fouling of the coral-sponge interface by other spatial reef competitors. On southeast Florida reefs the excavating tissue filaments of *C. delitrix* appear to be responsible for coral tissue loss at dead coral band distances up to 1 cm. These results suggest that outer reef sites (deepest) with high boulder coral density offshore southeast Florida are most vulnerable to *C. delitrix* colonization and may continue to suffer the greatest impacts of coral bioerosion.
2.2 Introduction

Sponges play many roles in coral reef dynamics; however some of their largest contributions are through bioerosion of the reef framework and competition with corals for space (Rützler, 1975; Lopez-Victoria et al. 2006; Bell, 2008; Gonzalez-Rivero, 2011). Of the 9,000 described Caribbean reef sponges, at least 36 species are known bioeroders (Hudson, 1977; Diaz & Rutzler, 2001; Zea & Weil, 2003), whose excavating activity may weaken the reef framework and can account for up to 90% of the total carbonate removal on coral reefs (Risk et al., 1995; Scoffin et al., 1980; Macdonald & Perry, 2003). With a CaCO₃ removal rate of up to 30 kg per m² yr⁻¹ (Calcinai et al., 2007), sponge bioerosion rates fall within the range of typical coral reef calcification rates (Andersson & Gledhill, 2013), and therefore, are capable of negating current levels of reef accretion. Considering stony corals are the primary builders of the reef framework, the impacts of bioeroding sponges on this group of organisms is important for both stony coral health and overall reef accretion. Excavating sponges from the genus *Cliona* are particularly aggressive bioeroders, capable of directly killing live coral tissue through both chemical and mechanical means (MacGeachy & Stearn, 1976; Pomponi, 1979; Highsmith et al. 1983; Zundelevich et al., 2007). *Cliona delitrix* (Pang 1973) is one species common offshore southeast Florida, frequently witnessed overgrowing entire coral colonies up to one meter in diameter (Rose & Risk, 1985; Ward-Paige et al., 2005).

Recent studies have noted increases in the abundance of excavating sponges on coral reefs throughout Florida (Ward-Paige et al., 2005; Gilliam, 2011) and the tropical western Atlantic (Cortes & Risk, 1985; Rose & Risk, 1985; Holmes, 2000; Rützler, 2002; Lopez-Victoria, 2003). An increase in density and benthic cover of these sponges is thought to be stimulated by environmental stressors facing reefs today such as increased nutrients and water temperatures (Schönberg, 2006; Schönberg & Ortiz, 2009). With the recent decline in coral cover attributed to combined environmental and anthropogenic stressors, the increasing abundance of excavating sponges poses yet another threat to the health of Florida’s coral reefs (Glynn, 1997; Williams et al., 1999; Rützler, 2002).

Numerous studies have explored possible factors controlling the distribution and abundance of excavating sponges including cross-shelf position (varying currents and
light levels) (Sammarco & Risk, 1990; Kiene & Hutchings, 1994; Tribollet & Golubic, 2005), nutrient levels (food accessibility) (Risk & MacGeachy, 1978; Hallock, 1988; Hallock et al., 1993; Holmes 1997; Lopez-Victoria & Zea, 2005; Ward-Paige et al., 2005) and the availability of suitable substrate (Alvarez et al., 1990). For coral-excavating sponges like *C. delitrix* that prefer to colonize recently dead areas on live stony corals, characteristics of the coral skeleton (density and growth morphology) along with factors that cause coral mortality (bleaching or disease) can also affect sponge distribution (Lopez-Victoria & Zea, 2005; Chaves-Fonnegra & Zea, 2007; Chiappone et al., 2007; Chaves-Fonnegra 2014). Two recent studies determined that food availability in the form of picoplankton was of utmost importance in shaping general Caribbean sponge communities (Lesser, 2006; Trussell et al., 2006), while others debate that predation on sponges plays a more important role (Pawlik et al., 2013); however physical and environmental variables guiding excavating sponge communities are largely unexplored.

Excavating sponge growth is a complex process that depends on sponge growth form and environmental parameters such as temperature and substrate (Hartman, 1958; Highsmith et al., 1983; Ward-Paige et al., 2005). Substrate characteristics such as coral skeletal density and structure are also important for bioeroding sponges that target stony corals (Ward-Paige et al., 2005). Some encrusting species, such as *C. tenuis*, erode a thin layer of tissue over the substrate and are able to grow quickly, while others, like *C. delitrix*, excavate deeper into the skeleton and grow slower (Chaves-Fonnegra et al., 2007). Other excavating sponges, such as *C. aprica*, contain photosynthetic symbionts that supplement the amount of energy available to the sponge for growth and allow for rapid growth rates (Hill, 1996, Zea & Weil, 2003).

While other studies have explored distributional patterns of coral-excavating sponges in the Florida Keys, no studies have examined their distribution, abundance, or growth rates in southeast Florida (Schmahl, 1991; Calahan, 2005; Ward-Paige et al., 2005; Chiappone et al., 2007). The first aim of this study was to characterize the distribution of *C. delitrix* across the coral reef communities offshore southeast Florida. The second aim was to compare the growth rates of *C. delitrix* and associated rates of
coral tissue loss across three reef habitats of different depths offshore southeast Florida. *Montastraea cavernosa* was selected as the stony coral subject because it is an important framework builder and abundant coral species within the study area. More specifically, the following objectives were addressed:

1) To determine if there is any correlation between *C. delitrix* density and site depth, coral density, distance to the nearest inlet, or distance to the nearest outfall.

2) To determine colonization preferences of *C. delitrix* in terms of coral species as substratum and reef habitat.

3) To compare the lateral growth rate of *C. delitrix* and related coral tissue loss in *M. cavernosa* across three reef habitats of different depths.

4) To determine the interaction distance between *C. delitrix* and *M. cavernosa* by examining coral tissue loss in relation to dead zone width.

Examining the general distribution and growth patterns of *C. delitrix* offshore southeast Florida will provide valuable information about the current impact of this sponge on local coral reefs, and if this impact is differential based on location, reef habitat or coral community species composition. This information can aid reef managers in developing future management plans to preserve local reef resources affected by this excavating sponge.

2.3 Study Area

This study was conducted offshore southeast Florida at the northern extent of the Florida Reef Tract (FRT). In much of this region, the FRT consists of three well-defined linear reefs that run parallel to the shoreline: a) the inner (3-7m depth), b) middle (6-8m depth), and c) outer (15-21m) reefs (Moyer et al., 2003; Banks et al., 2008; Walker et al., 2008). Colonized pavement habitats and nearshore hardbottom ridges are located inshore of the inner reef (Walker et al., 2008). Stony coral cover ranges from 1- 6 % across these habitats, with the highest coral cover found on the nearshore ridges (Gilliam et al., 2011).

Located within 3 km of the Florida mainland, these reef communities are impacted by various sources of land based pollution including nutrient runoff, treated
waste discharges and shipping port effluent. Two major inlets and two sewage outfall pipes are located in close proximity to southeast Florida reefs; the Hillsboro Inlet and Hillsboro outfall located towards the Northern end and Port Everglades along with the Hollywood outfall at the Southern end. The resultant eutrophication and pollution sources facing southeast Florida’s coastal waters every day may also negatively affect the coral reef environment and organisms living there.

2.4 Methods

2.4.1 Habitat Preferences of Cliona delitrix

To determine Cliona delitrix habitat preferences offshore southeast Florida, sampling was conducted at 21 reef monitoring sites used for the Broward County Yearly Biological Monitoring program (Gilliam et al., 2014) (Figure 2.1). At each of these 21 sites, three 20m x 1.5m belt transects were sampled as replicates to obtain quantitative data on stony coral and C. delitrix size and density. One of the three transects was a permanent transect used for the above mentioned monitoring project, while the other two were sampled at the site for this thesis project. Within each transect, all stony coral colonies (>4 cm) were identified to species, colony diameter and height were measured, and partial mortality was recorded. For each coral colony, the presence/absence of C. delitrix was noted. Because I was unable to determine if multiple sponge ramets on the colony surface were from only one or multiple sponge individuals, any visible C. delitrix tissue was assumed to stem from one sponge and considered to be one sponge individual.

Relationships between mean C. delitrix density (number of individuals/m²) per site and four environmental variables (site depth, stony coral density, distance to nearest inlet, and distance to nearest outfall) were explored independently using linear regression analyses. It was assumed that each site was most affected by both the closest inlet and closest outfall pipe. The measuring tool in ArcGIS 10.1© was used to determine the distance from each site to both inlets and both outfalls in kilometers, but only the smallest distance from each site to both inlets and outfalls was used for analysis.
Substratum preferences of *C. delitrix* were determined by using Ivlev’s Index of Electivity (Manly *et al.*, 1993). The index compares the actual pattern of stony coral colonization to the expected coral colonization pattern based on relative abundance of each coral species. Coral colony size was not considered in this analysis, and all coral colonies and sponge individuals were pooled across all 63 transects at 21 sites.

Ivlev’s index of electivity calculates an electivity value, \( e \), and states that:

\[
e = \frac{r_i - P_i}{r_i + P_i},
\]

where \( i \) represents the individual coral species, \( r_i \) is the proportion of that coral species colonized by *C. delitrix*, and \( P_i \) is the proportion of coral species \( i \) available. This index then ranks coral species from -1 to +1, where -1 indicates a rejection of the preferential *C. delitrix* colonization of the species, 0 indicates the species is colonized in proportion to its’ abundance, and +1 indicates a *C. delitrix* preference for that particular coral species.
Figure 2.1. Study area offshore southeast Florida where major city names on the mainland have been added for reference. The nearshore ridge is shown in maroon, and the inner, middle, and outer reefs are displayed in green, purple, and pink respectively. The green circles note the location of the 21 sites used to determine *C. delitrix* habitat preferences, the red circles mark the two outfall pipes, and the yellow triangles show the two inlets located within the county.
2.4.2 Lateral Growth of *Cliona delitrix* across Three Reef Habitats

To compare growth rates of *C. delitrix* and associated coral tissue loss across three reef habitats, a total of 41 *Montastraea cavernosa* coral-sponge pairs (colonies with visible *C. delitrix* individuals) were monitored at three sites of different depths. These sites were located on the nearshore ridge habitat (NR; N=11, 6.1 m), the middle reef (MR; N=15, 12.2 m), and the outer reef (OR; N=15, 18.3 m) (Figure 2.2).

![Figure 2.2](image_url)

Figure 2.2. Map showing the three reef sites of different depths used to measure *C. delitrix* growth rates and associated coral tissue loss offshore southeast Florida, (NR = Nearshore Ridge shown in red, MR = Middle Reef shown in blue, and OR = Outer Reef shown in pink).

Selected *M. cavernosa* colonies were under 1 meter in diameter, free of bleaching or disease, mostly alive (>50%), had one visible *C. delitrix* ramet on the colony surface, and a narrow dead zone interface indicative of a direct coral-sponge interaction (Chaves-
Fonnegra & Zea, 2011). Steel nails were driven into the coral skeleton along the dead zone between the sponge colony and surrounding live coral tissue and were used as reference points for growth measurements (minimum of 2 nails/coral, depending on the coral size) (Figure 2.3). Initial measurements from each nail to the nearest sponge tissue (SD), and from each nail to the nearest live coral tissue (CD) were taken for each coral-sponge pair using calipers (0.1 cm accuracy). These measurements were repeated twice, at 6 months and 12 months following the initial (t0) measurements.

Sponge growth and coral tissue loss rates were calculated at each nail:

\[
SD_{0 \text{ months}} - SD_{12 \text{ months}} = \text{Sponge growth (cm)/12 months}
\]

\[
CD_{12 \text{ months}} - CD_{0 \text{ months}} = \text{Coral tissue loss (cm)/12 months}
\]

Nails within the same coral colony served as replicates, and measurements were pooled to calculate mean sponge growth and coral tissue loss rates for each coral-sponge pair after both 6 and 12 months. This data was analyzed using a nested mixed-model
ANOVA where colony was nested within reef site and coral colony was treated as a random effect.

2.4.3 Coral Tissue Loss in Relation to Dead Zone Width

*Cliona delitrix* is known to directly kill live coral tissue at certain distances through the use of allelopathic chemicals and direct contact with excavating sponge filaments (Chaves-Fonnegra & Zea, 2007). Linear regression analysis was conducted between sponge growth and coral tissue loss rates at individual reference nails at various dead zone width intervals to determine the distance at which the sponge was able to directly cause coral mortality offshore southeast Florida. Using the measurement data collected in Section 2.4.2, I was able to calculate the dead zone width at individual reference nails by summing the SD and CD measurements. I assumed that if the sponge was directly causing coral mortality through contact, coral tissue loss rates would be correlated with sponge growth rates. Alternatively, if the dead zone width had exceeded the distance where excavating filaments could reach live coral tissue, this correlation would be absent. The dead zone width intervals examined include < 0.5 cm, < 1.0 cm, < 1.5 cm. The average dead zone width from all three monitoring periods was used in analysis. These methods were adapted from Chaves-Fonnegra and Zea (2011).

2.5 Results

2.5.1 Habitat Preferences

A comparison of habitat characteristics and *C. delitrix* densities using linear regression indicated that sponge density was most strongly correlated with stony coral density ($r^2 = 0.443, P = 0.001$) (Figure 2.4). Sponge density increased with coral density, and sponge densities also demonstrated an increase with site depth ($r^2 = 0.191, P = 0.048$) (Figure 2.5). However, mean *C. delitrix* densities were not significantly correlated with the distance from each site to either the nearest inlet ($r^2 = 0.001, P = 0.871$) (Figure 2.6) or nearest outfall ($r^2 = 0.017, P = 0.569$) (Figure 2.7). Autocorrelation was tested between site depth and coral density using linear regression, and no significant correlation was detected ($r^2 = 0.067, F = 1.358$, and $P = 0.25$).
Figure 2.4. *Cliona delitrix* density (individuals/m²) by site coral density.

![Graph showing Cliona delitrix density vs. coral density.]

\[ y = 0.1075x - 0.0671 \]
\[ R^2 = 0.44337 \]

Figure 2.5. *Cliona delitrix* density (individuals/m²) by site depth (m).

![Graph showing Cliona delitrix density vs. site depth.]

\[ y = 0.0097x - 0.0231 \]
\[ R^2 = 0.19099 \]
Figure 2.6. *Cliona delitrix* density (individuals/m²) by distance to nearest inlet (km).

![Graph showing *Cliona delitrix* density by distance to nearest inlet](image)

\[ y = 0.0013x + 0.0787 \]
\[ R^2 = 0.00143 \]

Figure 2.7. *Cliona delitrix* density (individuals/m²) by distance to nearest outfall (km).

![Graph showing *Cliona delitrix* density by distance to nearest outfall](image)

\[ y = 0.0037x + 0.0624 \]
\[ R^2 = 0.01744 \]
Cliona delitrix colonization patterns on individual stony coral species in relation to their proportional availability are summarized in Table 2.1. Of the 2,687 coral colonies of 24 species surveyed, 3.8 % (103 colonies) were currently colonized by visible C. delitrix individuals on the skeleton surface. The three most abundant and most frequently colonized coral species were Montastraea cavernosa, Porites astreoides, and Siderastrea siderea. No C. delitrix individuals were recorded on 13 of the 24 (54.2%) stony coral species encountered in this study and had electivity values of -1. Four additional species (Meandrina meandrites, Porites astreoides, Siderastrea siderea, and Stephanocoenia intersepta) also had negative electivity index values, showing a rejection of preferential colonization by C. delitrix, possibly due to their encrusting morphologies. Only one coral species (Madracis decactis) was found to have an electivity index value of 0, indicating that it was colonized in the exact proportion it was available. Finally, six coral species (Colpophyllia natans, Diploria clivosa, Diploria labyrinthiformis, Montastraea cavernosa, Montastraea faveolata, and Solenastrea bournoni) had positive electivity index values, suggesting that C. delitrix may have a colonization preference for these boulder species.

Table 2.1. Frequency (f) of stony coral colonization by C. delitrix in relation to the availability of individual species. f_a = frequency of availability, f_c = frequency of colonization, r_i = proportion of stony corals colonized by C. delitrix, P_i = proportion of stony corals available. The letters in parentheses next to the species name represents their most common growth morphologies; B = branching, E = encrusting, P = plating, and M = massive/boulder.

<table>
<thead>
<tr>
<th>Coral Species (Morphology)</th>
<th>f_a</th>
<th>P_i</th>
<th>f_c</th>
<th>r_i</th>
<th>( r_i - P_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acropora cervicornis (B)</td>
<td>121</td>
<td>0.0450</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td>Agaricia agaricites (E)</td>
<td>31</td>
<td>0.0115</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td>Agaricia fragilis (P)</td>
<td>3</td>
<td>0.0011</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td>Agaricia lamarcki (P)</td>
<td>4</td>
<td>0.0015</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td>Colpophyllia natans (M)</td>
<td>10</td>
<td>0.0037</td>
<td>1</td>
<td>0.0097</td>
<td>0.45</td>
</tr>
<tr>
<td>Dichocoenia stokesii (M)</td>
<td>76</td>
<td>0.0283</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td>Diploria clivosa (E/M)</td>
<td>14</td>
<td>0.0052</td>
<td>1</td>
<td>0.0097</td>
<td>0.30</td>
</tr>
<tr>
<td>Diploria labyrinthiformis (M)</td>
<td>5</td>
<td>0.0019</td>
<td>1</td>
<td>0.0097</td>
<td>0.68</td>
</tr>
<tr>
<td>Diploria spp. (E/M)</td>
<td>4</td>
<td>0.0015</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td>Diploria strigosa (M)</td>
<td>6</td>
<td>0.0022</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td>Eusmilia fastigiata (B)</td>
<td>5</td>
<td>0.0019</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
</tbody>
</table>
Table 2.1. Continued.

<table>
<thead>
<tr>
<th>Coral Species (Morphology)</th>
<th>( f_a )</th>
<th>( P_i )</th>
<th>( f_c )</th>
<th>( r_i )</th>
<th>( \frac{r_i - P_i}{r_i + P_i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Isophyllia sinuosa</em> (M)</td>
<td>1</td>
<td>0.0004</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td><em>Madracis decactis</em> (E)</td>
<td>104</td>
<td>0.0387</td>
<td>4</td>
<td>0.0388</td>
<td>0.00</td>
</tr>
<tr>
<td><em>Meandrina meandrites</em> (P/E)</td>
<td>93</td>
<td>0.0346</td>
<td>3</td>
<td>0.0291</td>
<td>-0.09</td>
</tr>
<tr>
<td><em>Montastraea cavernosa</em> (M)</td>
<td>516</td>
<td>0.1920</td>
<td>44</td>
<td>0.4272</td>
<td>0.38</td>
</tr>
<tr>
<td><em>Montastraea faveolata</em> (M)</td>
<td>52</td>
<td>0.0194</td>
<td>9</td>
<td>0.0874</td>
<td>0.64</td>
</tr>
<tr>
<td><em>Mycetophelia aliciae</em> (P)</td>
<td>3</td>
<td>0.0011</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td><em>Oculina diffusa</em> (B)</td>
<td>3</td>
<td>0.0011</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td><em>Porites astreoides</em> (E)</td>
<td>498</td>
<td>0.1853</td>
<td>11</td>
<td>0.1068</td>
<td>-0.27</td>
</tr>
<tr>
<td><em>Porites porites</em> (B)</td>
<td>70</td>
<td>0.0261</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td><em>Scolymia</em> spp. (P/E)</td>
<td>4</td>
<td>0.0015</td>
<td>0</td>
<td>0.0000</td>
<td>-1.00</td>
</tr>
<tr>
<td><em>Siderastrea siderea</em> (E/M)</td>
<td>604</td>
<td>0.2248</td>
<td>16</td>
<td>0.1553</td>
<td>-0.18</td>
</tr>
<tr>
<td><em>Solenastrea bournoni</em> (M)</td>
<td>61</td>
<td>0.0227</td>
<td>4</td>
<td>0.0388</td>
<td>0.26</td>
</tr>
<tr>
<td><em>Stephanocoenia intersepta</em> (E/M)</td>
<td>399</td>
<td>0.1485</td>
<td>9</td>
<td>0.0874</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Grand Total | 2687 | 1.0000 | 103 | 1.0000 |

The frequencies of colonization and mean densities of *C. delitrix* (number of sponges/m²) by reef habitat are summarized in Table 2.2. *C. delitrix* was found at all sites surveyed on the outer reef (OR) and while lower frequencies of the sponge were measured in the other two habitats, a majority of the sites showed a presence of the sponge. Using the Wilcoxon rank sum test, mean *C. delitrix* density was lowest on the nearshore ridge (NR) and similar to that of the middle reef (MR); however mean sponge density on the OR was significantly different from the other habitats and more than 3 times higher (DF = 2, \( q = 0.96, p < 0.01 \)). Sponges on the OR also accounted for 60.2% of the total individuals surveyed although OR sites only composed 28.6% of the total sites, further showing the concentration of *C. delitrix* on the OR.

Table 2.2. *Cliona delitrix* colonization frequency and density by habitat. The asterisk represents significantly higher sponge densities on the outer reef at \( p < 0.05 \).

<table>
<thead>
<tr>
<th>Habitat (# sites) (% of total effort)</th>
<th>Site Frequency (%)</th>
<th># of Individuals (% of total)</th>
<th><em>C. delitrix</em> Density (#/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR (9) (42.8%)</td>
<td>67%</td>
<td>23 (21.3%)</td>
<td>0.03 ± 0.05</td>
</tr>
<tr>
<td>MR (6) (28.6%)</td>
<td>83%</td>
<td>20 (18.5%)</td>
<td>0.04 ± 0.04</td>
</tr>
<tr>
<td>OR (6) (28.6%)</td>
<td>100%</td>
<td>65 (60.2%)</td>
<td>0.12 ± 0.10*</td>
</tr>
</tbody>
</table>

26
2.5.2 Lateral Growth Between Habitats

Yearly mean sponge growth rates varied greatly across reef habitat (Figure 2.8). Sponge growth rate was lowest on the MR (N=15, 0.058 ± 0.12 cm/yr) and highest on the OR (N=15, 0.613 ± 0.11 cm/yr), while sponges on the NR showed intermediate growth (N=11, 0.357 ± 0.13 cm/yr). The nearshore ridge habitat grouped similarly with both the middle and outer reefs, while the middle and outer reefs proved to be statistically different from one another, $F(2,37) = 5.52, p < 0.01$.

![Figure 2.8. Yearly average C. delitrix growth rates between sites. Bars represent one standard error. A and B denote statistically significant differences at p = 0.05.](image)

2.5.3 Coral Tissue Loss Between Habitats

Corals colonized by C. delitrix in all three habitats showed tissue loss after 12 months (NR N=11; MR N=15; and OR N=15) (Figure 2.9). The MR and OR showed similar coral tissue loss rates (0.350 ± 0.15 cm/yr and 0.347 ± 0.15 cm/yr, respectively)
that were higher than that of the NR (0.098 ± 0.17). Tissue loss rates grouped similarly among all three habitats using a nested mixed model ANOVA, $F(2,37) = 0.71, p = 0.50$.

Figure 2.9. Yearly average coral tissue loss rates by reef habitat. Bars represent one standard error.

In examining the relationship between sponge growth rates and coral tissue loss rates between habitats (Figs. 2.8 and 2.9), there are some interesting findings to note. The OR shows both the fastest sponge growth rate and highest coral tissue loss rate, as expected. However, the MR displays the slowest sponge growth rate of the three habitats, but also one of the highest coral tissue loss rates. This relationship suggests that there is some factor or process not examined in this study affecting sponge-coral interactions on the MR that may be both depressing sponge growth and stimulating coral tissue loss.

2.5.4 Coral Tissue Loss in Relation to Dead Zone Width

The dead zone width surrounding *C. delitrix* ranged from less than 1 mm to 8.1 cm. Rates of coral tissue loss were significantly correlated with sponge growth rates when individual reference nails with dead zone widths < 0.5 cm ($R^2 = 0.55$, $P < 0.05$, N
= 7) (Figure 2.10) and < 1.00 cm were pooled ($R^2 = 0.21$, $P < 0.01$, $N = 33$) (Figure 2.11). However, sponge growth rates and coral tissue rates were not significantly related when reference nails with dead zone widths < 1.5 cm were pooled ($R^2 = 0.01$, $P = 0.17$, $N = 129$).

![Figure 2.10](image1.png)

Figure 2.10. Linear regression of coral tissue loss rates and *C. delitrix* growth rates for dead zone widths < 0.5 cm.

![Figure 2.11](image2.png)

Figure 2.11. Linear regression of coral tissue loss rates and *C. delitrix* growth rates for dead zone widths < 1.00 cm.
2.6 Discussion

Results from this study indicate that *Cliona delitrix* follows general distributional patterns offshore southeast Florida. The density of *C. delitrix* individuals was positively correlated with site depth and coral density. Significantly higher sponge densities and growth rates were also found on the deepest habitat, the outer reef. No significant correlation was evident between *C. delitrix* density and site distance to the nearest inlet or outfall, suggesting that these nutrient sources may not be influencing sponge densities on a local scale.

The *C. delitrix* densities measured in southeast Florida are comparable to those from previous work with this species in other locations (Table 2.3). Additionally, a similar distributional pattern of increasing sponge density with depth was found in *C. delitrix* in the Florida Keys (Chiappone *et al.*, 2007) and in other Clionaid species across the western Atlantic (Lopez-Victoria & Zea 2005).

Table 2.3. *Cliona delitrix* densities measured across the tropical W. Atlantic.

<table>
<thead>
<tr>
<th>Authors (Date)</th>
<th>Location</th>
<th><em>C. delitrix</em> Densities</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>Broward County,</td>
<td>0.00 – 0.40 ind./m²</td>
</tr>
<tr>
<td></td>
<td>Southeast Florida</td>
<td></td>
</tr>
<tr>
<td>Chaves-Fonnegra <em>et al.</em> (2007)</td>
<td>San Andres Island, Colombia</td>
<td>0.08 – 0.54 ind./m²</td>
</tr>
<tr>
<td>Chiappone <em>et al.</em> (2007)</td>
<td>Florida Keys</td>
<td>0.01 – 0.24 ind./m²</td>
</tr>
</tbody>
</table>

A direct relationship between coral substrate availability and the abundance of *C. delitrix* has been suggested (Alvarez *et al.*, 1990), thus the higher sponge densities measured at my study sites with greater coral densities could be the result of more suitable substrate. Chaves-Fonnegra (2014) also determined that *C. delitrix* prefers to colonize recently dead areas of coral skeletons, so potential differences in recent coral mortality between habitats of different depths could also be driving this correlation.

Ivlev’s index shows that *Cliona delitrix* exhibited preferential colonization of massive, boulder-shaped coral species and avoided branching or foliose species. Similar colonization preferences in other Clionaid species and *C. delitrix* have been found in
previous studies across the Florida Reef Tract and Colombia (Ward-Paige et al., 2005; Lopez-Victoria et al., 2006; Chiappone et al., 2007, Chaves-Fonnegra & Zea, 2010). A possible explanation for this preference is that the massive boulder species contain a larger interior skeletal volume that serves as a refuge for the sponges from predators. Massive coral species could potentially provide a larger habitat allowing the sponges to reach larger sizes. Preferential colonization of boulder coral species by *C. delitrix* could alter the community composition of different coral morphologies on Caribbean reefs, favoring the persistence of plating or branching species in the future (Chaves-Fonnegra & Zea, 2011).

Other studies examining sponge growth in Florida, the Bahamas, and Belize have found similar results as mine of increased growth rates at depth, although their study subjects were non-boring species (Leichter et al., 1998; Lesser, 2006). Lesser (2006) showed comparatively faster linear growth of three common sponge species at deeper sites in Florida, corresponding with a higher abundance of food in the form of heterotrophic bacteria and prochlorophytes. Another study (Trussell et al., 2006) transplanted the common sponge *C. vaginalis* to both shallow (12m) and deep sites (25m) at Conch Reef in the Florida Keys and found faster sponge growth at the deeper site; again correlated with a higher abundance of food (picoplankton). There is some evidence that there may be more nutrients on the outer reef due to the depth of the local inlets and location of outfall pipes adjacent to this habitat, although direct nutrient, plankton, and bacteria measurements at my study sites are needed to determine if increased food is driving this growth difference. Additionally, upwelling occurs during the summer months under certain conditions in this region, leading to increases in nutrient and plankton concentrations (Smith, 1982). These increases may be proportionally greater on the outer reef due to the depth of the habitat and because it is closest to the deep ocean, which could subsequently, stimulate faster sponge growth.

The rate of growth of *Cliona delitrix* measured offshore southeast Florida was lower than that of three other species of encrusting type sponges from the genus *Cliona* measured in San Andrés Island, Colombia (Lopez-Victoria et al., 2006) (Table 2.4). As mentioned previously, *C. delitrix* excavates more deeply than other *Cliona* spp. and does
not have the associated photosymbionts that provide supplemental nutrition (Lopez-Victoria & Zea, 2005; Chaves-Fonnegra & Zea, 2011), lending to the slower rates of lateral growth measured here.

Table 2.4. Growth rates of various *Cliona* spp. of the Caribbean.

<table>
<thead>
<tr>
<th>Sponge Species</th>
<th>Mean Growth Rate (cm/yr)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cliona delitrix</em></td>
<td>0.3</td>
<td>This study</td>
</tr>
<tr>
<td><em>Cliona aprica</em></td>
<td>1.3</td>
<td>Lopez-Victoria &amp; Zea (2005)</td>
</tr>
<tr>
<td><em>Cliona caribbaea</em></td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td><em>Cliona tenuis</em></td>
<td>4.3</td>
<td></td>
</tr>
</tbody>
</table>

The *C. delitrix* growth rate reported here in *M. cavernosa* is also lower than that measured from *C. delitrix* individuals from other locations on other coral species (Table 2.5). One potential explanation for this reduced growth rate could be the type of fouling organisms present on the dead zones of corals colonized by *C. delitrix* (Chaves-Fonnegra & Zea, 2011). In San Andres Island, Colombia, where faster sponge growth was observed, turf algae was the most common colonizer of the dead zone (Chaves-Fonnegra & Zea, 2011). Through examination of images of the colonies used in my growth study offshore southeast Florida, I determined the coral dead zone was most frequently covered with a combination of sediment, macroalgae, and tunicates; possibly depressing sponge growth. Sedimentation stress is known to reduce sponge growth because it restricts water filtration and pumping by clogging internal canals (Gerrodette & Flechsig, 1979; Wilkinson & Cheshire, 1988), and high sedimentation rates have been noted at the sites used in this study from coastal development, storms, and beach renourishment activities (Jordan et al., 2010). Macroalgae and tunicates are also strong spatial competitors on coral reefs, so their colonization of the dead zone combined with the sedimentation stress may have influenced the lower sponge growth rates measured in this study.
Table 2.5. Known *Cliona delitrix* growth rates from the tropical W. Atlantic.

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean <em>C. delitrix</em> Growth Rate</th>
<th>Coral sp. Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Florida</td>
<td>0.34 cm/yr</td>
<td><em>Montastraea cavernosa</em></td>
</tr>
<tr>
<td>San Andrés Island, Colombia (Chaves-Fonnegra &amp; Zea, 2011)</td>
<td>1.1 cm/yr</td>
<td><em>Montastraea faveolata</em></td>
</tr>
<tr>
<td></td>
<td>0.9 cm/yr</td>
<td><em>Siderastrea siderea</em></td>
</tr>
</tbody>
</table>

In addition to location-specific differences, fundamental differences between the stony coral species used in the above studies (Table 2.5) could have influenced sponge growth differences. *Montastraea cavernosa* was used in this study and its’ digestive defensive ability to combat other coral species ranks higher than that of both *M. faveolata* and *S. siderea* (Logan, 1984). Therefore, it may be more effective at fighting off the sponge, leading to reduced sponge growth. *Montastraea cavernosa* also has thicker coral tissue than other species (Peters, 1984), which could play a role in the lower sponge growth rate observed. Both of these topics require further research.

Coral tissue loss was significantly correlated with *C. delitrix* growth at dead zone widths up to 1 cm in this study, suggesting that the sponge is causing direct coral mortality at distances up to 1 cm. The sponge-coral interaction appears to become decoupled beyond this distance due to confounding factors such as colonization of the dead zone by other spatial reef competitors (i.e. macroalgae, tunicates) capable of smothering adjacent coral polyps and releasing harmful chemical exudates (Potts, 1977; Jompa & McCook, 2003). Most of the dead zone widths measured in this study exceeded 1 cm; showing that local coral tissue loss in affected colonies may be the result of external factors in addition to *C. delitrix* colonization. Chaves-Fonnegra & Zea (2011) used similar methodology to determine the interaction distance between *C. delitrix* and *Siderastrea siderea* in Colombia, and found that the sponge directly caused coral mortality at distances up to 2 cm. The less intense fouling of the dead zone in Colombia, as mentioned earlier, may allow the sponge to directly impact coral tissue at further distances as there are fewer competitors colonizing the coral dead zone.
2.7 Conclusions

Across all reef habitats offshore southeast Florida, *C. delitrix* exhibited a clear colonization preference for boulder stony coral species, and avoided branching or foliose species. The density of *C. delitrix* individuals and rates of sponge growth were highest on the outer reef habitat, where coral colonies also showed some of the fastest tissue loss rates. Higher food availability at depth is likely the cause of faster *C. delitrix* growth rates on the outer reef, while sedimentation stress may have led to the reduced sponge growth measured on the nearshore ridge and middle reef. Increased growth may allow sponge individuals to reproduce and spread more on the outer reef, leading to the significantly higher sponge densities measured in this habitat. More sponge individuals were also found on sites with higher coral densities, likely resulting from the higher availability of preferred coral substrate.

Growth rates of *C. delitrix* offshore southeast Florida are reduced compared to rates from other locations, possibly due to intense fouling of the dead zone interface and use of a defensively superior coral species, *M. cavernosa*, in this study. *C. delitrix* appears to directly cause coral mortality at dead zone widths up to 1.0 cm in southeast Florida, although the settlement of fouling organisms on this dead zone may subsequently cause further coral mortality and increase its’ width. These results suggest that outer reef sites with high boulder coral cover are experiencing the greatest impacts from *C. delitrix* colonization.
2.8 Literature Cited


CHAPTER 3
DETERMINING THE EFFECT OF EXCAVATING SPONGE, CLIONA DELITRIX, REMOVAL ON STONY CORAL TISSUE LOSS OFFSHORE SOUTHEAST FLORIDA
3.1 Abstract

Excavating sponges are strong competitors for space on coral reefs, able to excavate and kill live stony corals. These sponges tend to dominate and overgrow entire coral colonies. For that reason, after stony corals become dislodged due to anthropogenic disturbances like ship groundings or anchor drags, or if they are targeted for removal prior to permitted impact projects, those with excavating sponges are not moved and reattached by reef managers. Despite the known negative effects of excavating sponges on stony corals very few studies have experimentally tested the competitive nature of this interaction. Also, coral restoration alternatives to eliminate excavating sponges from live corals have not been considered. In this study, I examined the effect of manual removal of the excavating sponge, *Cliona delitrix* (Pang 1973), on tissue loss of the stony coral *Montastrea cavernosa* (Linnaeus 1767), and its possibility as a restoration technique. A total of 33 *M. cavernosa* colonies colonized by small *C. delitrix* sponges (up to 10 cm in diameter) were examined. Sponge mesohyl was removed using a hammer and chisel from 22 of the affected coral heads, and 11 corals were left alone as controls. After sponge removal, the resultant cavities in the coral skeletons were filled to minimize future colonization by other bioeroders and promote coral tissue growth over the excavation. Cement was used as fill material on 11 of the coral colonies, and the remaining 11 cavities were filled with epoxy. Standardized photos of each coral head were taken immediately after, at 6 months and 12 months after sponge removal. Results show a reduction in coral tissue loss in colonies where sponge was removed, and both fill materials performed similarly reducing coral tissue loss. I also found that a majority of experimental corals showed no return of *C. delitrix* to the colony surface a year after removal. This study demonstrated that eliminating the bioeroding sponge competitor allows for the recovery of the stony coral competitor. Additionally, the technique used in this study can be applied to any stony coral colonized by *C. delitrix* to preserve, or at least slow the loss of, remaining live tissue.
3.2 Introduction

Excavating sponges are some of the most abundant bioeroders on coral reefs and are particularly strong competitors for space (Rützler, 1975; Vicente, 1978; Sullivan et al. 1983; Sullivan & Faulkner 1990; Chaves-Fonnegra & Zea 2007). Bioerosion by excavating sponges can account for up to 90% of the carbonate removal from coral skeletons and can remove up to 30 kg of $\text{CaCO}_3$ m$^{-2}$ yr$^{-1}$ from the reef substrate; capable of negating overall reef accretion rates and causing reef collapse or destruction (Scoffin et al., 1980; Calcinai et al., 2007; Andersson & Gledhill, 2013). At least 36 species of Caribbean reef sponges are known bioeroders, and 20 are from the genus *Cliona* (Diaz & Rützler, 2001; Zea & Weil, 2003). Coral-excavating sponges frequently overgrow and kill entire coral colonies up to 1 meter in diameter due to their mechanical capabilities to directly excavate carbonate coral skeletons and the allelopathic chemicals contained in their mucus detrimental to live coral tissue (Sullivan et al.1983; Sullivan & Faulkner, 1990; Chaves-Fonnegra et al., 2008).

*Cliona delitrix* (Pang 1973) is one bioeroding species that is abundant offshore southeast Florida and has been shown to affect approximately 4% of stony corals locally (see Chapter 2). The decline in coral cover across the Caribbean has been attributed to a variety of natural and anthropogenic stressors (Gardner et al., 2005; Aronson & Precht, 2006; Mumby et al., 2006), and the abundance of excavating sponges is another threat that has increased significantly (Rutzler, 2002; Lopez-Victoria, 2004; Ward-Paige et al., 2005). The rise in density and cover of these sponges is further supported by various factors that are damaging to stony corals yet beneficial to sponge growth, such as rises in temperature and nutrient levels (Rose & Risk, 1985; Holmes, 1997; Holmes, 2000; Rutzler, 2002). As the various stressors that threaten the persistence of stony corals continue, understanding the impact of excavating sponges on stony coral growth will become increasingly important.

Currently, during any impact minimization, mitigation, or restoration project involving stony coral reattachment or relocation in southeast Florida, corals with excavating sponge colonization are not moved and reattached (Dr. Ken Banks, Broward County Natural Resources Planning and Management Division, pers. comm.).
rationale is that the time, money, and effort required to relocate and reattach these affected colonies are wasted resources because of the perception that the coral will likely die.

Despite the widespread acceptance of the negative effects of excavating sponges on stony corals, no studies have experimentally tested the competitive nature of this interaction to date. The ecological interaction between excavating sponges and stony corals was first considered as epizoism (Antonius & Ballesteros, 1998) or infestation (Glynn, 1997), but other studies demonstrate that these organisms are in asymmetric competition where the sponges tend to dominate and overgrow entire coral colonies (Rützler, 2002). In the case of *C. delitrix* colonized stony corals, both the sponge and live coral tissue are competing for space created by the coral (the coral skeleton), as habitat. Previous studies on competitive interactions in the marine environment have shown that removing one competitor can allow for recovery of the other (Tanner, 1995; Jompa & McCook, 2002).

In this study, I test the above principle using the competitive interactions between excavating-sponges and stony corals. I manually removed *Cliona delitrix* individuals from affected coral colonies and filled the resultant cavity to explore the direct effect of sponge colonization on stony coral tissue loss. Additionally, I compare coral tissue loss rates when using two different fill materials, cement and epoxy, to determine the efficacy of both to promote coral overgrowth and minimize colonization by other bioeroders.

3.3 Methods

3.3.1 Sponge Removal and Cavity Filling

To determine the effect of *Cliona delitrix* removal on stony coral tissue loss, a total of 33 *Montastraea cavernosa* colonies colonized by small sponges (up to 10 cm in diameter) were utilized in this study. Sponges of this size were targeted because they excavate shallower cavities (usually < 5 cm) within the coral colonies making them easier to remove. In July 2012, sponges were manually removed from 22 of the affected coral
colonies. Most of the sponge tissue and affected skeleton was removed using a hammer and chisels. The resultant cavities in the coral colonies were cleaned of remaining sponge tissue using a steel wire scrub brush. The remaining 11 coral-sponge colonies were monitored as controls.

After sponge removal, the resultant cavities in the coral skeletons were filled to promote tissue overgrowth of the excavation and prevent future colonization by other bioeroders. A pH balanced cement was used on 11 of the coral colonies, and 11 were filled with ALL FIX© two-part marine epoxy. Cavities were filled by manually applying the fill material to the same level as the surrounding colony surface, and smoothing the edges against the adjacent live tissue. These two fill materials were selected because they have been used in previous restoration efforts without major detriments to coral tissue, and corals have effectively proven to overgrow them (Collier et al., 2007; Young et al., 2012).

3.3.2 Coral Tissue Loss Monitoring and Analysis

Images of each coral colony were taken immediately after sponge removal and cavity filling, and were repeated at 6 months and 12 months after sponge excavation. Control colony images were also taken at the same time. Also during 6 and 12 month monitoring, the presence of visible *C. delitrix* tissue on the colony surface was noted along with the presence of other bioeroders on or around the sponge cavity (i.e. other sponges, polychaetes, barnacles).

In order to standardize images between monitoring periods for comparison, initial, 6 month, and 12 month images were first aligned to the same viewing angle using ArcGIS 10.1© software. I used the ‘georeferencing’ tool to match features such as unique coral polyps or worm tubes between images to ensure they were the same size and angle. After aligning the viewing plane and size, all images were then imported into NCRI CPCe 3.6© for tracing and surface area calculations.

The scale for each image was calibrated using a metal object of known length placed in every image on the same viewing plane so surface area measurements could be compared accurately. For each control colony, the live coral tissue border surrounding
the sponge was traced, and for each experimental colony, the live tissue boundary around the filled cavity was traced. CPCe 3.6© software was then used to calculate the surface area within the live tissue boundary, which will be referred to as the ‘dead area’. Images from all three time periods (0, 6, and 12 months) were traced three times each, and the three surface area measurements per time period were averaged to obtain a mean surface area value.

For analysis of both the 6 month and 12 month monitoring periods, the percent change in dead area ($DA$) was calculated using the following formula:

$$\% \text{ change in } DA = \left(\frac{DA_f - DA_i}{DA_i}\right) x 100,$$

where $DA_f$ is the final dead area and $DA_i$ represents the initial dead area. A positive percentage change represents coral tissue loss (final dead area > initial dead area), and a negative percentage change represents coral tissue growth over the dead area.

To test for differences in coral tissue mortality (change in dead area) between treatment groups and fill materials, non-parametric Wilcoxon Rank Sum tests were conducted for each monitoring period due to failure to meet the assumptions of normality and equal variance. To test for differences between fill materials in the presence/absence of $C. delitrix$ 12 months after removal, a Pearson’s chi-square test was conducted. To determine if the initial sponge size had an influence on the presence/absence of $C. delitrix$ 12 months after removal, a student’s t-test was conducted. All tests were performed using JMP10© software.

3.4 Results

A summary of all dead area measurements and percent change values for every colony in each treatment group is summarized by time period in the Appendix.

3.4.1 Percent Change in Dead Area between Treatments

During both monitoring periods, coral colonies in the control group (where the sponge remained) showed the greatest increase in the dead area, whereas colonies in the
sponge removal treatment (cement and epoxy pooled) showed a much smaller increase in the dead area (Figure 3.1); representing less coral tissue loss. Although the controls showed an increase about three times greater than that of the removal group after 6 months, both treatments proved to be statistically similar using the Wilcoxon rank sum test (mean ranks of control and removal treatments were 20.55 and 14.14 respectively; S = 185, Z = 1.76, p = 0.08). After 12 months however, the change in dead area was significantly higher in the control group when compared to the sponge removal group, showing that manual sponge removal significantly decreased the loss of live coral tissue (mean ranks of control and removal treatments were 23.00 and 13.55 respectively; S = 230, Z = 2.62, p < .01).

Figure 3.1. Mean percent change in dead area ± SE per treatment for both monitoring periods after *C. delitrix* removal. The asterisk represents significant statistical differences comparing both treatments at 12 months (p < 0.05).

3.4.2 Percent Change in Dead Area between Fill Materials

During both 6 and 12 months after sponge removal, the cement filled colonies showed a greater increase in the dead area than those filled with epoxy (Figure 3.2). The increase in dead area was consistent across both monitoring periods in the cement group,
while colonies filled with epoxy actually showed a decrease in the dead area after 12 months, representing coral tissue overgrowth. Fill materials were determined to be statistically similar using the Wilcoxon rank sum test at both 6 and 12 months after sponge removal (6 months - The mean ranks of cement and epoxy were 13.82 and 9.18 respectively; $S = 101, Z = -1.64, p = 0.10$) (12 months - The mean ranks of cement and epoxy were 14.09 and 8.91 respectively; $S = 98, Z = -1.84, p = 0.07$).

![Figure 3.2](image.png)

Figure 3.2. Mean percent change in dead area ± SE per fill material at both 6 and 12 months after C. delitrix removal.

### 3.4.3 Presence of Cliona delitrix After Removal

Immediately after sponge removal and cavity filling, no experimental colonies contained any visible portions of C. delitrix tissue on the colony surface. After 6 months however, 14% of colonies from the experimental treatments showed visual presence of C. delitrix, and this percentage increased to 36% after 12 months (Table 3.1). A higher percentage of colonies in the cement group showed the presence of C. delitrix during both monitoring periods, though after 12 months this percentage did not differ by
treatment, $X^2(1, N = 22) = 0.79, p = 0.37$. I additionally examined the initial sponge size to see if that had an influence on the presence of *C. delitrix* 12 months after removal (Appendix), and no statistical effect was detected, $t(11.78) = 1.10, p = 0.29$. One colony with *C. delitrix* tissue present on the surface at the 6 month monitoring event no longer showed presence of the sponge at 12 months, indicating either that the previously visible sponge had died, or subsided deeper into the coral skeleton beneath the surface.

Table 3.1. Percentage of *M. cavernosa* colonies showing *C. delitrix* tissue on colony surface 6 and 12 months after sponge removal.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>6 months</th>
<th>12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>18%</td>
<td>45%</td>
</tr>
<tr>
<td>Epoxy</td>
<td>9%</td>
<td>27%</td>
</tr>
<tr>
<td>Overall</td>
<td>14%</td>
<td>36%</td>
</tr>
</tbody>
</table>

3.5 Discussion

This study indicates that the removal of *Cliona delitrix* significantly reduces coral tissue loss in *Montastraea cavernosa*. Similar results can be expected for a majority of other Caribbean coral species due to similarities in mounding growth form and ubiquitous distribution across reef habitats. These findings support previous suggestions of the nature of this relationship that excavating sponges are superior competitors of space with stony corals (Antonius & Ballesteros, 1998; Chornesky, 1989; Glynn, 1997; Rützler, 2002; Lopez-Victoria, 2003). Similar results have been found in studies examining the ecological interaction between stony corals and other space competing organisms. Examples include significant increases in coral growth after macroalgal competitors were removed (Tanner, 1995; Jompa & McCook, 2002). Removal of the excavating sponge, *C. delitrix*, can thus be an effective means to lower rates of coral tissue loss and preserve the remaining live tissue.
Both fill materials proved to be effective in reducing the amount of coral tissue loss compared to the controls even though coral overgrowth of the removal cavities was not witnessed in all experimental colonies. Forrester et al. (2011) found that stony corals have similar growth rates over both materials. One aspect that may have affected this result was an error in the methods and my efficiency in filling the cavities after the sponge was removed. Ideally after sponge removal, the fill material was to be applied directly adjacent to the remaining live coral tissue creating a smooth bordering edge that would allow for easy coral overgrowth. However, in many cases (particularly for the cement filled colonies), there were wide areas of old dead skeleton present between the cavity and live coral tissue that were not chiseled off because sponge tissue was not visible in these locations. When not covered by the fill material, these dead areas provided substrate for other fouling organisms (macroalgae, tunicates, etc.) to settle on where they would be in direct contact with the coral tissue, negatively affecting growth (see Lopez-Victoria, 2006; Chaves-Fonnegra & Zea, 2011).

Observational differences between fill materials could also partially explain the tissue loss results. During in situ monitoring events, the cement fills were visually covered with more algae, sediment, and tunicates than the epoxy fills, likely influencing the greater amount of tissue loss measured in the cement filled colonies. Additionally, previous restoration projects have found cement to be caustic to octocoral tissue (Jaap 2000), thus using this material may have caused minor tissue burning around the removal cavity; even when applied carefully and using a pH balanced blend. Epoxy appeared to attach better to the bare skeleton cavity and old dead areas mentioned previously, better preventing colonization of exposed coral skeleton by other competitors.

Besides reducing coral tissue loss, the sponge removal technique also appeared to be effective in preventing the reappearance of the sponge. Over 60% of the experimental corals in this study showed no visual presence of *C. delitrix* after one year, indicating an apparent relief of the coral from the sponge’s excavating activities during this period. In the small number of coral colonies where *C. delitrix* was seen on the colony surface, the sponge was located adjacent to the removal cavity in areas of the coral skeleton where it was not witnessed prior. Two possible explanations for this include regrowth and
resurfacing of remaining sponge tissue left behind after sponge removal, or new colonization of the dead coral substrate by sponge recruits. Chaves-Fonnegra (2014) found that *C. delitrix* has many reproductive events throughout the year and that it also exhibits a strong preference for recently dead coral substrate (clean of other invertebrates and macroalgae). Thus, it is possible that visible sponges are new recruits.

Future research is needed to better understand the interaction between *Cliona delitrix* and stony corals. Due to the slow-growing nature of the stony coral species used in this study, *M. cavernosa*, monitoring experimental colonies beyond 12 months would provide further insight into the effect of sponge removal on a longer-term scale. Also, a longer monitoring period would provide insight into the eventual fate of the experimental colonies in terms of whether or not they would be recolonized by *C. delitrix* or if they would suffer mortality from other causes such as disease or bleaching. Foster and others (2008) found that competitive interactions with macroalgae reduced the reproductive output of *Montastraea annularis*; but when the algae was removed, a greater number and larger coral eggs resulted. So examining the fecundity of *M. cavernosa* before and after sponge removal could provide insight into what effect *C. delitrix* colonization has on coral reproduction.

### 3.5.1 Management Considerations

These findings have implications that can enhance present day coral reef management practices. Currently, during any impact minimization, mitigation, or restoration project involving stony coral reattachment or relocation, corals with any ‘negative health conditions’ (i.e. disease or boring sponge colonization) are not moved or reattached (Dr. Ken Banks, Broward County Natural Resources Planning and Management Division, pers. comm.). The rationale is that the time, money, and effort required to relocate and reattach these affected colonies are wasted resources because the coral will inevitably die. However, this study shows that with a small amount of additional resources commonly available during any such project (hammer, chisels, cement/epoxy), the *C. delitrix* associated coral mortality can be reduced if not completely eliminated using this technique. For small coral colonies that are not yet sexually mature, the effort may not be worth it, but for larger colonies that contribute many more offspring
to future stony coral populations (Chornesky & Peters, 1987), this technique should be considered.

If this technique was to be utilized by coral reef managers, I would make a few minor recommendations. First, I would recommend attempting this technique on corals with small *C. delitrix* individuals (up to 10 cm in diameter) composed only one ramet. These qualities likely represent early stages of sponge development that would be less difficult to manually remove. Second, I would stress the importance of completely removing the entire dead skeleton around the sponge individual, or at least covering it with the fill material, so the coral tissue has the least amount of resistance in overgrowing the cavity and subsequently has the best chance to recover. Finally, because both fill materials induced similar effects on coral tissue loss, I would suggest using cement in large scale projects because it is more time and cost effective. Epoxy would be the suggested fill material in smaller-scale projects where more resources can be dedicated to sponge removal.

### 3.5.2 Conclusions

This work proves that manual removal of *Cliona delitrix* is successful in reducing the rate of coral tissue loss in *Montastraea cavernosa*. Additionally, this study provides support that these two organisms are actively competing for space, where the sponge is the dominant competitor. Both cement and epoxy serve as effective fill materials for the resultant sponge cavity to promote coral overgrowth and prevent colonization by other bioeroders. Manual removal is also effective at maintaining the absence of the *C. delitrix* from the coral surface for at least one year after removal. Finally, this technique has implications in highly developed coral reef areas like southeast Florida, where it can be used to preserve remaining live tissue of stony corals currently colonized by *C. delitrix*. 
3.7 Literature Cited


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CHAPTER 4
SUMMARY AND CONCLUSIONS
4.1 Summary

- The density of *Cliona delitrix* individuals offshore southeast Florida was positively correlated with reef site depth and stony coral densities, while no significant relationship existed between sponge density and distances to the nearest inlet or outfall pipe (Figures 2.4-2.7).

- *Cliona delitrix* exhibited a clear colonization preference for boulder stony coral species while avoiding branching or foliose species (Table 2.1).

- *Cliona delitrix* densities and yearly growth rates varied across three reef habitats of different depths in southeast Florida, but were significantly higher on the deepest habitat; the outer reef (Table 2.2. and Figure 2.8).

- Coral colonies colonized by *C. delitrix* showed similar tissue loss rates after 12 months across three reef habitats of different depths offshore southeast Florida (Figure 2.9).

- Offshore southeast Florida, *C. delitrix* is directly responsible for coral tissue loss at distances up to 1 cm, and the settlement of fouling organisms on the dead coral band surrounding the sponge may subsequently cause further coral mortality (Figure 2.10).

- Manual removal of the coral-excavating sponge, *C. delitrix*, and the subsequent filling of the resultant cavity is a successful practice to reduce the amount of coral tissue loss in the stony coral, *M. cavernosa* (Figure 3.1).

- Both epoxy and cement served as effective fill materials reducing coral tissue loss and preventing colonization within the removal cavity by other bioeroding organisms. No significant difference in the amount of coral tissue loss was found between fill materials (Figure 3.2).

- Manual sponge removal and filling the resultant cavity (with epoxy or cement) was effective at maintaining the absence of *C. delitrix* from the coral surface for at least one year after removal in a majority of experimental colonies (Table 3.2).
4.2 Conclusions

- *Cliona delitrix* follows general distributional patterns offshore southeast Florida of increasing sponge density (number of individuals/m²) with site depth and coral density.

- Outer reef sites with relatively high boulder coral cover are most vulnerable to this excavating sponge and may continue to suffer the greatest impacts of *C. delitrix* colonization. This finding could potentially lead to a faster loss of live coral tissue on the outer reef, and an overall stony coral community shift to more foliose or branching coral species like *Porites* spp., *Agaricia* spp., *E. fastigiata*, or *O. diffusa* in southeast Florida.

- *Cliona delitrix* and the stony coral *Montastraea cavernosa* are actively competing for space, and the excavating sponge is the dominant competitor. Similar to other competitive interactions in the coral reef environment, removal of the excavating sponge reduces the loss of live coral tissue.

- Manual sponge removal is a technique that can be used to preserve the remaining live tissue of stony corals colonized by *C. delitrix*. It has management implications in highly developed locations adjacent to reef environments, like southeast Florida, where numerous impact minimization, mitigation, and restoration projects involving coral reattachment and relocation are permitted every year. Marine resource managers should update their permits and protocols to include this technique when dictating the effort that should be done when reattaching or relocating stony corals colonized by excavating sponges.
APPENDIX
### Appendix 1. Dead area measurements and percent change in dead area values for every colony in each treatment group 6 months after sponge removal.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Colony</th>
<th>Fill Material</th>
<th>Initial Surface Area (cm²)</th>
<th>Final Surface Area at 12 months (cm²)</th>
<th>% Change in SA</th>
<th>Mean % Change</th>
</tr>
</thead>
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<tr>
<td>GC11</td>
<td>143.98</td>
<td>143.37</td>
<td>143.70</td>
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<td>28.44</td>
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<td>29.28</td>
<td>28.52</td>
<td>-2.66</td>
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<td>GC17</td>
<td>92.68</td>
<td>92.84</td>
<td>93.28</td>
<td>85.40</td>
<td>-1.60</td>
<td>N/A</td>
</tr>
<tr>
<td>GC19</td>
<td>94.05</td>
<td>92.84</td>
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<td>85.40</td>
<td>-1.60</td>
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<td>GC21</td>
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Appendix 2. Dead area measurements and percent change in dead area values for every colony in each treatment group 12 months after sponge removal.
Appendix 3. Coral colonies in each treatment group showing the presence of *C. delitrix* at each monitoring period. Initial sponge size is also indicated.

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