ECOLOGICAL ROLE OF BURROWING SEA CUCUMBERS, *HOLOTHURIA ARENICOLA*, IN ABACO, BAHAMAS

by

Liberty Boyd

A Thesis Submitted to the Faculty of

The Harriet L. Wilkes Honors College

in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science in Liberal Arts and Sciences

with Concentrations in Marine Biology and Environmental Science

Wilkes Honors College of

Florida Atlantic University

Jupiter, Florida

May 2018

ECOLOGICAL ROLE OF BURROWING SEA CUCUMBERS, *HOLOTHURIA ARENICOLA*, IN ABACO, BAHAMAS

by

Liberty Boyd

This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Jon Moore, and has been approved by members of her supervisory committee. It was submitted to the faculty of The Honors College and was accepted in partial fulfillment of the requirements for the degree of Bachelor of Science in Liberal Arts and Sciences.

SUPERVISORY COMMITTEE:

____
Dr. Jon. A. Moore

____
Dr. James Wetterer

____
Dean Ellen Goldey, Wilkes Honors College

____
Date

ACKNOWLEDGEMENTS

I would like to thank The Science Exchange, Friends of the Environment, and Florida International University for the internship opportunity, funding, and equipment. I also thank the Wilkes Honors College Foundation and the Life Long Learning Society of FAU for funding the research internship. Special thanks to Ryley Parent, Laura Thornton, and Maximillian Theo for their assistance with field work and sample collection.

ABSTRACT

Author:	Liberty Boyd
Title:	Ecological role of burrowing sea cucumbers, *Holothuria arenicola*, in Abaco, Bahamas
Institution:	Harriet L. Wilkes Honors College of Florida Atlantic University
Thesis Advisor:	Dr. Jon A. Moore
Degree:	Bachelor of Science in Liberal Arts and Sciences
Concentrations:	Marine Biology and Environmental Science
Year:	2018

Bioturbators serve as ecosystem engineers, influencing community dynamics of the environments in which they are endemic. Currently, the bioturbator, *Holothuria arenicola,* a species of burrowing sea cucumbers, is listed as data deficient by the IUCN. These animals may affect the structure and function of seagrass beds, which are critical habitats for various species. To assess the ecological role of *H. arenicola* , I conducted field surveys, calculated mound, and analyzed mound nutrient levels. I gathered data through monitoring study plots, conducting Bran-Blanquette seagrass surveys (Fourqurean et al., 2001), capturing GoPro video, and collecting samples. Results indicate an insignificant difference between nutrient levels and the ambient environment. However, a positive correlation between seagrass density and active mounds correlation is suggestive of a non-nutrient related ecological relationship between burrowing sea cucumbers and seagrass density. Follow-up studies are needed to further asses the ecological role of *H. arenicola* on seagrass beds.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Ecosystem engineers - species that alter the habitats in which they live as a result of a specific behavior- heavily influence the design and composition of an environment. Almost every habitat is significantly affected by the presence of an ecosystem engineer, but for this study, the focus is on the effects of the burrowing sea cucumber, *Holothuria arenicola* (Semper) in the seagrass communities of Abaco, Bahamas (Figure 1). *Holothuria arenicola* is found in the Indo-Pacific, Mediterranean, and Western Atlantic and are becoming overexploited in many areas such as Asia and Northern Africa (Razek et. al, 2007). The risk of increased harvest of this species and other Holothurians is becoming more prevalent in the Western Atlantic and Caribbean, making it imperative to understand their ecological roles for proper assessment of the health of delicate seagrass bed communities and regulation for fisheries.

Figure 1. Holothuria arenicola, Abaco, Bahamas

The Abaco Islands are comprised of vast neritic seagrass habitats dominated by three seagrass species: *Thalassia testudinium* (turtle grass), *Halodule wrightii* (shoal grass), and *Syringodium filiforme* (manatee grass) (Ogden, 1976). These coastal ecosystems serve as important nursey habitats for juvenile fishes and provide a food source for a variety of grazers (Sedberry and Carter, 1993; Nagelkerken et al., 2000, Heck et al., 2003, Baggett et al. 2010). Seagrass beds in the Bahamas are densely populated with sea cucumbers, including the burrowing sea cucumber (Mosher, 1965; Mosher, 1980). Their mounds appear in the seagrass beds as small sand patches from above. While these organisms physically alter their environment, the behaviors and niches of other organisms that they coexist with are consequently changed and influenced. The distribution of sea cucumber species in the Bahamas, particularly *Holothuria arenicola*, had been previously studied by researcher Carol Mosher and through his study, he determined that *H. arenicola* was one of the most abundant species in the Bahamas, but was only found in places of high water exchange (Mosher, 1980). The species were generally 20-30 cm in length with a tan pigmentation with black splotches (Mosher, 1980). Individuals were found in neritic habitats consisting of sandy bottom and seagrass communities (Mosher, 1980). Specifically, in Marsh Harbor, Abaco, Mosher also observed a predominate local species of gray colored individuals that only burrowed in habitats with pure sand bottoms. Mosher concludes that due to mound formation and distribution of sediment, *H. arenicola* must have a significant impact on the economy of its environment (Mosher, 1980). Further supporting Mosher's study, another project assessed the exchange of bacteria from the sediment to the guts of sea cucumbers and showed that their feeding behaviors make them important bioturbuators in tropical shallow waters (Plotieau et al., 2013). Regarding the species reproductive strategies, their primary method is sexual reproduction, but they can also reproduce asexually through fission (Razek et. al, 2007). In order to determine the sex of an individual, internal examination of the gonads is necessary, which results in fatality (Siddique and Ayub, 2015). Due to their ability to reproduce independently, proximity to potential mates should not be a determinate of population size or distribution, however, more research is necessary to make a definitive conclusion. Through these behavioral practices including habitat preference, feeding methods, and reproductive strategies, the ecological roles of *H. arenicola* are imperative to the health and sustainability of near shore marine ecosystems. Understanding the ecological role of *H. arenicola* as ecosystem engineers is essential to comprehending their effects on other organisms in the environment, from the primary producers to the habitat's apex predators.

Multiple species of sea cucumbers are currently listed as endangered by the IUCN (International Union for Conservation of Nature) Red List (Conand and Gamboa, 2013). These species have been subjected to population declines for decades due to a myriad of anthropogenic influences, which includes overharvesting, pollution, and bycatch (Anderson et al, 2011; Purcell et al, 2013). Worldwide, sea cucumbers have been rapidly declining in numbers because they are relatively easy to catch for fisheries and are increasing in demand from Asian seafood markets (Purcell et al., 2010; Chen, 2005). Sea cucumber fisheries are most prominent in Asia, but have been becoming more popular in the Caribbean (Chen, 2005). The market for sea cucumbers in the Bahamas began in 2010 in North Andros which targeted two species of sea cucumbers, *Holothuria mexicana* (black sea cucumber) and *Astichopus multifidus* (furry sea cucumber) (Dahlgren, 2011). Within a year of the start of this fishery, sea cucumber densities in this area compared to non-fished areas experienced a decrease of 77-83% (Dahlgren, 2011). This indicates that the sea cucumber fisheries is unsustainable and poses a high threat to sea cucumber populations in the Bahamas (Dahlgren, 2011). *Holothuria arenicola* has not yet been targeted by the sea cucumber fisheries, but has the potential to be if the numbers of other target species become depleted. Sea cucumbers are grown in aquaculture facilities around the world, and these cucumber farms are becoming more common (Conand, 2003). Implementing and developing a sea cucumber farm in the Bahamas and Caribbean could alleviate the need to harvest sea cucumbers from the wild.

Through this study, the information gained on the abundance and ecological roles of the species will hopefully provide better insight into the potential danger that fisheries may have on local populations of sea cucumbers in the Bahamas. The complete removal of sea cucumbers from certain environments may reduce primary production in the food chain and may lead to the loss of aerobic sediments, affecting sediment infauna (Purcell et al. 2013). Sea cucumber population declines will cause a cascading effect on the health of the marine environments in which they live due to their unique niches and complex ecological roles. In order to reduce the anthropogenic threats to these species, participating in public outreach is essential in making communities understand the importance of these organisms and habitats to both their lifestyles and the marine environment as a whole. Through continued research and increased public education, the protection of these ecosystem engineering species and subsequently the marine environments in which they live can be achieved through the installment of marine sanctuaries and political legislation.

The current need to evaluate the ecological role of burrowing sea cucumbers and their effects on seagrass bed habitats prompted this study. In order to gain a full understanding of this topic, the population of *Holothuia arenicola* in Abaco, Bahamas was assessed in order to determine population sizes and overall species distributions, burrowing behavior, and nutrient inputs into the ambient environment.

MATERIALS AND METHODS

Site Description

Spanning from early June to mid-August of 2016, data was collected in the Abaco Islands to assess various aspects of the ecology of sea cucumbers in near shore habitats of seagrass communities. The primary studies were conducted in two sites, Hills Creek and Snake Creek, in Abaco, Bahamas (Figure 2). Both sites are located on the eastern side of the island, had an inlet open to the Sea of Abaco, had similar tidal ranges and water depths < 2 m, and had similar benthic make up consisting of sea grass and sandy bottom. The benthos in both sites was covered by >50% *Thalassia testutinum* (turtle grass) and *Halodule wrightii* (shoal grass).

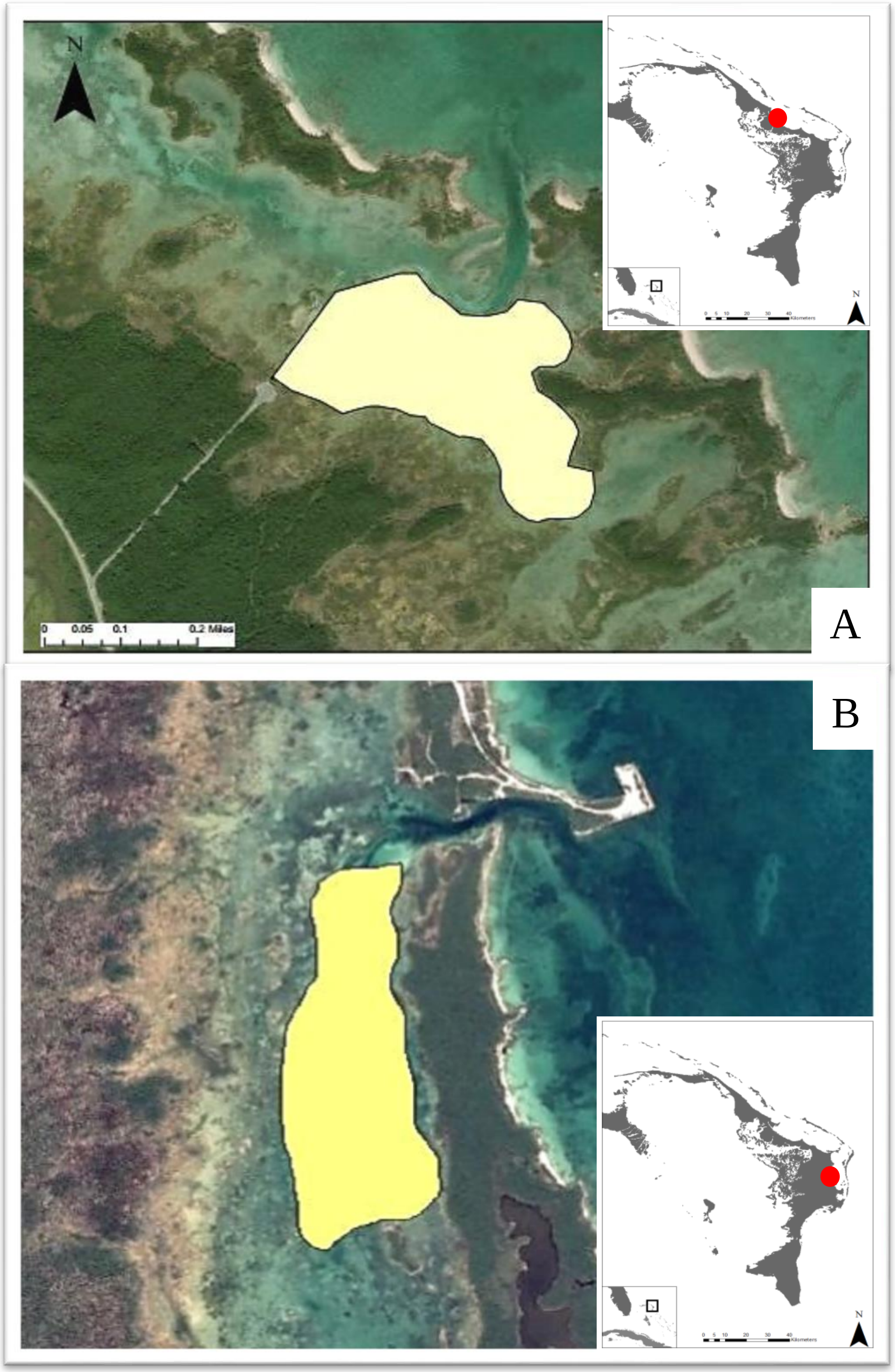

Figure 2. Map of study sites with yellow polygon indicting study area. A. Hills Creek (top) & B. Snake Creek (bottom).

Experimental Design

Serval methods of data collection were used in the experiment to measure different ecological and behavioral aspects of *Holothuria arenicola.*

To enumerate the population density of burrowing sea cucumber mounds in each site, 50 m x 1 m transects (n=15) were conducted haphazardly throughout each site. The number of active and inactive sea cucumber mounds and the dominant seagrass were recorded for each transect.

To assess the effects of sea cucumber modifications of sea grass beds through their construction of mounds, three 15 m^2 plots were created in each site (Figure 3). These plots were observed of a 32-day periods from mid-June to July. The plots had no fencing and open to allow for natural flow of water and movement of organisms. For each plot, the edges were measured with transect tape and four red marking flags were placed in each corner of the 15 m square.

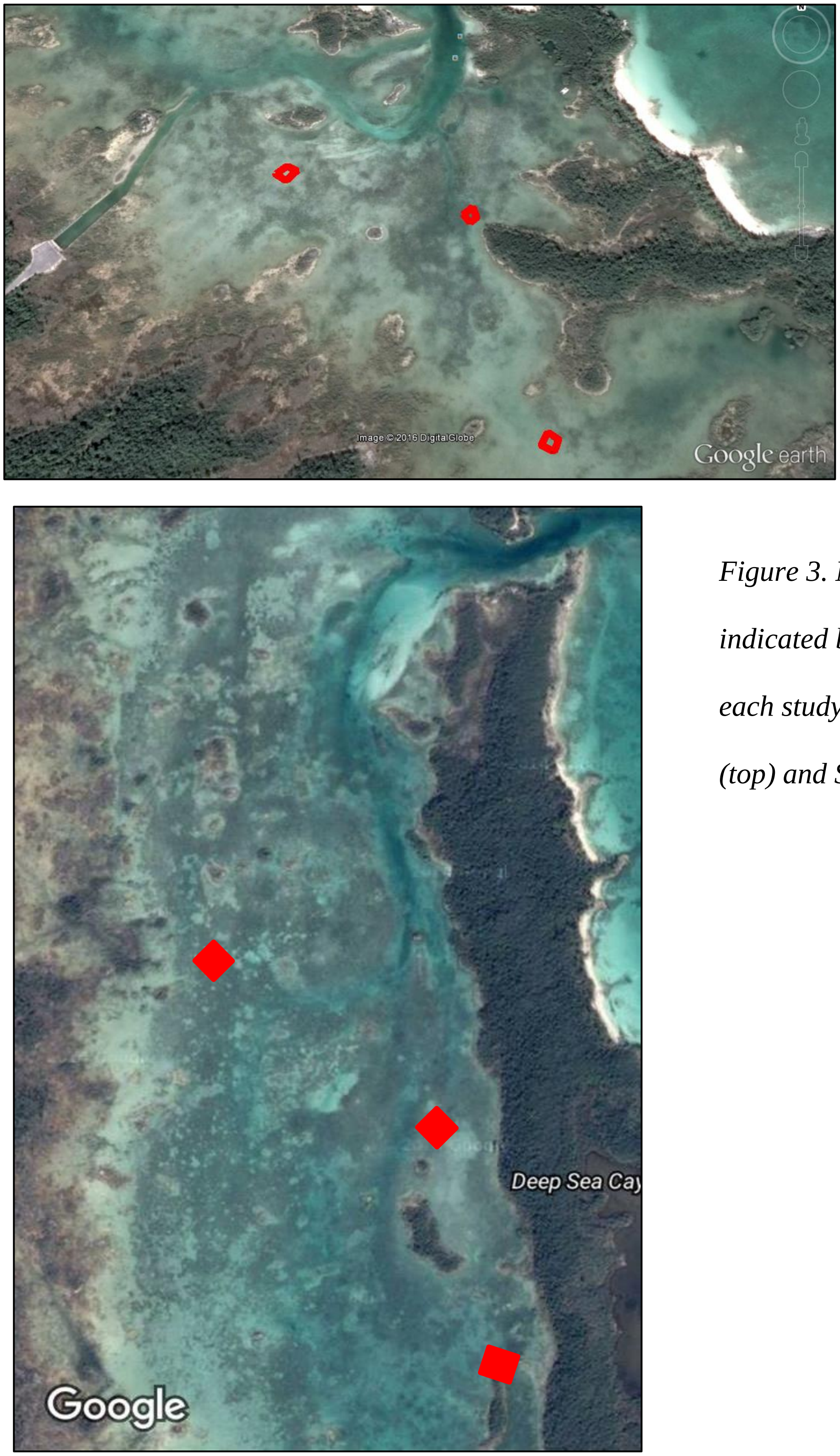

Figure 3. Maps of plot locations indicated by red squares in each study site. Hills Creek (top) and Snake Creek (bottom)

Within these boundaries, all of the mounds were marked with flagging tape tied to wooden stakes. Active mounds were marked with orange flagging tape and the inactive mounds were marked on the wooden stake with yellow flagging tape (Figure 4).

Figure 4. Photo of active (orange flag right) & inactive mound (yellow tape, left).

Figure 5. Photo of <u>Holothuria arenicola</u> fecal pellets on top of sea cucumber mound.

Active mounds were classified only by the presence of fecal pellets on top of the mounds in order to refrain from disturbing the mounds in the study site by digging up the mounds to excavate the sea cucumber (Figure 5). The plots were reassessed approximately once a week throughout the study period. During each check, all of the flags were counted and the mounds were observed to see if the activity state (inactive or active) had changed. If the mound had changed from inactive to active, orange tape would be tied above the yellow tape on the marker. If the mound changed from active to inactive, the same thing would be done except with new yellow tape. All of the changes in mound activity is recorded along with the number of markers present. To conclude the reevaluation survey of the site, any new mounds that formed were marked with a new wooden marker and flagging tape with its respective color depending on the state of mound activity. At the end of the study period, 5 seagrass surveys using the Bruan-Blanquet Survey Method were conducted in each plot for each site (n=30) to evaluate seagrass abundance and density.

To assess the building rates of burrowing sea cucumber mounds, individual animals were displaced and transplanted into an enclosed 1 m^2 cage made using thin mesh chicken wire. The chicken wire was connected using zip ties and PVC pipes for corners (Figure 6). One end of the PVC pipe was longer than the cage to securely be placed in the sand to prevent movement. Once the cage was constructed, a GoPro was attached to the inside of the cage about ¾ up to cage from the bottom and was attached to face the ground at an angle, getting the entire bottom of the cage in the shot. The GoPro was set at 1080p 30fps in the video setting. The GoPro video camera was then used record the time it takes for the animal to construct the mound, as well as the animal's building behaviors and techniques. Once the cage was set up in the field, a cucumber was placed in the middle of the cage and the GoPro was turned on to record. The cages were left alone to record until the camera battery power died (approximately 3 hours of footage) and the cameras were picked up the following day. The videos were taken in the evening in order to record the individuals at

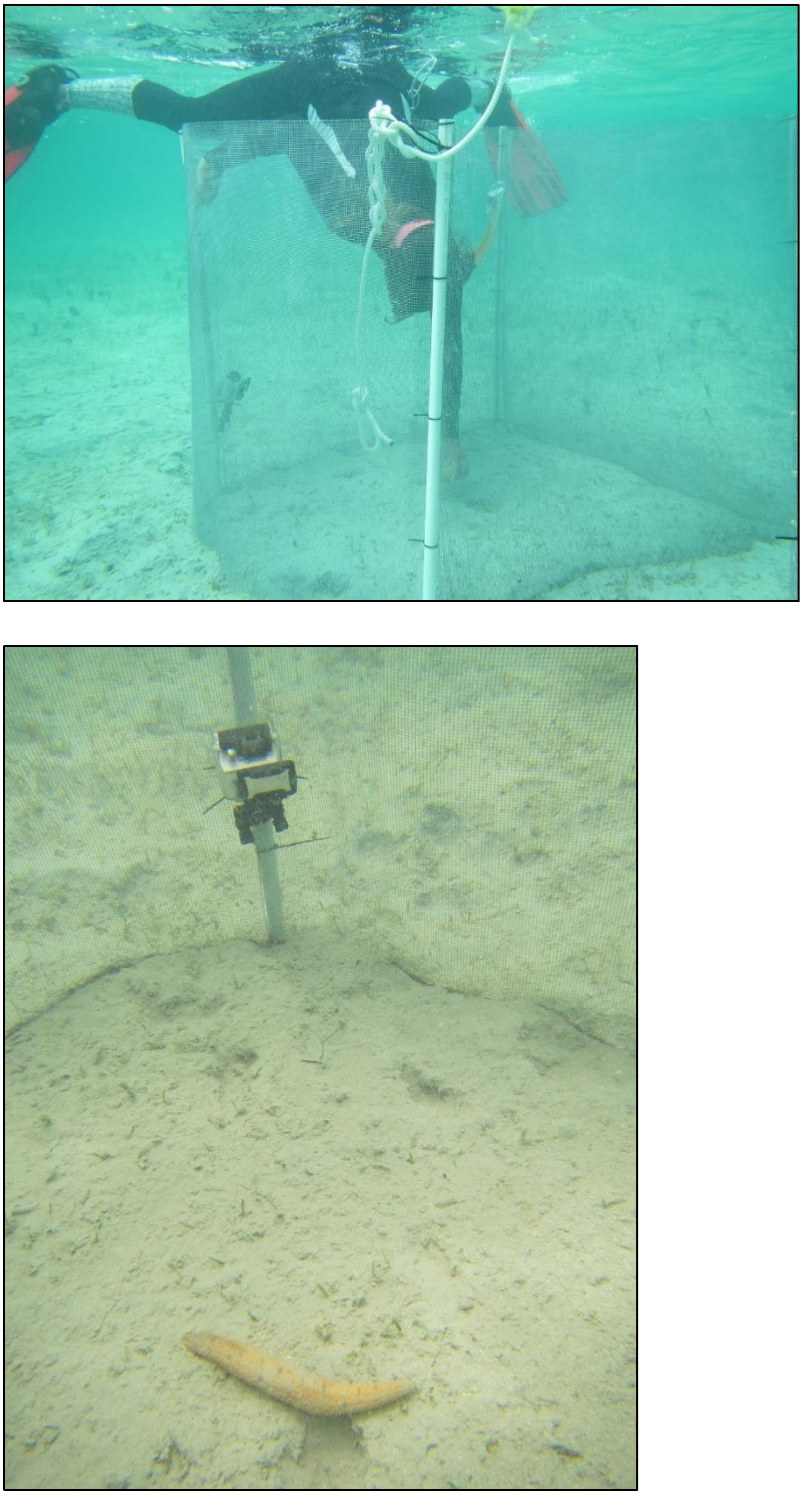

Figure 6. Photos of GoPro cage with diver placing sea cucumber in the cage (top) and attached GoPro videotaping a sea cucumber (bottom).

their most active hours. The cages were left up for about two weeks with the sea cucumber in place to observe the progression of mound creation. After two weeks, photographs of the bottom of the cage were taken. Then the GoPros were reattached and another round of videos were taken of the active mounds to see active mound behavior.

To assess the nutrient input of burrowing sea cucumbers, samples of mound and ambient sediment, seagrass, algae, and fecal pellets were taken at each site. Six active mounds chosen haphazardly were sampled per site (n=12). Mounds were measured for diameter and height.

Sampling Methods

Burrowing sea cucumber individuals were excavated by hand to minimize damage. Once an active mound was located, one finger was used to dig into the top of the mound until the sea cucumber was felt. Typically, the individual would retreat further into its burrow, allowing the extractor to dig further into the mound. With the other hand, the extractor dug into the base of the mound in order to catch the cucumber in the middle of its burrowing tunnel. Once the sea cucumber was successfully pulled from its burrow, the individual would contract. The contracted lengths of the sea cucumbers were recorded and then transplanted into a cage to be videotaped burrowing.

Samples of active mounds were taken at both sites. 6 mounds were sampled at each site for fecal pellets, mound sediment, seagrass and algae adjacent to the mound, and sediment, seagrass, and algae away from the mound at least one meter from any other active mounds for control (Figure 7). All samples were put into whirl-pak bags and chilled directly after being taken from the water in a small cooler. Fecal pellets, due to their delicate nature, were carefully sampled from the top of the mound using waterproof paper to scoop it into the whirl-pak. Samples were all taken back to the lab and immediately placed in the freezer until they were ready to be processed.

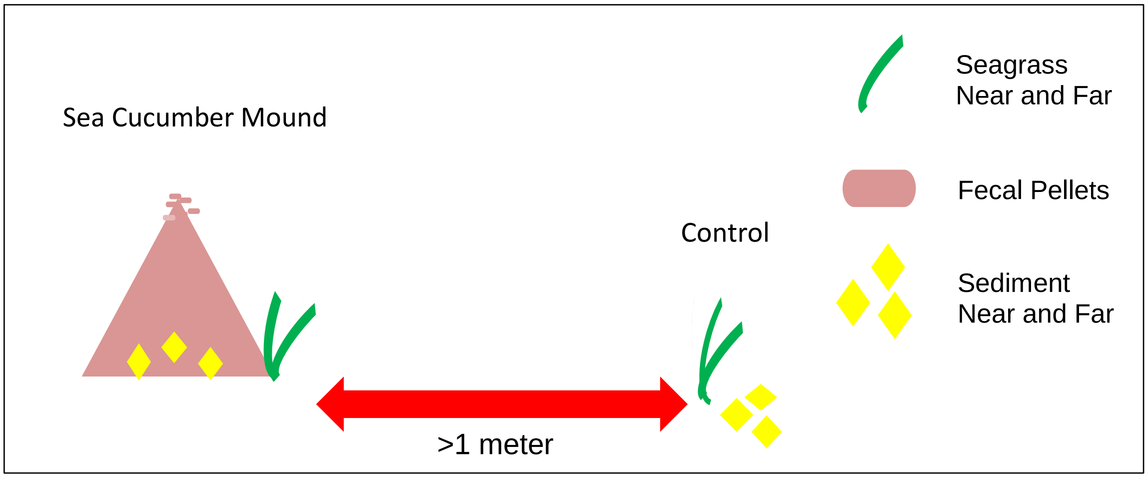

Figure 7. Graphic depiction of mound and control sampling

Sample processing

The frozen seagrass and algae samples were thawed, measured, and weighed. The samples were then put into labeled tin foil packets and placed into a dehydrator for 24 hours. After being dried, the seagrass and algae samples were crushed into a fine powder using a mortar and pestle and then placed into labeled sample vials. The sediment and fecal samples were dried in tin foil boats in the dehydrator for 24 hours. Once dried, they were also placed into labeled sample vials. The sample vials were then transferred from the Bahamas to Florida International University in Miami, Florida where they were dried again to eliminate any moisture, weighed and prepped. A Nitrogen and Carbon analysis machine was use to obtain the percentage of each element within all the samples. Once the results of the Nitrogen and Carbon analyses were completed, the mean percent of Nitrogen and

Carbon between the control and mound samples were compared using a two sample, two-tailed t-test in Excel.

RESULTS

Burrowing Sea Cucumber Behavior

Burrowing sea cucumbers, like other species of Holothuroidea, have very slow movements and contract their muscles to push themselves forward. The GoPro footage revealed that after a few moments of being placed in the cage, the individual would begin to loosen its body and elongate into its full length. The anterior of the animal was the only end to elongate while the posterior stayed in the same position. Once fully elongated, the cucumber began burrowing with its anterior end, pushing into the sand horizontally. The animal continued burrowing into the sand until it is completely covered and no longer visible. This process ranged between 1-3 hours (Appendix A). After approximately ten days, the sea cucumbers were revisited and found only a presence of fecal pellets; no full mounds had been constructed. This suggests that the mounds are constructed gradually over time as fecal deposits build up.

Burrowing Sea Cucumber Abundance and Seagrass Coverage

The number of active burrowing sea cucumbers within the observational plots changed throughout the study period. In Hills Creek (Site 1) there was a lower density of burrowing sea cucumbers and lower percent coverage of *Thalassia* (Figure 8, Tables 1,2, and 3). Snake Creek (Site 2) had a greater density of sea cucumbers and a greater percent coverage of *Thalassia* (Figure 8, Tables 1, 2, and 3).

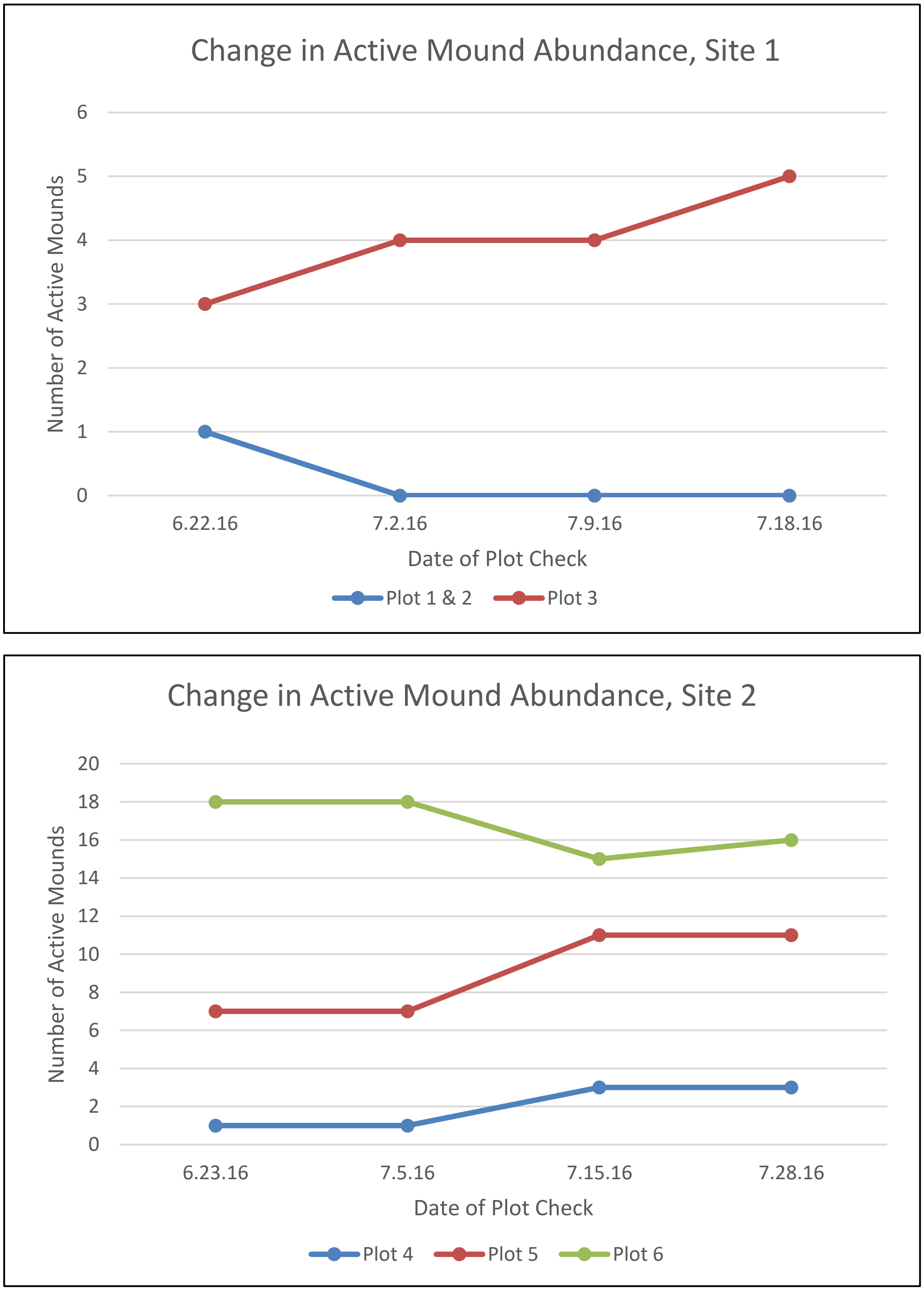

Figure 8. Line graphs depicting the number of active sea cucumber mounds over time throughout the study period in each site. Site 1, Hills Creek (Top) and Site 2, Snake Creek (Bottom).

Table 1. Active and inactive sea cucumber density per plot at the end of the study period.
Hills Creek

plot 1	0 active mound / sq m	1.6 inactive mound/sq m
plot 2	0 active mound / sq m	3.1 inactive mound/sq m
plot 3	0.33 active mound / sq m	1 inactive mound/sq m

Snake Creek

plot 4	0.2 active mound / sq m	0.46 inactive mound/sq m
plot 5	1.06 active mound / sq m	1.6 inactive mound/sq m
plot 6	0.73 active mound / sq m	1.53 inactive mound/sq m

Table 2. Seagrass percent coverage per site based of the Bran-Blanquette survey method.

Percent Seagrass Coverage Site 1			
	Plot 1	Plot 2	Plot 3
Tt	<5%	<5%	<5%
Hw	5-25%	25-50%	5-25%
Percent Seagrass Coverage Site 2			
	Plot 4	Plot	Plot 6
Tt	25-50%	25-50%	50-75%
Hw	<5%	<5%	<5%

Table 3. Average number of active and inactive sea cucumber mounds per site.
Transect Data

Transect Data	**Active mound total**	**Inactive mound total**	**Active mound avg.**	**Inactive mound avg.**
Hills Creek	11	78	0.8	5.52
Snake Creek	53	50	3	3.3

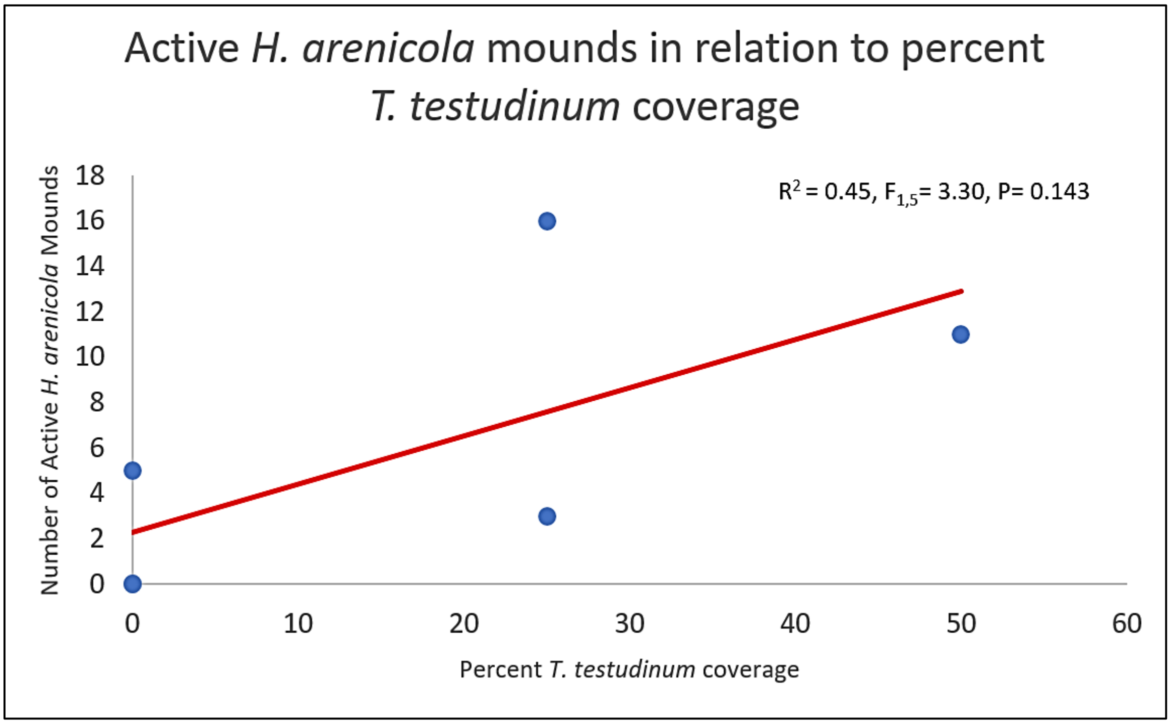

Figure 9. Positive trend between number of active burrowing sea cucumber mounds in relation to percent turtle grass coverage.

The number of active *H. arenicola* mounds and percent seagrass coverage observed had a positive correlation, but it was not statistically significant (P-value=0.143, α=0.05) (Figure 9, Table 2). Cucumber mound activity was not a significant driver of seagrass coverage.

Nutrient Analysis

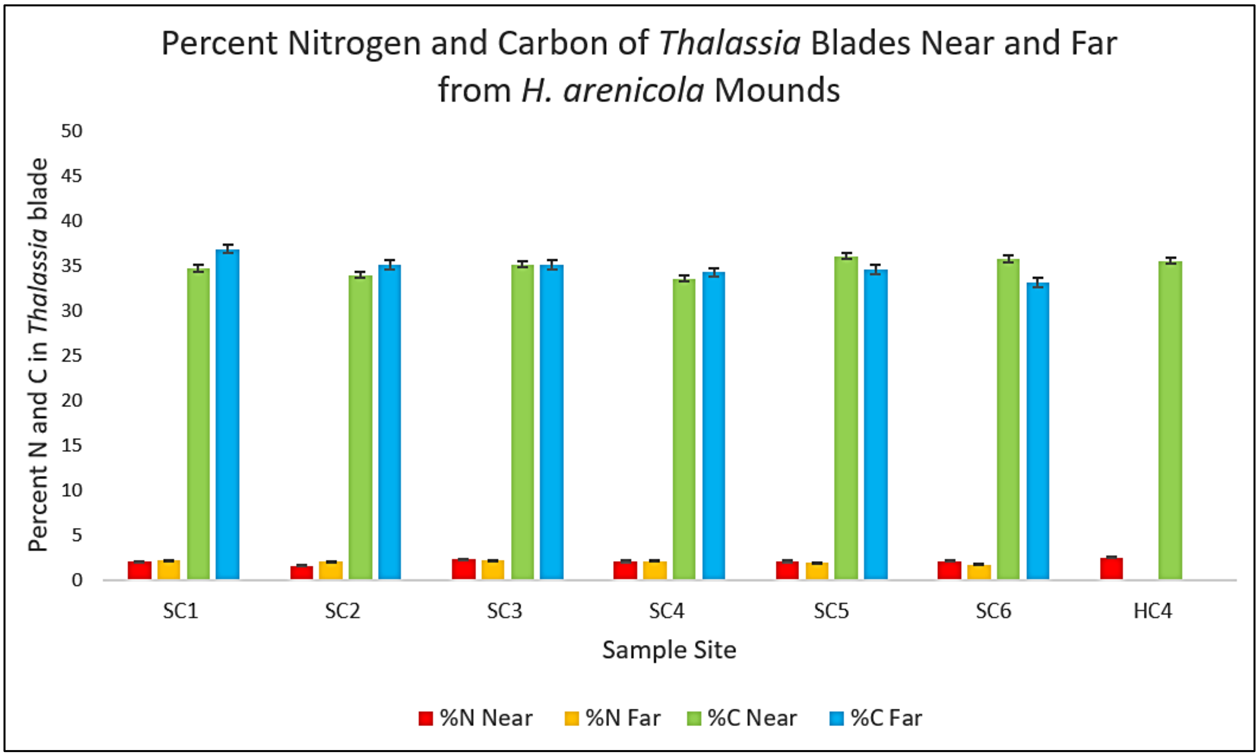

Figure 10. Nitrogen and Carbon percentages in T. testudinum blade samples near and far from the burrowing sea cucumber mounds in Snake Creek (SC) and Hills Creek (HC), with standard error bars.

Percent N between *T. testudinum* samples taken directly adjacent to the mounds and those taken one meter away from the mounds were not significantly different (Appendix B) (t=0.72, df= 11, *P*=0.48; Figure 10). Percent C between near and far mound *T. testudinum* samples were not statistically significant (t=0.20, df=11, *P*=0.84; Figure 10). This indicated that there is no nutrient gradient for both N and C observed between burrowing sea cucumber mounds and the ambient sediment.

Nitrogen and carbon in fecal and mound sediment samples were not significantly different (%N P=0.92; %C P=0.5). The mean %N and %C for fecal samples were $\mu=0.03$ and $\mu=13.56$ respectively. This is suggestive that burrowing sea cucumber defecation has little to no effect on overall nutrient availability.

DISCUSSION

Burrowing sea cucumber behavior is atypically of other Holothurians. The burrowing sea cucumbers observed in this study spent little to no time on the surface before immediately beginning to burrow back into the sediment which suggests that burrowing sea cucumbers typically do not spend time outside of their burrows. In addition, the contracting behavior seen when excavating the cucumbers may be an adapted defense mechanism against predators.

Preliminary results suggest that burrowing sea cucumbers may not exert strong effects on nearshore seagrass beds in regards to nutrients. Burrowing sea cucumber feces add little to no extra nutrients to seagrasses. Sea cucumbers are very efficient at up taking nutrients due to the microbial communities in their gut (Gao et al. 2014). I suspect that this is why their feces have very low nutrient content and there was no observed nutrient gradient in the sediment and seagrass samples between the mound and the control.

The results showed a positive correlation between the abundance of active burrowing sea cucumber and *Thalassia* coverage. There may be an indirect relationship between burrowing sea cucumbers and seagrass not mediated through nutrients, but the mechanisms driving that relationship are unknown. Through visual observations during the study, Hill’s Creek had lower seagrass densities and lower burrowing sea cucumber abundance, while the opposite was found in Snake Creek. This leads us to believe there is some alternative relationship between seagrass and *H. arenicola.*

Thalassia testudinum is known to have slow regrowth in areas that have been damaged by natural and anthropogenic influences such as propeller scars or coastal development (Dawes et al., 1997). Other species, such as stone crabs have been noted to create fragmentation in seagrass beds through burrowing (Valentine et al. 1994). As an ecosystem engineer, burrowing sea cucumbers may pose a threat to seagrass communities as they create patches of inhabitable space within the seagrass bed, damaging rhizomes and fragmenting the seagrass bed. This may allow for a primary successional species such as shoal grass to take over the seagrass bed (Fourqurean et al., 1995). More research is necessary to determine if burrowing sea cucumber mounds fragment and damage seagrass beds.

CONCLUSIONS

Burrowing sea cucumbers in Abaco, Bahamas are abundant in neritic seagrass communities. They appear to have no influence on seagrass bed communities in regard to nutrient input, and may be a source of seagrass bed fragmentation. More research is needed to determine the ecological role of *H. arenicola* in the Bahamas. This is particularly important as sea cucumber fisheries in the Bahamas continue to expand and grow.

APPENDIX

A. Go Pro Data

cage #	camera	type	GPS N	GPS W	time in	cucumber length	date	site
day 1: set up cages, attached gopros, dug up cucumbers								
1	8	sandy	26.63725	77.28486	6:33 PM		6/29/16	Hills Creek
2	10	1/2	26.63724	77.28471	6:28 PM		6/29/16	Hills Creek
3	9	seagrass	26.63715	77.28459	6:56 PM		6/29/16	Hills Creek
4	2	inactive mound	26.63717	77.28486	6:33 PM		6/29/16	Hills Creek
5	7	sandy	26.63722	77.28486	6:28 PM		6/29/16	Hills Creek
6	5	seagrass	26.63717	77.28463	6:30 PM		6/29/16	Hills Creek
day 2: attached gopros, dug up cucumbers								
4	8	sandy seagrass			17:45	19 cm	7/17/16	HIlls Creek
5	1	sandy seagrass			17:42	16 cm	7/17/16	HIlls Creek
1	11	sandy seagrass			17:38	12 cm	7/17/16	HIlls Creek
2	9	sandy seagrass			17:29	13.5 cm	7/17/16	HIlls Creek
6	7	sandy seagrass			17:18	17 cm	7/17/16	HIlls Creek
3	12	sandy seagrass			17:26	23 cm	7/17/16	HIlls Creek
day 3: attached gopros to cages with previous active mounds from the cucumbers that were placed in the cages on 7/17/6, ***** **Cucumber length is actilly size of the active mound**								
4	4	active mound			14:10	10 cm	7/27/16	Hills Creek
1	1	active mound			14:16	8 cm	7/27/16	Hills Creek
3	6	active mound			14:56	8 cm	7/27/16	Hills Creek
2	3	active mound			15:02	10 cm	7/27/16	Hills Creek
6	2	active mound			15:22	9 cm	7/27/16	Hills Creek

Hills Creek

date	mound	mound diam. 1 (cm)	mound diam 2.(cm)	Avg. mound diam (cm)	mound height (cm)	cuc length (cm)
7/27/16	1	36	36	36	5	
7/27/16	2	40	41	40.5	5	39
7/27/16	3	46	42	44	8	
7/27/16	4	51	48	49.5	12	
7/27/16	5	30	30	30	9	
7/27/16	6	29	40	34.5	9	

Snake Creek

date	mound	mound diam. 1 (cm)	mound diam 2.(cm)	Avg. mound diam (cm)	mound height (cm)	cuc length (cm)
7/28/16	1	27	24	25.5	11	no mounds were dug up
7/28/16	2	30	20	25	8	
7/28/16	3	22	19	20.5	4	
7/28/16	4	28	38	33	14	
7/28/16	5	42	46	44	13	
7/28/16	6	49	44	46.5	12	

B. Nutrient Composition for Mound, Fecal, and Seagrass Samples

Sample Name	% N	% C
SC01 Near Tt	2.048	34.674
SC01 Far Tt	2.176	36.859
SC06 Near Tt	2.149	35.778
SC06 Far Tt	1.732	33.152
SC05 Far Tt	1.914	34.551
SC02 Near Tt	1.624	33.947
SC04 Far Tt	2.122	34.268
SC02 Far Tt	2.064	35.126
SC05 Near Tt	2.135	36.079
SC03 Near Tt	2.304	35.148
SC03 Far Tt	2.207	35.08
SC04 Near Tt	2.109	33.558
HC04 Near Tt	2.562	35.533
HC04 Near Sf	2.673	35.703
HC03 Far CGA	0.193	19.923
HC02 Far CGH	1.253	17.379
HC01 Far Sf	2.713	34.932
HC04 Near Hw	2.92	41.372
HC05 Far Hw	2.69	39.655
HC06 Far Hw	3.053	42.089
HC01 Near Hw	2.052	38.855
HC02 Near Hw	2.349	41.045
HC06 Near Hw	1.785	39.788
HC01 Far Hw	2.016	38.674
HC02 Far Hw	1.741	38.623
HC03 Far Hw	2.312	40.549
HC05 Near Hw	2.085	39.503
SC01 Near CGH	0.709	17.041
SC06 Near CGP	1.2	21.971
HC04 Near CGP	0.881	18.664
HC04 Near CGH	0.543	16.046
SC01 Far CGH	0.673	16.398
SC06 Far CGP	1.728	27.092
SC01 Far CGP	1.279	22.099
HC03 Near Hw	2.35	41.693
HC03 Near BAT	1.274	31.235
HC03 Near Sf	2.309	37.801
HC01 Near BAT	0.554	29.016
SC05 Far CGH	0.989	18.483
SC04 Far BAT	0.828	25.319
SC03 Far CGP	1.438	22.963
SCM1	0	13.086
SCM2	0.163	13.547
SCM3	0	13.076
SCM4	0	13.299
SCM5	0	13.403
SCM6	0	13.678

S1F1	0	13.843
SCF2	0.199	14.079
SCF3	0	13.499
SCF4	0	14.305
SCF5	0.16	14.043
SCF6	0	13.558
HCM1	0.165	14.306
HCM2	0	14.382
HCM3	0	14.209
HCM4	0	14.233
HCM5	0	13.881
HCM6	0	14.205

HCF1	0	13.353
HCF2	0	10.614
HCF3	0	13.623
HCF4	0	13.986
HCF5	0	13.428
HCF6	0	14.335
C1HC	0	14.705
C2HC	0	15.523
C3HC	0.189	15.382
C4HC	0	14.783
C5HC	0.174	14.891

REFERENCES

Anderson, S. C., Flemming, J. M., Watson, R., & Lotze, H. K. (2011). Serial exploitation of global sea cucumber fisheries. *Fish and Fisheries*, *12*(3), 317-339.

Baggett, L. P., Jr, K. L. H., Frankovich, T. A., Armitage, A. R., & Fourqurean, J. W. (2010). Nutrient enrichment, grazer identity, and their effects on epiphytic algal assemblages: field experiments in subtropical turtlegrass, *Thalassia testudinum*, meadows. *Marine Ecology Progress Series*, *406*, 33-45.

Chen, J. (2005). Present status and prospects of sea cucumber industry in China. *Ile*, *1*, 25-38.

Conand, C. (2003). *Advances in sea cucumber aquaculture and management* (No. 463). Food & Agriculture Org, United Nations, Rome.

Conand, C. & Gamboa, R. 2013. *Holothuria arenicola*. The IUCN Red List of Threatened Species. International Union for the Conservation of Nature, Gland, Switzerland 2013:e.T180437A1630561. http://dx.doi.org/10.2305/IUCN.UK.20131.RLTS.T180437A1630561.en. Downloaded on **27 March 2017**.

Dahlgren, C. (2011). The Sea Cucumber Fishery In The Bahamas. The Perry Institute. for Marine Science, Lee Stocking Island, Bahamas

Dawes, C. J., Andorfer, J., Rose, C., Uranowski, C., & Ehringer, N. (1997). Regrowth of the seagrass *Thalassia testudinum* into propeller scars. *Aquatic Botany*, *59*(1-2), 139-155.

Fourqurean, J. W., Powell, G. V., Kenworthy, W. J., & Zieman, J. C. (1995). The effects of long-term manipulation of nutrient supply on competition between the seagrasses *Thalassia testudinum* and *Halodule wrightii* in Florida Bay. *Oikos*, 349-358.

Fourqurean, J. W., Willsie, A., Rose, C. D., & Rutten, L. M. (2001). Spatial and temporal pattern in seagrass community composition and productivity in south Florida. *Marine Biology*, *138*(2), 341-354.

Gao F, Li F, Tan J, Yan J, Sun H (2014) Bacterial Community Composition in the Gut Content and Ambient Sediment of Sea Cucumber *Apostichopus japonicus* revealed by 16S rRNA Gene Pyrosequencing. PLoS ONE 9(6): e100092. doi:10.1371/journal.pone.0100092

Heck Jr, K. L., Hays, G., & Orth, R. J. (2003). Critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series*, *253*, 123-136.

Mosher, C. (1965). Notes on natural evisceration of the sea cucumber *Actinopyga agassizi* Selenka. *Bulletin of Marine Science*, *15*(1), 255-258.

Mosher C. (1980). Distribution of *Holorthuria arenicola* Semper in The Bahamas with Observations on Habitat, Behavior, and Feeding Activity (Echinodermata: Holothuroidea). Bulletin of Marine Science 30(1): 1-12

Nagelkerken, I., Van der Velde, G., Gorissen, M. W., Meijer, G. J., Van't Hof, T., & Den Hartog, C. (2000). Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Estuarine, coastal and shelf science, 51*(1), 31-44.

Plotieau T, Lavitra T, Fillan DC, Eeckhaut I. (2013). Bacterial Diversity of the Sediments Transiting though the gut of *Holothuria scabra*. Mar Biol 160: 3087-3101

Purcell, S. W., Lovatelli, A., Vasconcellos, M., & Ye, Y. (2010). Managing sea cucumber fisheries with an ecosystem approach. *FAO Fisheries and Aquaculture Technical Paper,* no. 520

Purcell SW, Mercier A, Canand C, Hamel JF, Toral-Granda MV, Lovatelli A, Uthicker S. (2013). Sea cucumber fisheries: global analysis of stocks management measures and drivers of overfishing. *Fish and Fisheries* 14: 34-59

Razek, F. A., Rahman, S. A., Mona, M. H., El-Gamal, M. M., & Moussa, R. M. (2007). An observation on the effect of environmental conditions on induced fission of the Mediterranean sand sea cucumber, *Holothuria arenicola* (Semper, 1868) in Egypt. *Beche-de-Mer Information Bulletin*, *24*, 45-48.

Sedberry, G. R. & Carter, J. (1993) The fish community of a shallow tropical lagoon in Belize, Central America. *Estuaries* 16, 198–215.

Siddique, S., & Ayub, Z. (2015). Population dynamics and reproduction of *Holothuria arenicola* (Holothuroidea: Echinodermata) in coastal waters of Pakistan, North Arabian Sea. *Journal of the Marine Biological Association of the United Kingdom*, *95*(6), 1245-1254.

Valentine, J. F., Heck Jr, K. L., Harper, P., & Beck, M. (1994). Effects of bioturbation in controlling turtlegrass (*Thalassia testudinum* Banks ex König) abundance: evidence from field enclosures and observations in the Northern Gulf of Mexico. *Journal of Experimental Marine Biology and Ecology*, *178*(2), 181-192.