

2015

## Habitat Value of Restored Intertidal Shoreline for Fish and Macro-benthic Communities in Northeast Florida

Shannon K. Dunnigan  
*University of North Florida, skdunnigan@aol.com*

Follow this and additional works at: <https://digitalcommons.unf.edu/etd>



Part of the [Marine Biology Commons](#), and the [Terrestrial and Aquatic Ecology Commons](#)

---

### Suggested Citation

Dunnigan, Shannon K., "Habitat Value of Restored Intertidal Shoreline for Fish and Macro-benthic Communities in Northeast Florida" (2015). *UNF Graduate Theses and Dissertations*. 597.  
<https://digitalcommons.unf.edu/etd/597>

This Master's Thesis is brought to you for free and open access by the Student Scholarship at UNF Digital Commons. It has been accepted for inclusion in UNF Graduate Theses and Dissertations by an authorized administrator of UNF Digital Commons. For more information, please contact [Digital Projects](#).

© 2015 All Rights Reserved

HABITAT VALUE OF RESTORED INTERTIDAL SHORELINE FOR FISH AND  
MACROBENTHIC COMMUNITIES IN NORTHEAST FLORIDA

by

Shannon Kelley Dunnigan

A thesis submitted to the Department of Biology  
in partial fulfillment of the requirements for the degree of

Master of Science in Biology

UNIVERSITY OF NORTH FLORIDA

COLLEGE OF ARTS AND SCIENCES

December, 2015

Unpublished work c2015 Shannon Kelley Dunnigan

**CERTIFICATE OF APPROVAL**

The thesis of Shannon Kelley Dunnigan is approved:

(Date)

\_\_\_\_\_  
Dr. Kelly Smith, advisor

\_\_\_\_\_  
Dr. Nikki Dix

\_\_\_\_\_  
Dr. Eric Johnson

Accepted for the Biology Department:

\_\_\_\_\_  
Dr. Cliff Ross  
Chair

Accepted for the College of Arts and Sciences:

\_\_\_\_\_  
Dr. Barbara Hetrick  
Dean

Accepted for the University:

\_\_\_\_\_  
Dr. John Kantner  
Dean of The Graduate School

To my parents, my twin pillars,  
without whom none of this would have been possible

## ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor and friend, Dr. Kelly Smith. Thank you for giving me the opportunity to learn from you and trusting me to run your lab during the summers. I learned so much from you, especially how to make anything into something that can be used out in the field. Your advice and criticism as well as good humor and wit have been so encouraging during this whole process. I thoroughly enjoyed learning from you and all our adventures out in the field (including the bugs, crab, and boat troubles!). Thank you also to my committee members Drs. Nikki Dix and Eric Johnson for all your aid in the development of my project as well as helping me learn more about oysters, statistics, and keeping me focused on my objectives.

Thank you to the staff at the Guana Tolomato Matanzas National Estuarine Research Reserve for providing support, vehicles, and gear to conduct the biological monitoring on the restoration site: Andrea Noel, Mathew Monroe, Pam Marcum, and especially Jason Lynn. Jason, if it were not for you constantly helping us to get out on the water, we would have missed half of our collections. I am indebted to you and incredibly grateful.

I want to thank all the undergraduates in the Smith “Mud” Lab who came out and helped us collect all of our samples. We could not have done this project without all of you! I could not have imagined a better field crew than the Mud Lab-seriously. A special thanks to Brian Alexander and Nadja Capps for helping me with crab identifications, collections, and putting in just about as many hours into this project as I have!

Thank you to all the folks who kept me sane and made each day better than the last: Ruthie Barbas, Kris Amatuli, Jen Raabe, and Amy Keagy. Thank you for all of your encouragement, the wonderful conversations, and good memories. Thank you to my best friends Matthew Potter and Karly Gilchrist for constantly making sure that I always took some time to enjoy the little things. I am truly grateful for my boyfriend, Kevin Potter. When times were tough, you always knew how to cheer me up; oftentimes by offering up a smile, snack, and a hug.

Lastly, I thank my parents, for their love and constant support. I absolutely could not have accomplished any of this without you both. Thanks for encouraging me to always do my best, be careful, and have fun.

## Table of Contents

LIST OF TABLES .....	VII
LIST OF FIGURES .....	XIII
LIST OF APPENDIX FIGURES.....	XX
ABSTRACT.....	XXII
INTRODUCTION .....	2
<b>CHAPTER 1: COMMUNITY VARIATION IN MACROBENTHIC FAUNA BETWEEN RESTORED AND UNRESTORED INTERTIDAL HABITATS .....</b>	<b>4</b>
1.1 ABSTRACT .....	4
1.2 INTRODUCTION.....	6
1.3 MATERIALS AND METHODS.....	10
<i>Study Area.....</i>	<i>10</i>
<i>Collection Methods.....</i>	<i>11</i>
<i>Environmental Data .....</i>	<i>13</i>
<i>Statistical Analyses.....</i>	<i>13</i>
1.4 RESULTS.....	17
<i>Dominant species.....</i>	<i>17</i>
<i>Objective 1: Compare abundance and diversity of benthic communities on the artificial reef to adjacent natural oyster reef and unstructured mud bottom sites. ....</i>	<i>19</i>
<i>Objective 2: Determining whether the type of artificial treatment affects the abundance and diversity of benthic macroorganisms.....</i>	<i>20</i>
<i>Objective 3: Identifying short-term (1 year) changes in benthic communities of the restored and unrestored sites.....</i>	<i>22</i>
<i>Objective 5: Describing relationships between environmental factors (temperature and salinity) and the abundance and diversity of benthic macroorganisms. ....</i>	<i>23</i>
1.5 DISCUSSION .....	25
1.6 ACKNOWLEDGMENTS.....	32

<b>CHAPTER 2: FISH ASSEMBLAGES ASSOCIATED WITH RESTORED AND UNRESTORED INTERTIDAL HABITATS.....</b>	<b>60</b>
2.1 ABSTRACT .....	60
2.2 INTRODUCTION.....	62
2.3 MATERIALS AND METHODS.....	65
<i>Study Area</i> .....	65
<i>Collection Methods</i> .....	66
<i>Statistical Analyses</i> .....	67
2.4 RESULTS.....	70
<i>Objective 1: Identify trends in juvenile fish and mobile crustacean abundance and diversity between the artificial reef and unstructured habitat. ....</i>	<i>70</i>
<i>Objective 2: Compare larger nekton abundance associated with restored and unrestored sites. ....</i>	<i>75</i>
2.5 DISCUSSION .....	77
2.6 ACKNOWLEDGEMENTS .....	80
 <b>APPENDIX I: THE GTM NERR WRIGHT’S LANDING LIVING SHORELINE PROJECT</b>	
.....	CXII
REFERENCES .....	CXXII
VITA.....	CXXVIII

## LIST OF TABLES

Table	Page	
1-1	<p>Benthic settlement trays summary of effort. This table includes deployment month, deployment completion, months collections were not made, and mean elevation (m) <math>\pm</math> standard error. In some cases these omissions were due to deployment delays to avoid conflicts with restoration efforts, or due to collection days due to poor weather. FLAR and CAR were removed prior to elevation equipment became available, therefore elevations were not taken for those trays. Elevation measurements were collected for each tray in May 2015 using an EPOCH 50 GNSS System connected to the Mayport CORS (Continuously Operating Reference Station) by cell phone signal to correct the elevation to centimeter accuracy. Elevations were measured in U.S. Survey Feet and converted to meters afterwards for analysis. Other sites for comparison include unrestored eroding shoreline (UMB), Natural reef habitats (TNR, GNR, and GLNR). GNR was added to NR as a natural “target” site due to concerns that the original TNR site along the Tolomato River might not be representative of other natural reefs. GLNR was added to see if live oyster in the tray would impact fish recruitment to settlement trays.</p>	37
1-2a	<p>Mean abundance (ind. tray<sup>-1</sup>, NPT <math>\pm</math> standard error) of all invertebrates by treatment collected in settlement trays along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef only (n=39); FLAR, fiber log only treatment (n=18); CAR, combination of fiber log and artificial oyster reef (n=12); UMB, unstructured mud bottom (n=38); TNR, natural reef adjacent to restoration site in Tolomato River (n=30); GNR, natural reef in the Guana River (n=12); GLNR, natural reef in the Guana River with live oyster (n=12). FLAR and CAR were only sampled between June and November 2014. GNR and GLNR were added in February 2015.</p>	42
1-2b	<p>Mean abundance (ind. tray<sup>-1</sup> <math>\pm</math> standard error) by treatment of all fish species collected in plastic settlement trays (0.516 m<sup>2</sup>) along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef only (n=39); FLAR, fiber log only treatment (n=18); CAR, combination of fiber log and artificial oyster reef (n=12); UMB, unstructured mud bottom (n=38); TNR, natural reef adjacent to restoration site in Tolomato River (n=30); GNR, natural reef in the Guana River (n=12); GLNR, natural reef in the Guana River with live oyster (n=12) . FLAR and CAR were only sampled between June and November 2014. GNR and GLNR were added in February 2015.</p>	43



1-3	<p>Summary of means, standard errors and mean differences of the Shannon-Wiener diversity index (H') for settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.</p>	45
1-4	<p>Summary of back transformed means, standard errors and mean differences of abundance (ind. tray-1) for plastic settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.</p>	47
1-5	<p>Summary of means, standard errors and mean differences of the elevations (m) for plastic settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June 2014 and July 2015. Elevation is based off the Mayport Continuous ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.</p>	50
1-6	<p>Summary of back transformed means, standard errors and mean differences of abundance (ind. tray-1) for plastic settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. ORAR, artificial oyster reef only; CAR, combination oyster and fiber log; FLAR, fiber log only; UMB, unstructured mud bottom; NR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.</p>	52

1-7	<p>Summary of means, standard errors and mean differences of the Shannon-Wiener diversity index (H') for plastic settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. ORAR, artificial oyster reef only; CAR, combination oyster and fiber log; FLAR, fiber log only; UMB, unstructured mud bottom; NR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.</p>	53
1-8	<p>Pairwise R statistic values from the analysis of similarity (ANOSIM) for benthic macrofaunal communities collected in plastic settlement trays within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. R values range from 0 to 1 with the higher values indicating high separation between the communities. ANOSIM was conducted with 999 permutations. ORAR, artificial oyster reef only; CAR, combination oyster and fiber log; FLAR, fiber log only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River.</p>	55
1-9	<p>Spearman's <math>\rho</math> (N= 162) between mean abundance (ind. tray-1) and Shannon-Wiener diversity (H') and mean temperature (<math>^{\circ}</math>C) and salinity (ppt) as well as the maximum and minimum values of each environmental variable taken the nearby Florida Department of Environmental Protection (FLDEP) platform (Station 872-0494 at 29.99472<math>^{\circ}</math>N, 81.32956<math>^{\circ}</math>W) 48-hours prior to each collection date.</p>	58
2-1	<p>Species list of specimens caught in a 6.1-m bag seine (3.18-mm mesh) bag seine at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between November 2013 and July 2015. Presence in either the restoration site (AR) or adjacent unstructured mud bottom (UMB) habitat is indicated with a P for each sampling year. Species are listed alphabetically, first by order then family and species.</p>	86-88
2-2	<p>Summary of means, standard errors and mean differences of density (number of organisms per m<sup>2</sup> sampled, with each seine haul = 60m<sup>2</sup>) of juvenile fish and crustaceans collected in restored and unstructured habitats in a 20-ft bag seine (1/8-in mesh) by season at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250<math>^{\circ}</math>N, 81.3262806<math>^{\circ}</math>W), Florida, U.S.A., between November 2013 and July 2015. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.</p>	90

2-3	<p>Summary of means, standard errors and mean differences of Shannon-Weiner (<math>H'</math>) diversity indices from seine hauls within restored and unstructured habitats using a 6.1-m bag seine (3.18-mm mesh) of juvenile fish and crustaceans collected by season at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A., between November 2013 and July 2015. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.</p>	92
2-4	<p>Spearman's <math>\rho</math> (<math>N=90</math>) between density (number of organisms per <math>m^2</math> sampled, with each seine haul = <math>60m^2</math>) and Shannon-Wiener diversity (<math>H'</math>) and the regression-estimated parameters of temperature (<math>^{\circ}C</math>), salinity (ppt), and dissolved oxygen (mg/L) per seine haul. A handheld YSI Pro 2030 Model multiprobe was used to record environmental conditions at each site during each sampling event. Additionally environmental conditions were measured continuously every 15-min throughout the study period by a datasonde deployed at a nearby GTM NERR System-Wide Monitoring Program station, Pine Island (30.05086°N, 81.36747°W). The resulting equations for estimating conditions at the study site were: temperature = <math>0.987x + 1.293^{\circ}C</math> (<math>R^2 = 0.978</math>), salinity = <math>0.619x + 9.36</math> ppt (<math>R^2 = 0.746</math>), and dissolved oxygen = <math>0.881x + 1.687</math> mg/L (<math>R^2 = 0.907</math>).</p>	93
2-5	<p>Summary of CPUE (number of animals per <math>m^2</math>) for juvenile fishes and mobile crustaceans caught monthly in a 6.1-m bag seine (3.18-mm mesh) by habitat at the Wright's Landing restoration site along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve in October and November 2013. Means (standard error) are presented. Artificial reef (AR) site later became the combination treatment consisting of both artificial oyster reef and fiber logs (<math>n=4</math>) while the unstructured site sampled in 2013 became the northern fiber log only restoration treatment (<math>n=4</math>). Specimens are listed alphabetically by family then species.</p>	94
2-6	<p>Summary of CPUE (number of animals per <math>m^2</math>) for juvenile fishes and mobile crustaceans caught monthly in a 6.1-m bag seine (3.18-mm mesh) by habitat at the Wright's Landing restoration site along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve, January-December 2014. Rare species (only caught once or twice) are not reported in this table. Means (standard error) are presented. Total represents the total for the habitat: all the species included in the entire table. Number of seine hauls represented as (<math>n=\#</math>). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. Specimens are listed alphabetically by family then species.</p>	95-97

2-7	<p>Summary of CPUE (number of animals per 60m<sup>2</sup>) for nekton caught monthly in a 6.1-m bag seine (3.18-mm mesh) by season and habitat at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve in 2014. Means (standard deviations) are presented. Total represents the total for the habitat: all the species included in the entire table. Number of seine hauls represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. Specimens are listed alphabetically by family then species.</p>	98-100
2-8	<p>Summary of CPUE (number of animals per soak hour) for nekton caught in a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) by season and habitat along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and November 2014. Means (standard deviations) are presented. Number of nets set represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. (NR) are natural oyster reefs. UMB and NR sites were located in both the Guana and Tolomato Rivers. Specimens are listed alphabetically by order, then family and species.</p>	103-106
2-9	<p>Summary of CPUE (number of animals per soak hour) for nekton caught in a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) by river and habitat along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and November 2014. Means (standard deviations) are presented. Number of nets set represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. (NR) are natural oyster reefs. Specimens are listed alphabetically by order, then family and species.</p>	107-108
2-10	<p>Summary of back transformed means, standard errors and mean differences of the CPUE (number of animals per soak hour) for a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) sampled along restored and unrestored intertidal habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and December 2014. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.</p>	110

2-11	Spearman's $\rho$ (N= 86) between CPUE (number of animals per soak hour) and temperature ( $^{\circ}$ C), salinity (ppt), and dissolved oxygen (mg/L) per seine haul. A handheld YSI Pro 2030 Model multiprobe was used to record environmental conditions at each site during each sampling event.	111
------	---	-----

## LIST OF FIGURES

Figure		Page
1-1	Location map of the study site in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Hatched section represents the northern GTM NERR boundary. Star indicates Wright's Landing, the site of the living shoreline restoration project.	33
1-2	Deployed fiber (coir) logs along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W) Florida, U.S.A. These logs were installed approximately 5 m from the existing <i>Spartina</i> marsh edge in the high intertidal zone. Logs were placed in 20-m arcs both behind constructed oyster reefs (pictured), and alone, along eroding shoreline.	34
1-3	Map of the tray locations along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Four of the tray treatments were within or adjacent to the restored oyster reef along Wright's Landing (indicated in red). ORAR, artificial oyster reef only; FLAR, fiber log only treatment; CAR, combination of fiber log and artificial oyster reef; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River; GNR, natural reef in the Guana River, this site contained both shell trays as well as trays with live oyster.	35
1-4	Deployed plastic settlement tray behind one section of the artificial reef installed along the Guana Peninsula in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Trays contained one layer of oyster shell ( <i>Crassostrea virginica</i> ) as well as four bricks for stabilization. They were deployed behind reefs (natural and artificial) as well as 3 m in front of fiber logs and at approximately the same elevation within an unstructured site.	36
1-5	Composition of the total abundance of all species collected within restored and unrestored intertidal habitats in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Three trays were deployed in each treatment and sampled on a monthly basis between January 2014 and July 2015. ORAR, artificial oyster reef; UMB, unstructured mud bottom habitat approximately 50-m south along the same shoreline from the artificial reef; and TNR, natural reef 0.54 km across the Tolomato River from the restored site.	38

1-6 Composition of the total abundance (NPT) of all species collected within restored and unrestored intertidal habitats by season in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Three trays were deployed in each treatment and sampled on a monthly basis between January 2014 and July 2015. . ORAR, artificial oyster reef; UMB, unstructured mud bottom habitat approximately 50 m south along the same shoreline from the artificial reef; and TNR, natural reef 0.54 km across the Tolomato River from the restored site. There were variable numbers of trays collected within each season. Asterisks represent treatments not sampled. 39

1-7 Composition of the total abundance of all species collected within restored and unrestored intertidal habitats in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Three trays were deployed in each treatment and sampled on a monthly basis between July and November 2014. Total catch by treatment was divided up into crab, fish and shrimp species. ORAR, artificial oyster reef only (n=18); CAR, combination of artificial oyster and fiber log (n=18); FLAR, fiber log only (n=12); UMB, unstructured mud bottom habitat approximately 50-m south along the same shoreline from the artificial reef (n=18); and TNR, natural reef across the Tolomato River from the restored site (0.54-km) (n=15). 40

1-8 Composition of the total abundance of all species collected within restored and unrestored intertidal habitats by season in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Three trays were deployed in each treatment and sampled on a monthly basis between July and November 2014. Total catch by treatment was divided up into crab, fish and shrimp species. ORAR, artificial oyster reef only; CAR, combination of artificial oyster and fiber log; FLAR, fiber log only; UMB, unstructured mud bottom habitat approximately 50-m south along the same shoreline from the artificial reef; and TNR, natural reef across the Tolomato River from the restored site (0.54-km). Summer (n=39) and Fall (n=42). 41

- 1-9 Shannon-Wiener diversity index ( $H'$ ) for settlement trays collected within restored and unrestored habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef; UMB, unstructured mud bottom habitat approximately (distance) south along the same shoreline from the artificial reef; TNR, natural reef across the Tolomato River from the restored site (0.54-km). Each treatment had 39 trays except for TNR ( $n=27$ ). Significance levels presented as letters above bars are from Tukey's Honestly Significant Difference (HSD) post hoc tests. 44
- 1-10 Mean abundance (ind. tray<sup>-1</sup>) for plastic settlement trays collected within restored and unrestored habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015 across four seasons: A) Spring, B) Summer, C) Fall, and D) Winter. ORAR, artificial oyster reef ; UMB, unstructured mud bottom habitat approximately (distance) south along the same shoreline from the artificial reef; TNR, natural reef across the Tolomato River from the restored site (0.54-km). Each treatment in the spring had 12 trays except for TNR ( $n=3$ ). All treatments had 15 trays in the summer and three in the winter. There were nine trays in each treatment in fall, except TNR ( $n=6$ ). Significance levels presented as letters above bars are from Tukey's Honestly Significant Difference (HSD) post hoc tests. 46
- 1-11 Spatial similarity of benthic communities demonstrated with non-metric multidimensional scaling between January 2014 and July 2015. Each point represents the fourth root transformed average species abundance (number tray<sup>-1</sup>) for all three trays collected within each treatment per collection date. Ovals indicate a similarity of 50% (solid) and 60% (dash) as a result of CLUSTER analysis. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef on the Tolomato River across from the restoration site. 2-D stress: 0.18. 48



1-12	<p>Mean elevation (m) relative to mean sea level (MSL) of settlement trays deployed along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; NR, natural reef adjacent to restoration site in Tolomato River; GNR, natural reef at the mouth of the Guana River; GLNR, Guana natural reef with live oyster. There were three trays in each treatment. Treatments with different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test.</p>	49
1-13	<p>A) Mean abundance (number ind. tray-1) and B) Shannon-Weiner diversity index (<math>H'</math>) by treatment for all species collected in settlement trays along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. ORAR, artificial oyster reef only (n=18); CAR, combination oyster and fiber log (n=18); FLAR, fiber log only (n=12); UMB, unstructured mud bottom (n=17); TNR, natural reef adjacent to restoration site in Tolomato River (n=15). Different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test.</p>	51
1-14	<p>Spatial similarity of benthic communities demonstrated with non-metric multidimensional scaling in 2014. Each point represents the fourth root transformed average species abundance (ind. tray-1) for all three trays collected within each treatment per collection date. Collections were made monthly between June and November 2014. Season each collection took place is indicated next to the point. Ovals indicate a similarity of 60% (solid) and 80% (dash) as a result of CLUSTER analysis. ORAR, artificial oyster reef only; CAR, combined fiber log and artificial oyster; FLAR, fiber log only; UMB, unstructured mud bottom; NR, natural reef on the Tolomato River across from the restoration site. 2-D stress = 0.17.</p>	54
1-15	<p>Mean abundance (ind. tray-1) and Shannon-Weiner diversity index (<math>H'</math>) by year and treatment for all species collected in plastic settlement trays along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River. There were nine trays in each treatment with the exception of NR in 2015 (n=6). Treatments with different letters indicate significant difference.</p>	56

1-16	<p>Spatial similarity of benthic communities demonstrated with non-metric multidimensional scaling between 2014 and 2015. Each point represents the fourth root transformed average species abundance (number tray<sup>-1</sup>) for all three trays collected within each treatment per collection date. Only UMB, ORAR, and NR are used because they were collected within the summer season of both years. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; NR, natural reef on the Tolomato River across from the restoration site. Ovals indicate a similarity of 60% (solid) as a result of CLUSTER analysis. 2-D stress: 0.12.</p>	57
1-17	<p>Average abundance of all species (number tray<sup>-1</sup>; NPT) for each collection date of benthic settlement trays sampled between January 2014 and July 2015 in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, FL, U.S.A (30.0225250°N, 81.3262806°W). Average abundance includes all species from every treatment sampled on each collection date. Temperature (°C) and salinity (ppt) are presented as the average of data collected every six minutes 48-hrs prior to tray collections from the Florida Department of Environmental Protection Tolomato River water quality data sonde (29.99472°N, 81.32956°W).</p>	59
2-1	<p>Location map of the study site in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Hatched section represents the northern GTM NERR boundary. Star indicates Wright’s Landing, the site of the living shoreline restoration project.</p>	81
2-2	<p>Deployed fiber (coir) logs along Wright’s Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W) Florida, U.S.A. These logs were installed approximately 5-m from the existing <i>Spartina</i> marsh edge in the high intertidal zone. Logs were placed in 20-m arcs both behind constructed oyster reefs (pictured), and alone, along eroding shoreline.</p>	82
2-3	<p>Map of the seine locations along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Monthly seining was conducted on restored sites (artificial oyster reef and fiber log reefs) as well as an unstructured mud bottom site 50-m south of the artificial reef between November 2013 and July 2015.</p>	83

- 2-4 Seining with a 6.1 m bag seine (3.18-mm mesh) within the artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W) Florida, U.S.A. The seine was pulled 20 m parallel to the shoreline in 25 to 50 cm water depth. Seine poles were kept 3 m apart using a measured line so that each haul sampled approximately 60 m<sup>2</sup> of habitat. 84
- 2-5 Map of the gill net sets along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Monthly seining was conducted on restored sites (artificial oyster reef and fiber log reefs) as well as an unstructured mud bottom site 50-m south of the artificial reef between November 2013 and July 2015. An experimental monofilament gill net approximately 20-m long with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) was used to sample large nekton associated with restored and unstructured intertidal habitats May and December of 2014. Gill nets were set during daylight hours, on an incoming tide, perpendicular to the shoreline, with 0.5-1 hour soak times depending on present conditions. 85
- 2-6 Average density (number of organisms per m<sup>2</sup> sampled, with each seine haul = 60m<sup>2</sup>) of juvenile fish and crustaceans collected in restored and unstructured habitats in a 20-ft bag seine (1/8-in mesh) by season at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A., between November 2013 and July 2015. Spring (n=25); Summer (n=23); Fall (n=16); Winter (n=26). Error bars represent one standard error. Seasons with different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test. 94
- 2-7 Average Shannon-Weiner (H') diversity indices from seine hauls within restored and unstructured habitats using a 6.1-m bag seine (3.18-mm mesh) of juvenile fish and crustaceans collected by season at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A., between November 2013 and July 2015. Spring (n=25); Summer (n=23); Fall (n=16); Winter (n=26). Error bars represent one standard error. Seasons with different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test. 91

- 2-8 Spatial similarity of juvenile fish and mobile crustacean assemblages demonstrated with non-metric multidimensional scaling between October 2013 and July 2015 by A) Season and B) Year. Each point represents the fourth root transformed species abundance (number tray<sup>-1</sup>) for each seine haul (N=89) in both artificially restored and unstructured habitats. Ovals indicate a similarity of 60% as a result of CLUSTER analysis. Sampling took place within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A. 2-D stress: 0.14. 101
- 2-9 Spatial similarity of juvenile fish and mobile crustacean assemblages demonstrated with non-metric multidimensional scaling between October 2013 and July 2015 by A) Habitat and B) Tidal Stage. Each point represents the fourth root transformed species abundance (number tray<sup>-1</sup>) for each seine haul (N=89) in both artificially restored and unstructured habitats. Habitat AR represents the artificial site consisting of both artificial oyster and fiber log treatments; UMB is an unstructured site 50-m south of the artificial reef. Sampling took place within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A. 2-D stress: 0.14. 102
- 2-10 Average CPUE (number of animals per soak hour) for a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) sampled along restored and unrestored intertidal habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A. between May and December 2014. Error bars represent one standard error. Different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test. 109

## LIST OF APPENDIX FIGURES

Figure		Page
I-1	Map of oyster restoration along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (GTM NERR). Wright's Landing is along the eastern shoreline of the Tolomato River on the Guana peninsula. Fiber logs were installed within the Benthic habitat 5m from the marsh edge in addition to 100-m north of the reef along the same shoreline. Source: Friends of the GTM Reserve <a href="http://gtmnerr.org/Oyster-Reef-Restoration-Project.php">http://gtmnerr.org/Oyster-Reef-Restoration-Project.php</a>	<i>cxiv</i>
I-2	Installed artificial reef segments along Wright's Landing Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken September 4, 2013 following the installation of the final segments on the southern end.	<i>cxv</i>
I-3	Complete fiber log installation on the southern end of the existing artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken April 26, 2014 following the installation. Logs were placed in 20-m arcs behind the constructed oyster reefs using wooden stakes and twine. Plastic mesh bags filled with oyster cultch were placed in front of the logs for stabilization.	<i>cxvi</i>
I-4	Complete fiber log installation 100-m north of the existing artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken July 15, 2014 following the installation. Logs were placed in 20-m arcs approximately five meters in front of <i>Spartina</i> marsh grass on unstructured eroding shoreline using wooden stakes and twine. Plastic mesh bags filled with oyster cultch were placed in front of the logs for stabilization.	<i>cxvii</i>
I-5	Fiber log movement on the southern installation of the combination of artificial oyster reef and fiber log site along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken July 15, 2014 after the installation of the fiber log only treatment was installed 100-m north of the artificial oyster reef.	<i>cxviii</i>

- I-6 Evidence of shipworm (*Teredo* sp.) colonization of the wooden stakes securing all the fiber logs installed within the artificial oyster reef as the combination living shoreline treatment along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken July 15, 2014 after the installation of the fiber log only treatment was installed 100-m north of the artificial oyster reef. *cxix*
- I-7 Degradation and partial removal of the fiber logs installed 100-m north of the existing artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken January 17, 2015. Logs were placed in 20-m arcs approximately five meters in front of *Spartina* marsh grass on unstructured eroding shoreline using wooden stakes and twine in July 2014. *cxx*
- I-8 After the partial removal of degraded fiber log material off the northern end of the artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. This was the northern combination living shoreline site with both the artificial reefs and fiber logs. Photo was taken in January 17, 2015. *cxxi*

## ABSTRACT

Oyster reefs are declining worldwide, as well as the economic and ecological value of oysters to their respective systems. Numerous restoration efforts have been undertaken in hopes of re-establishing these shellfish populations. This study evaluated a restoration project within the Guana Tolomato Matanzas estuary in northeast Florida, U.S.A., to investigate community structure as well as seasonal patterns in species abundance and diversity of juvenile fish and benthic macrofauna within restored and unrestored intertidal habitats along the Guana Peninsula. The first objective was to determine whether the artificially created reefs provided similar quantity and diversity of benthic macrofauna as adjacent unrestored habitats. The second objective was to specifically characterize resident and transient fish assemblages associated with the artificial reef and adjacent unrestored habitats. Benthic macrofauna were quantified using plastic settlement trays deployed in triplicate at each site and sampled monthly for a year. Community structure differed by habitat, confirmed through an analysis of similarity. High abundances of *Petrolisthes armatus* on the natural reef sites largely contributed to dissimilarity in community composition between the natural reef and the restored sites. Fish assemblages were quantified using monthly seine and gill nets set adjacent to restored and unrestored intertidal habitats. Diversity was similar between the restored and unrestored sites, however, there was very little species overlap between the two sites. The dominance of post-larval and juvenile spot (*Leiostomus xanthurus*), anchovies (*Anchoa mitchelli* and *A. hepsetus*) and mullet (*Mugil* sp.) led to high density and low diversity in seine collections during the winter months. Overall, the gill net survey did not show any patterns in fish abundance associated with particular habitats in the area, however this is the first assessment in this region using gill netting. Constructed oyster

reefs created immediate habitat for resident species and enhanced habitat value compared to unstructured mud bottom.



## INTRODUCTION

The eastern oyster (*Crassostrea virginica*; hereafter oyster) forms three-dimensional reefs which enhances productivity within estuaries as juvenile fish and crustaceans recruit and utilize these reefs as foraging grounds and refuge (Breitburg 1999; Coen and Luckenbach 2000; Grabowski et al. 2005; Harding and Mann 2003; Rodney and Paynter 2006; Tolley and Volety 2005). Oyster reefs support highly diverse communities along the South Atlantic and Gulf coasts of the United States, with many species that are either rare or absent from adjacent habitats (Wells 1961; Dame 1979; Zimmerman et al. 1989; Harding and Mann 2001; Lenihan et al. 2001).

Historically, oyster reefs were one of the dominant biogenic habitats found within bays and estuaries around the world. It is currently estimated that 85% of the reefs have been lost worldwide as a result of over-fishing, disease, increased sediment loading, pollution and the introduction of nonnative species (Beck et al. 2011; Lenihan et al. 1999; Lenihan and Peterson 1998; MacKenzie et al. 1997). Due to this decline in overall habitat quality and functioning, as well as the economic and ecological value of oysters to their respective systems, numerous restoration efforts have been undertaken in hopes of re-establishing these shellfish populations. In the past, the main goal of restoration has been the enhancement of oyster populations for resource extraction with the direct or indirect ecosystem services derived from these habitats being largely ignored and/or underestimated (MacKenzie, 1983; 1996a,b). Only recently has the loss of ecosystem function associated with these shellfish communities been included in research examining development and loss of this habitat (Coen and Luckenbach 2000; Coen et al. 2007; Kennedy et al. 2011; La Peyre et al. 2014).

Oysters may also play a role in reducing shoreline erosion. Typically, a common method to combat shoreline erosion involves armoring the land/water interface using materials such as

bulkheads, concrete mats, and cement sea walls (Hillyer et al. 1997). These structures often increase the amount of erosion and provide little habitat for estuarine species. In contrast, the use of living shorelines, or natural stabilization techniques using organic materials, such as oysters and vegetation, has been found to not only cease or reverse coastline erosion, but also improve water quality and create habitat for aquatic and wetland species (Piazza et al. 2005; Scyphers et al. 2011; Whalen et al. 2011). Planting of native marsh vegetation has been used effectively for shoreline stabilization, but this method poses challenges in high energy areas where erosive forces, such as boat wakes, may overcome the possible stabilization properties of the plantings (Gleason et al. 1979; Williams 1993). The ribbed mussel (*Geukensia demissa*) is commonly associated with salt marsh cordgrass (*Spartina alterniflora*) and has been used in vegetative planting restoration to aid in stabilization of *S. alterniflora*. It attaches via byssal threads to the basal portion of *S. alterniflora* stems. As a byproduct of filter feeding, the mussel deposits fecal material and has been found to aid in the accretion of sediment and stimulation of *S. alterniflora* growth by influencing soil nutrient levels (Bertness 1984).

Previous oyster restoration efforts have utilized a variety of methods from artificial breakwaters, PVC materials, and concrete boulders to the use of organic oyster cultch and surf clamshell (*Spisula solidissima*) as an alternative substrate to oyster (Nestlerode et al. 2007). Unfortunately, if the goal of the restoration project is to develop a fully functioning reef, oftentimes juvenile oysters (spat) fail to recruit to these artificial materials. Without the settlement of oyster larvae, a reef cannot grow. Spat has been found to preferentially recruit to adult oyster shell over many alternative materials; however, coating materials with cement slurry has found to enhance the settlement of oyster larvae (Nestlerode et al. 2007; Manley et al. 2008). Typically, the goal in using a living shoreline with oyster materials is to develop a functioning

reef that provides similar ecosystem services as established natural reefs. The development of a functioning reef from the installed structures can reduce effort to maintain the artificial structure as well as enhance productivity at the site through recruiting and developing natural oysters.

Several studies have used restoration efforts to assess the role of oyster reefs as critical fish habitat, especially for commercially and recreationally important species such as spotted sea trout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), and many species of flounder (*Paralichthys* spp.) (Peterson et al. 2003; Scyphers et al. 2011). Unfortunately, not all ecosystem services have been found to develop shortly after a restoration (La Peyre et al. 2014). Therefore, just as important as the actual restoration itself, monitoring and assessment of restoration efforts in terms of ecosystem services, particularly the provision of habitat, can allow for better management practices in future efforts with the goal of habitat enhancement.

The Guana Tolomato Matanzas National Estuarine Research Reserve (GTM NERR) constructed a living shoreline of oyster shell bags and fiber logs in order to mitigate shoreline loss along the Tolomato River in northeast Florida, U.S.A. The goal of this project was to investigate community structure as well as seasonal patterns in species abundance and diversity of juvenile fish and benthic macrofauna within restored and unrestored intertidal habitats along the Guana Peninsula. The first objective was to determine whether the artificially created reefs provided similar quantity and diversity of benthic macrofauna as adjacent unrestored habitats. The second objective was to specifically characterize the resident and transient fish assemblages associated with the artificial reef and adjacent unrestored habitats.

## Chapter 1

### Community variation in macrobenthic fauna between restored and unrestored intertidal habitats

#### 1.1 ABSTRACT

Oyster reefs are declining worldwide, as well as the economic and ecological value of oysters to their respective systems. Numerous restoration efforts have been undertaken in hopes of re-establishing these shellfish populations. This study evaluated a restoration project within the Guana Tolomato Matanzas estuary in northeast Florida, U.S.A., to determine whether artificially created reefs provide similar quality habitat to adjacent natural reefs by (1) comparing the abundance, diversity and community composition of benthic macrofauna between restored and unrestored sites, (2) identifying short-term (1 year) changes in the macrofauna between the sites, (3) looking at seasonal differences among the treatments, and (4) describing relationships between environmental factors (temperature and salinity) and the abundance and diversity of benthic macroorganisms. Benthic macrofauna were quantified using plastic settlement trays deployed in triplicate at each site and sampled monthly for a year. Community structure differed by habitat which was confirmed through an analysis of similarity. High abundances of *Petrolisthes armatus* on the natural reef sites largely contributing to dissimilarity in community composition between the natural reef and the restored sites. The individual artificial treatments did not differ, however, the constructed oyster reefs created immediate habitat for resident

species and enhanced habitat value compared to unstructured mud bottom. There was no change among treatments after one year; however, communities on the restored and natural reefs remained different, largely driven by the presence of *P. armatus*.

Key Words: benthic, oyster, macroinvertebrate, communities, Florida, restoration

## 1.2 INTRODUCTION

Oyster reefs support highly diverse communities along the South Atlantic and Gulf coasts of the United States, with many species that are either rare or absent from adjacent habitats (Wells 1961; Dame 1979; Burrell Jr. 1986; Zimmerman et al. 1989; Lenihan et al. 2001). The eastern oyster (*Crassostrea virginica*; hereafter oyster) forms three-dimensional reefs which enhance secondary and tertiary productivity within estuaries as juvenile fish and crustaceans recruit to and utilize these reefs as foraging grounds and refuge (Breitburg 1999; Coen and Luckenbach 2000; Harding and Mann 2003; Grabowski et al. 2005; Tolley and Volety 2005; Rodney and Paynter 2006). Additionally, oyster reefs provide other types of ecosystem services such as water filtration, prevention of coastal erosion, boat wake mitigation, and carbon sequestration (Volety et al. 2014).

Harding and Mann (2001) suggested that oyster reefs provide a greater quantity, quality and diversity of food than adjacent unstructured habitats. One of the most abundant taxonomic groups in estuarine habitats are xanthid mud crabs, which feed on molluscs and other crustaceans on oyster reefs (Lee and Kneib 1994; Meyer 1994). Additionally, several benthic fish species, such as *Gobiosoma bosc* (naked goby), rely on oyster reefs for refuge, food, and nesting sites (Wells 1961). Many resident reef species serve as a resource for juveniles of commercially and economically important species such as *Morone saxatilis* (striped bass), *Pomatomus saltatrix* (bluefish), *Sciaenops ocellatus* (red drum), and juvenile groupers, snappers (Crabtree 1978; Crabtree and Dean 1982; Wenner et al. 1990; Mullany and Gale 1996; Harding and Mann 2003; Grabowski et al. 2005; Pierson and Eggleston 2014).

Historically, oyster reefs were one of the dominant biogenic habitats found within bays and estuaries around the world. It is currently estimated that 85% of the reefs have been lost

worldwide as a result of over-fishing, disease, increased sediment loading, pollution and the introduction of nonnative species (Beck et al. 2011; Lenihan et al. 1999; Lenihan and Peterson 1998; MacKenzie et al. 1997). Due to this decline in overall habitat quality and functioning, as well as the economic and ecological value of oysters to their respective systems, numerous restoration efforts have been undertaken in hopes of re-establishing these shellfish populations. In the past, the main goal of restoration has been the enhancement of oyster populations for resource extraction with the direct or indirect ecosystem services derived from these habitats being largely ignored and/or underestimated (MacKenzie 1983; 1996a,b). Only recently has the loss of ecosystem function associated with these shellfish communities been included in research examining development and loss of this habitat (Coen and Luckenbach 2000; Coen et al. 2007; Kennedy et al. 2011; La Peyre et al. 2014).

Previous oyster restoration efforts have utilized a variety of methods from artificial breakwaters, PVC materials, and concrete boulders to the use of organic oyster cultch and surf clamshell (*Spisula solidissima*) as alternative substrates to oyster (Nestlerode et al. 2007). Living shorelines, a form of natural stabilization using organic materials, such as oysters and natural vegetation, have been found to also improve water quality in addition to creating habitat for aquatic and wetland species. In fact, these projects have been found to cease or reverse coastal erosion and serve as critical habitats for plants, fishes, and invertebrates (Scyphers et al. 2011; Whalen et al. 2011; Kreeger and Padeletti, 2013). However, the effectiveness of an oyster and fiber log combination treatment in creating fish habitat has not been investigated to date.

Restoration projects provide the opportunity to study the influence of adjacent habitats in structuring restored site communities; in this case, the food resources that are present. Unfortunately, not all ecosystem services have been found to develop shortly after a restoration

(La Peyre et al. 2014). Additionally, many restoration projects are carried out with little or no monitoring, which prevents assessment of success and adaptive management strategies from being employed.

The Guana Tolomato Matanzas National Estuarine Research Reserve (GTM NERR) constructed a living shoreline of oyster shell bags and fiber logs on the Tolomato River to mitigate shoreline loss along the Guana Peninsula in northeast Florida, U.S.A. The main goal of this study was to assess the habitat quality of created oyster reefs along the Tolomato River by comparing resident communities on created reefs with communities on unstructured mud bottom (the dominant habitat prior to shoreline restoration) and on natural reefs. Several research objectives were pursued in this study within the context of a few related hypotheses:

1. Compare abundance and diversity of benthic communities on the artificial reef to adjacent natural oyster reef and unstructured mud bottom sites.

**Hypothesis 1:** It was expected that the created reefs would support higher abundances and diversity of benthic macroorganisms than the unstructured site as well as have abundances and diversity values comparable to adjacent natural reefs.

**Hypothesis 2:** The community structure of the artificial reef should be more similar the natural oyster reef than to the unstructured site.

2. Determine whether the type of artificial treatment affects the abundance and diversity of benthic macroorganisms.

**Hypothesis 3:** Individually, fiber logs and oyster shell living shoreline projects have been found to increase abundance of fish and crustaceans; therefore, there will be no difference in diversity or abundance within the artificial treatments



themselves, however, there will be higher abundances and diversity within the combination treatment.

**Hypothesis 4:** The artificial treatments will support similar communities and therefore there will be no difference in the community structure between the treatments.

3. Identify short-term (1 year) changes in benthic communities of the restored and unrestored sites.

**Hypothesis 5:** Communities on the artificial reef should more closely resemble the natural reef over time.

4. Examine seasonal trends in abundance and diversity.
5. Describe relationships between environmental factors (temperature and salinity) and the abundance and diversity of benthic macroorganisms.

### 1.3 MATERIALS AND METHODS

#### *Study Area*

Sampling occurred along the Guana Peninsula within the northern GTM NERR, Florida, U.S.A. (30.0225250°N, 81.3262806°W) (Figure 1). The Guana Peninsula is surrounded by the Guana and Tolomato Rivers of the GTM estuary. The GTM estuary is a subtropical, well-mixed, lagoonal estuary consisting of *Spartina alterniflora*-dominated marshes as well as mixed salt marsh-mangrove habitats (Valle-Levinson et al. 2009; Williams et al. 2014). The Tolomato River is a segment of the Atlantic Intracoastal Waterway and shorelines are subject to high wave energies from boat wakes and wind.

The GTM NERR constructed a living shoreline using oyster shell between 2012 and 2013. The artificial oyster reef extends approximately 328 m along the Tolomato bank of the Guana Peninsula. Reefs were constructed of plastic mesh bags filled with oyster shell stacked in 5.5 m long segments within the low intertidal zone. An additional artificial treatment using fiber (coir) logs was installed along the marsh edge in April 2014 at a higher elevation (typically about 30 to 40 cm above the lower oyster reefs). These logs were modeled after the Delaware Estuary Living Shoreline Initiative (DELSI) method used in the Delaware Bay Estuary and installed approximately 5 m from the existing *Spartina* marsh edge (Whalen et al. 2011). Logs were placed in 20 m arcs both behind constructed oyster reefs, and alone, along eroding shoreline (Figure 2). As will be discussed later, the fiber logs did not last more than few months, and most were degraded and removed by winter of 2014 (APPENDIX I). In spring of 2015, upper elevation oyster bags were deployed to replace the footprint of the fiber log arcs. Replacement of the upper elevation habitats was still continuing when this project was concluded.

Benthic community sampling occurred between January 2014 and July 2015. In 2014, five habitats were sampled: the artificial oyster reef (ORAR), the fiber log only (FLAR) 100 m north of the artificial reef along the same shoreline, a combination site with both fiber logs and artificial oyster reef segments (CAR), a natural oyster reef (TNR) approximately 0.54 km across the Tolomato River from the artificial reef, and an unstructured mud bottom site (UMB) 50 m south of the restoration along the Guana Peninsula. In 2015, an additional natural oyster reef site (GNR and GLNR) at the mouth of the Guana River was sampled as a comparison to the natural reef community at the Tolomato River site (2 km, from the Tolomato natural reef site) (Table 1, Figure 3).

### ***Collection Methods***

Ventilated plastic settlement trays (86 L x 60 W x 15 H cm; 0.516-m<sup>2</sup>) lined with 3-mm VEXAR® plastic mesh screening were used to quantify abundance and diversity of benthic fishes and crustaceans. The catch efficiency of substrate trays has not been well studied, though they have previously been used as a method to collect and quantify benthic fish and invertebrates (Lenihan et al. 2001; Lehnert and Allen 2002; Eash-Loucks et al. 2014). Trays were deployed at low tide within the lower intertidal zone along the restoration site and on the mud flats behind the natural oyster reefs along the Tolomato River. Fiber log trays were placed 3 m channel side of the fiber logs installed 100 m north of the artificial reef. Trays in the combination treatment were deployed in the combination treatment on the northern portion of the artificial reef. They were placed directly behind artificial reefs, in between the reef and the fiber logs. The artificial oyster reef only trays were also placed directly behind the reefs, shoreward, however they were located 20 m south of the combination treatment. Attempts were made to deploy each tray at similar elevations relative to the mean water level in the region. Elevation measurements were

collected for each tray in May 2015 using an EPOCH 50 GNSS System connected to the Mayport CORS (Continuously Operating Reference Station) by cell phone signal to correct the elevation to centimeter accuracy. The trays deployed on sites with fiber logs were removed prior to the elevation equipment becoming available; therefore, no elevation measurements were taken for the FLAR and CAR trays. Elevations were measured in U.S. Survey Feet and converted to meters for analysis.

Settlement trays consisted of a layer of *C. virginica* oyster cultch (approximately one 5-gallon bucket full), rinsed and replaced after each collection event. Trays were deployed in triplicate at each treatment site and sampled on a monthly basis for over a year (January 2014-July 2015) (Figure 4). Trays deployed in January 2014 were removed in December and replaced with new trays in January 2015. New cultch was also used due to large quantities of existing cultch lost in original trays. The sites with the fiber logs (FLAR and CAR) were only sampled between June and November 2014. For the natural reef sites at the mouth of the Guana River, the trays were deployed in the same manner as the previous treatments (GNR); however, in addition to the cultch substrate trays, three trays were also deployed at this reef using live oyster shell (GLNR). Live oyster trays were deployed by excavating a 0.516-m<sup>2</sup> section of the oyster reef, setting the trays within the hollowed reef, and then placing the excavated natural oyster into the tray.

Efforts were made to retrieve all the trays from approximately 0.5 m of water on an outgoing tide. Trays were collected one at a time with the contents rinsed, sieved, bagged, placed on ice, and returned to the lab for identification and measurement. The trays were not cleaned and the cultch was rinsed and returned to emulate the accumulation of natural fouling in nearby habitats. Large crustaceans and fish were identified, measured (carapace width, CW, for crabs and

standard length, SL, for fish), and released away from the sampling site. All organisms were identified to the lowest possible taxon. Following identification, specimens were preserved in 95% ethanol. Sampling did not take place in Aug 2014, Jan-Feb 2015, and May 2015 due to unexpected circumstances as well as delays in the installment of additional restoration treatments (Table 1).

### ***Environmental Data***

Faunal patterns were compared to temperature (°C) and salinity (ppt) data collected from a nearby Florida Department of Environmental Protection (DEP) platform (Station 872-0494 at 29.99472°N, 81.32956°W) that recorded water temperature and salinity every 6 minutes using a Greenspan EC250 sensor linked for conductivity and water temperature, and a Stevens DataLogic 3000 Environmental Data Logger. Data were downloaded from 48 hrs prior to collections. Measurements were not taken precisely when collections were made since specific sampling locations experience great variability due to varying water levels. The DEP platform provided a record of the general water conditions that potential recruiting organisms experienced.

### ***Statistical Analyses***

Passive collection with settlement trays precluded the calculation of species densities (number per area); therefore, the abundance of species collected within each tray was expressed as the mean number per tray (no. tray<sup>-1</sup>, NPT) (Eash-Loucks et al. 2014). Species diversity was calculated for each tray using the Shannon-Wiener diversity index ( $H'$ ). Although efforts were made to retrieve all trays from approximately 0.5 m of water, this was not always possible, resulting in inconsistent catch of *Palaemonetes* shrimps throughout the study. This was primarily

due to incorrectly timing the tides for collections and these shrimps were only caught when water was present over the trays. Therefore, *Palaemonetes* were excluded from the analyses

All data were checked for normality using the Kolmogorov-Smirnov test. Logarithmic transformation of the abundance metric, NPT, and the removal of an outlier, were necessary to achieve normality and homogeneity of variance. In some cases, the data remained non-normal (specifically  $H'$ ); these data were still analyzed with analysis of variance (ANOVA) due to its robustness and insensitivity to skewness (Glass et al. 1972). All data were reported as untransformed mean  $\pm$  standard error with the exception of the statistical results of analyses using the transformed abundance, these were reported using the back transformed means  $\pm$  standard error. IBM SPSS Statistics (Windows, Version 22.0. Armonk, NY: IBM Corp) was used for all analyses of abundance and diversity.

#### *Abundance and diversity*

The effects of season and treatment on abundance (transformed NPT) and species diversity ( $H'$ ) were analyzed using a multivariate analysis of variance (MANOVA), and then separately using a one-factor ANOVA for each response variable (Underwood 1981). A one-way ANOVA was used to test for differences in the elevation of trays deployed in each treatment. A two-factor (season and treatment) MANOVA was used on all five of the treatments sampled in 2014 within the summer and fall seasons. The MANOVA was followed by a one-factor ANOVA for each response variable. All post-hoc comparisons were made using Tukey's Honestly Significant Difference (Tukey HSD) test for factors with more than one level.

Abundance and diversity of all the natural reef communities (TNR, GNR, and GLNR) were compared using a Kruskal-Wallis test because they did not meet the assumptions for parametric statistics. This test also helped determine differences between trays using live oyster compared to

oyster cultch. Since each response variable and factor were tested individually, a sequential Bonferroni adjustment was used to determine the significance of each test.

Short-term changes in benthic communities between the restored and unrestored sites were identified by comparing the summer collections of both years because the spring was not as well sampled in 2014. A MANOVA was used to analyze the effect of year and treatment on abundance and diversity, then separately using an ANOVA for each response variable. The variances of the response variables were not equal, therefore, the Welch's ANOVA was used for the separate ANOVAs as it is stricter and does not assume equal variances. Additionally, a Games-Howell test was used for post-hoc comparisons.

Spearman's rank correlation was used to examine the association of environmental variables (average temperature and salinity of continuous measurements taken 48 hrs prior to each collection) with benthic macrofaunal abundance and diversity.

#### *Community analyses*

Non-metric multidimensional scaling (NMDS) was used to determine similarity of benthic communities by season and treatment. A Bray-Curtis similarity matrix was constructed using the fourth root of the mean NPT of all species in each treatment by sampling date and used in the MDS. The transformation reduced the weight of abundant species and enabled the contribution of less abundant or rare species to the overall community structure (Eash-Loucks et al. 2014). The similarity index was also used to conduct a one way analysis of similarity (ANOSIM) on community separation based on season and treatment. A similarity percentage (SIMPER) analysis was conducted to determine which species contributed the most to dissimilarities among treatments and seasons. Nine hundred and ninety nine permutations were used in both the

ANOSIM and SIMPER analyses. All community multivariate analyses were conducted using PRIMER statistical software (version 7.0; Clarke et al. 2014).



## 1.4 RESULTS

There were 8,434 specimens (305 fishes; 8,129 invertebrates) from 30 different species (12 fishes; 18 invertebrates) collected during the length of the study (June 2014-July 2015).

Invertebrates were primarily caught and observed within the trays (438 shrimp, 7,691 crabs).

Crabs were the dominant group within each treatment and across the seasons (Figures 5,6,7,8).

As such, the dominant species throughout the study were invertebrates: *Petrolisthes armatus* (the green porcelain crab), *Panopeus herbstii* (the common mud crab), and *Eurypanopeus depressus* (the flat mud crab) (Table 2a,b).

### ***Dominant species***

#### *Petrolisthes armatus*

The green porcelain crab was the numerical dominant throughout the study and made up 58% of the total catch ( $30.23 \pm 3.34$  NPT) (Table 2a). They comprised more than half of the total catch on each of the natural reefs (82%, 52%, and 58% of the Tolomato natural reef, Guana natural reef, and Guana natural reef live oyster trays, respectively). *P. armatus* was most abundant on the Tolomato natural reef ( $86.13 \pm 11.23$  NPT) and least abundant on the artificial oyster habitat ( $8.08 \pm 0.90$  NPT).

#### *Panopeus herbstii*

The common mud crab was the second most abundant species ( $12.78 \pm 0.75$  NPT). Overall, there were fewer common mud crabs collected than the green porcelain crab; however, the common mud crab outnumbered the green porcelain crab in all of the artificial reef sites (Table 2a).

#### *Eurypanopeus depressus*

The third most dominant species was the flat mud crab ( $2.79 \pm 0.38$  NPT) which was primarily found in higher abundances on the natural oyster reefs compared to the other treatments (Table 2a). The most flat mud crabs were collected in the Guana reef live oyster trays ( $8.58 \pm 1.73$  NPT) and the fewest in the fiber log treatment ( $0.5 \pm 0.34$  NPT). There was no observed difference in flat mud crab abundance across the seasons.

### *Fishes*

A total of 305 fish from 12 different species were caught during this study. Fishes only contributed a small portion to the overall catch in the study (3.6%); however, there were trends in fish abundance associated with restored and unrestored habitats (Table 2b). The catch was primarily dominated by gobies: *G. bosc* ( $0.73 \pm 0.15$  NPT), *Ctenogobius boleosoma* (darter goby;  $0.50 \pm 0.10$  NPT), and *C. smaragdus* (emerald goby;  $0.17 \pm 0.05$  NPT), in order of respective abundance. The unstructured site had the highest number of fish species (nine), followed by the fiber log only (eight) and the artificial oyster reef (six). The live oyster trays on the Guana reef had only darter gobies. Only the darter goby was collected in all sampled habitats.

In 2014, there were four rare (less than 5 individuals) species: *Eucinostomus* sp. (mojarra), *Lutjanus synagris* (lane snapper), *Opsanus tau* (oyster toadfish), and *Symphurus plagiusa* (blackcheek tonguefish). These rare species were all caught in the fiber log only treatment except for the blackcheek tonguefish which was caught twice in the combination treatment. *Diplectrum* sp. (sand perch), *Lagodon rhomboides* (pinfish), *Leiostomus xanthurus* (spot), lane snapper, and *Menidia* sp. (silversides) were only found on the unstructured site.

Gobies were the only fishes collected on the natural reefs with the exception of one larval red snapper (*Lutjanus campechanus*) collected in the Guana natural reef trays in April 2015.

*Fundulus heteroclitus* (mummichog) and mangrove snapper were found on the artificial reefs

and unstructured site, however mummichog were more abundant in the unstructured site ( $0.26 \pm 0.21$  NPT). Both the lane and mangrove snappers were collected more often in the fiber log only treatment. No seasonal pattern in fish abundance was apparent.

***Objective 1: Compare abundance and diversity of benthic communities on the artificial reef to adjacent natural oyster reef and unstructured mud bottom sites.***

#### *Abundance and diversity*

There was a significant interaction effect between season and treatment on the combined dependent variables (abundance and diversity), Pillai's Trace  $F(12, 186) = 3.272$ ,  $p < 0.001$ . Two-factor (season and treatment) univariate ANOVAs on each response variable revealed only treatment to have an effect on diversity ( $F(2, 93) = 29.39$ ,  $p < 0.001$ ). Community diversity was highest at the artificial reef site and lowest on the Tolomato natural reef site, but did not differ by season (Figure 9, Table 3). Treatment effects on abundance were analyzed separately by season due to an interaction between season and treatment. Overall, abundance statistically differed between the treatments in every season (Fall  $F(2, 21) = 13.36$ ,  $p < 0.001$ ); Winter  $F(2, 6) = 20.121$ ,  $p < 0.05$ ; Spring  $F(2, 24) = 9.689$ ,  $p < 0.001$ ; Summer  $F(2, 42) = 13.032$ ,  $p < 0.001$ ). The natural reef had the highest abundance in every season (Figure 10 Table 4). A Kruskal-Wallis test revealed no difference in abundance or diversity between the three natural reef treatments (TNR, GNR, and GLNR).

#### *Community analyses*

Multivariate analysis revealed some differences in benthic communities between the treatments, with the natural reef trays grouping more closely to one another than the other treatments (stress=0.18) (Figure 11). Communities differed by season ( $r = 0.196$ ,  $p = 0.007$ ) and treatment ( $r = 0.134$ ,  $p = 0.003$ ). Pairwise comparisons of treatments showed only the natural reef and

artificial oyster reef communities to significantly differ ( $r = 0.274$ ,  $p = 0.002$ ). SIMPER analysis showed a 44% dissimilarity between the communities in these treatments primarily driven by higher abundances of *P. armatus* and *E. depressus* on the natural reef compared to the artificial reef site. The artificial site had more *Alpheus heterochaelis* (big-clawed snapping shrimp) than the natural reef. These three species contributed to 41% of the dissimilarity between the natural and artificial reef communities.

The communities in the winter were different from those in the fall ( $r = 0.699$ ,  $p = 0.006$ ). More *A. heterochaelis* and *P. herbstii* were collected in the fall and the presence of *Rithropanopeus harrisi* (the estuarine mud crab) and *Hexapanopeus augustifrons* (the smooth mud crab) in winter, contributed to the differences in community composition between the two seasons. Typically fewer numbers of every species were collected in the spring, which caused it to differ from the summer ( $r = 0.232$ ,  $p = 0.004$ ) and fall ( $r = 0.266$ ,  $p = 0.006$ ) communities.

#### *Elevation*

Settlement tray elevations were different among treatments ( $F(4, 10) = 12.186$ ,  $p < 0.001$ ). Post-hoc comparisons using the Tukey HSD test indicated that the mean elevation of the artificial reef trays was significantly lower than the mean of the natural reef trays except for the live oyster trays at the Guana reef. Trays at the unstructured mud bottom site were deployed at the lowest elevation, however it did not differ from the tray elevations on the artificial reef. Elevations did not differ among natural reef trays (Figure 12, Table 5).

#### ***Objective 2: Determining whether the type of artificial treatment affects the abundance and diversity of benthic macroorganisms.***

There were 4,718 specimens (189 fishes; 4,529 invertebrates) from 24 different species (9 fishes; 15 invertebrates) collected in 81 trays between all three artificial treatments and the two

unrestored sites used as a comparison during this period (combination reef, oyster bag artificial reef, fiber log reef, Tolomato natural oyster reef, and unstructured mud bottom) between June and December 2014.

### *Abundance and diversity*

The results of the two-factor (season and treatment) MANOVA on abundance and diversity for the treatments collected in 2014 were significant Wilks' lambda test:  $p < 0.05$  for all main effects). There was no effect of season on abundance, however diversity did differ by season ( $F(1, 78) = 5.881, p < 0.05$ ). Fall communities ( $1.07 \pm 0.05 H'$ ) were more diverse than summer communities ( $0.88 \pm 0.05 H'$ ).

Diversity and abundance differed by treatment ( $F(4, 75) = 11.088; F(4, 75) = 14.538$ , respectively,  $p < 0.001$ ). The natural reef had the highest overall abundance (Figure 13a; Table 6) and significantly differed from all the artificial treatments ( $p < 0.001$ ; fiber log only,  $p < 0.05$ ). The unstructured site was only higher than the artificial oyster and combination treatments ( $p < 0.05$ ). Although abundance was not statistically different between the artificial treatments, there were higher catches in the fiber log treatments. The artificial treatments were more diverse than the unstructured and natural reef sites (Figure 13b; Table 7). The unrestored sites had lower diversity than the artificial treatments. The natural reef had the lowest diversity.

### *Community analyses*

There were some differences in composition of the benthic communities between summer and fall, with all the sites in the fall grouping together and the artificial sites (CAR, FLAR, ORAR) more closely grouped together than the unrestored sites (UMB and TNR) in summer (stress=0.18) (Figure 14). Communities were significantly different from one another by season ( $r=0.159, p=0.003$ ) and treatment ( $r=0.204, p=0.002$ ). There was a low amount of dissimilarity in

the species composition between the summer and fall communities (39%), primarily driven by *G. bosc*, *P. armatus*, and *A. heterochaelis*, which contributed to 33% of the seasonal dissimilarity. All of these species were more abundant in the fall.

The species composition of the natural reef differed from all of the artificial sites ( $p < 0.05$ ). The communities on the artificial sites did not differ from one another and only the combination treatment was different from the unstructured site communities (Table 8). The natural reef communities were between 37-39% dissimilar to each of the communities within the artificial treatments. *P. armatus* was more abundant on the natural reef and contributed to the most amount of dissimilarity between the combination and artificial oyster treatments with the natural reef 21.38% and 18.34%, respectively. Additionally, more *G. bosc* were collected in the combination and artificial oyster treatments than the natural reef. *A. heterochaelis* contributed the most to the dissimilarity between the natural reef and the fiber log only treatment (14.33%), more were caught in the fiber log treatment. The dissimilarity between the combination reef and unstructured site communities were largely driven by more *P. armatus* and *A. heterochaelis* in the unstructured site.

***Objective 3: Identifying short-term (1 year) changes in benthic communities of the restored and unrestored sites.***

*Abundance and diversity*

Year and treatment were significant on the combined response variables (Pillai's Trace: year,  $p < 0.05$ ; treatment,  $p < 0.001$ ) with no significant interaction, therefore, separate ANOVAs were performed. Abundance did not differ between the two years, however it did between the treatments, Welch's  $F(2, 27.36) = 17.43$ ,  $p < 0.001$ . The artificial reef and unstructured site did not differ from each other, however they both had lower abundances than the natural reef ( $p <$

0.05). Diversity was different between the two years Welch's  $F(1, 40.67) = 8.82, p = 0.005$  with 2015 being much more diverse than 2014. Diversity was also statistically different between the treatments (Welch's  $F(2, 25.79) = 43.482, p < 0.001$ ) however, only the artificial reef and natural reef were significant as the artificial reef was much more diverse than the natural reef ( $p < 0.001$ ) (Figure 15).

### *Community analyses*

Multivariate analysis of the benthic communities in the summer of both 2014 and 2015 showed that the natural reef trays clustered together in both years, however no discernable pattern was observed in artificial reef or unstructured mud bottom treatments (stress=0.12) (Figure 16). The communities of both years were significantly different ( $r = 0.299, p = 0.01$ ) and were significantly different by treatment ( $r = 0.288, p = 0.011$ ). Pairwise comparisons of the treatments revealed the natural reef to differ from both the unstructured site ( $r = 0.336, p = 0.032$ ) and the artificial reef ( $r = 0.54, p = 0.008$ ), but there was no difference between the communities in the artificial reef and unstructured site.

The communities of both years were 48% dissimilar which was largely due to *R. harrisi*, *E. depressus*, and *P. armatus* (13, 13, and 10% contribution, respectively) which were in higher abundances in 2015. A rare species, *Dyspanopeus sayi* (Say's mud crab), was only present in 2014 and also made the communities in 2014 more different than 2015. The benthic communities of the three treatments were all between 45-47% dissimilar. Primarily, the presence of *D. sayi* in the unstructured site contributed to the dissimilarity of this treatment from either of the other sites. High abundance of *A. heterochaelis* in the artificial reef largely resulted in this community being different from the natural reef. *P. armatus* was in the highest abundance in the

natural reef and as such contributed the most to the dissimilarity of this site from the unstructured site and the artificial reef.

***Objective 5: Describing relationships between environmental factors (temperature and salinity) and the abundance and diversity of benthic macroorganisms.***

Temperature positively correlated with abundance and diversity (Table 9). The average, maximum, and minimum temperature 48 hours prior to each collection significantly correlated with the abundance and diversity that day (Figure 17). There appeared to be no relationship between the salinity and either of the response variables.



## 1.5 DISCUSSION

The intertidal benthic communities along the Tolomato River were characterized by a few abundant species typically found on temperate oyster reefs (Posey et al. 1999, Meyer 1994, Breitburg 1999, Coen et al. 1999a, b). Created living shorelines supported more diverse benthic communities than adjacent natural reefs and unstructured mud bottom. Overall abundance was highest on the natural reefs, driven by dominance of a single, invasive species. All artificial treatments had similar abundances and diversities suggesting that overall, individual and combined living shoreline treatments provided similar habitat quality. Constructed oyster reefs created immediate habitat for resident species as well as enhanced habitat value compared to unstructured mud bottom, particularly for fish species. After a year, there were higher abundances and greater diversity across all treatments, and the catch, diversity, and community composition of the restored and natural reefs remained different. Results also indicated that temperature and elevation may be important environmental factors for structuring communities in these intertidal habitats.

Crabs were the dominant group collected within the trays across all seasons, similar to previous studies in Southwest Florida (Tolley and Volety 2005). *P. armatus*, *P. herbstii* and *E. depressus* were the three dominant species in this study and also made up the largest portion of adult specimens collected during the decadal crab survey previously conducted within the GTM NERR, approximately 44 km south of the restoration site (Eash-Loucks et al. 2014). Mean species abundance also resembled values seen in the decadal survey, with the exception of *P. armatus* which was observed at higher numbers ( $36.10 \pm 4.78$  NPT) than what was seen towards the end of the decadal study (summer 2012,  $7.9 \pm 2.7$  NPT). This may suggest population growth of this species. Even the highest abundance, observed in the summer of 2003 ( $29.4 \pm 8.3$  NPT),

was lower than the catch seen in this study. Another possible difference may be due to the different geographic location of the previous study which was along the Matanzas River in the southern portion of the GTM NERR south of St. Augustine, Florida, U.S.A. Eash-Loucks et al. (2012) also deployed their trays subtidally on natural oyster reefs; however, their trays were only exposed during extreme low tides. Abundances of *P. armatus* did not reach densities as high as thousands of crabs m<sup>-2</sup>, which have previously been documented in South Carolina and Georgia estuaries (Hollebone and Hay 2007).

Elevated community diversity of the restored site compared to the unstructured site was similar to expectations based on previous studies (Harding and Mann 2001; Rodney and Paynter 2006; Humphries et al. 2011; Humphries and La Peyre 2015). The high abundance found in unstructured site and low abundances in the artificial reef site could be attributed to the fact that settlement trays were the only form of habitat in the unstructured site while artificial oyster reefs were present in addition to settlement trays in the restored site. Therefore, species abundance may have been overestimated in the unstructured site. Having some structure versus none, in the case of the unstructured site, may increase the value of the habitat (Geraldi et al. 2009; Humphries et al. 2011).

The patterns of high abundance and low diversity on the natural reef sites in the Tolomato and Guana Rivers were, however, not anticipated. Restored sites were expected to support similar densities and abundances as the natural reef, when in fact, the restored site had greater diversity than the natural reef even though there was a lower overall abundance. This was due to the large number of *P. armatus* at the natural reef site. Similarly, in southwest Florida, xanthid crab densities on restored reefs were similar to those on natural oyster reefs, but *P. armatus* densities were lower on restored reefs (Milbrandt et al. 2015).

Patterns among sites did not change after a year of the establishment of the restoration site. The artificial reef still had the highest diversity and lowest abundance while the community on the natural reef was still dominated by *P. armatus*. It was expected that the artificial site would resemble the natural reef after a year. Pierson and Eggleston (2014) found that fish abundance on recently created reefs resembled natural reefs after 6-8 months of the installation. It is likely that more time may be required before the benthic communities on restored sites are no longer as different as those on adjacent natural reefs. Unlike nekton, which can easily move from one habitat to the next within a smaller timeframe, members of the benthic community, such as the xanthid mud crabs, are much smaller and utilize reefs for their structure as refuge. These species may be less likely to seek out additional habitat or even distant reefs from their own; therefore, colonization of these alternative sites may be primarily driven by larval recruitment.

Elevation may also play a role in driving the changes seen in catch and diversity between the artificial and natural oyster reefs. All of the trays deployed on the natural reefs were at higher elevations than the trays on the restoration site (by about 0.2 m) because the created reefs were established at lower elevations initially. All of the natural reef sites also had the highest abundances of *P. armatus*. However, *P. armatus* has been observed at higher densities in low intertidal compared to high intertidal habitats (Hollebone and Hay 2007). It is also possible that higher abundances of *P. herbstii* on the artificial reef displaced *P. armatus* into adjacent habitats. *P. herbstii* have been observed to prey upon *P. armatus*, although this does not occur universally (Hollebone and Hay 2008; Pintor and Byers 2015).

Seasonally, abundance of *P. armatus* was highest during the summer of both years. In their native range, they thrive in water temperatures between 16 to 29°C (Oliveira and Masunari 1995), which are within the range of temperatures observed during summer months in northeast

Florida. Eash-Loucks et al. (2012) found that although environmental parameters (temperature and salinity) did not have a significant impact on the overall crab community composition, *P. armatus* did decline with decreasing temperatures. Similar patterns were observed in estuaries on the Georgia coast, U.S.A. (Hollebone and Hay 2008).

*E. depressus* was most abundant on the natural reef sites, especially in the live oyster trays on the Guana natural reef. They have been found to prefer shell (cleaned clusters) and live clusters rather than sand bottom (Tolley and Volety 2005). This species is an omnivore that preys on juvenile oysters and, despite the availability of oyster shell substrate and suitable prey, they are typically not found until new oyster clusters have developed on created reefs (Meyer 1994; Meyer and Townshend 2000). This suggests that they prioritize structure and the presence of recruiting oyster larvae on reefs when colonizing new habitat and some time may be required before natural densities are found on created habitats. As such, *E. depressus* may serve as a good indicator species of quality habitat for restored oyster reef projects.

Tolley and Volety (2005) suggest that habitat for resident fishes and decapod crustaceans is dependent upon the presence of three-dimensional space; however in this study no significant difference was found between catch and diversity of the live oyster trays and the other natural reef trays with shells for most species. Three-dimensional space was not measured in either tray type, therefore the value of interstitial space within the area cannot be supported in this study. Sampling the live oyster trays was difficult. Sometimes organisms, such as *P. armatus*, crawled into the interstices of the live oyster clumps and were unable to be collected without destroying the oyster. The inability to collect all organisms may mean that the variables collected for the live oyster trays are underestimating what would be present within those trays. On the last

collection of the live oyster trays the clumps were broken up, but this did not increase catch numbers.

Patterns in abundance and diversity across the seasons may have been influenced by the degradation of the fiber log restoration treatments and subsequent installation of a new artificial treatment in the spring of 2015. This new treatment consisted of mesh bags filled with oyster shells stacked onto fiber mats where the fiber logs were originally placed. The fiber logs were found to degrade over time, primarily as a result of high wake energy in this system, which is adjacent to Florida's Intracoastal Waterway (APPENDIX I).

Although the artificial treatments appeared to not significantly differ from one another in terms of overall abundance and diversity, more fish species were collected within sites that had fiber logs. During the course of the study, many collections were made while the trays were exposed potentially affecting presence of fish and leading to variable fish catch. It is also possible that the trays were deployed too high in the intertidal for fish utilization in all treatments. Regardless, more fish were collected within areas that had a living shoreline treatment placed in the upper intertidal zone, suggesting that habitat in the upper intertidal may provide fish with refuge during high tide. This is contrary to a study by Lehnert and Allen (2002) in an estuary near Georgetown, South Carolina, U.S.A., which found typically more fishes of all species captured in trays placed in subtidal areas over intertidal sites. In northeast Florida, there are no subtidal oyster reefs such as in South Carolina. Therefore, fish may be found in intertidal habitats more often than subtidal due to the presence of intertidal three-dimensional structure. This suggests that intertidal structure may be particularly important for providing habitat for fishes in this region.

Blennies and gobies are common inhabitants of oyster reefs (Humphries et al. 2011, Breitburg 1999; Lehnert and Allen 2002), yet no blennies were collected in this study. This may have been a function of the sampling gear and lack of complex three-dimensional structure within the trays, although Kulmann (1998) found that blennies prefer shells with unfouled interiors for spawning. It is possible that over-fouling of the oyster shells in the trays may have occurred and resulted in blennies seeking alternative refuge. Larval gobies and blennies have been found to dominate summer ichthyoplankton in systems with oyster reefs such as the Chesapeake Bay (Breitburg 1999), but they have not been found in high densities as ichthyoplankton within this system (Korsman 2013). This suggests that blennies may not be naturally abundant within this region.

Naked gobies were the dominant fish during both years. They are the numerical dominant in temperate oyster reef habitats and have been found in densities ranging from 18 to 20 individuals per 0.42 m<sup>2</sup> using shell-filled trays deployed subtidally in Inlet Creek, South Carolina (Giotta 1999). Coen (2002) reported mean densities of 4 to 9 individuals/m on natural oyster reefs in intertidal areas of Inlet Creek, which is more similar to the results from this study. It is likely that fish either darted off during collections or preferred nearby structure to what was provided within the substrate trays.

Many previous oyster reef community studies, such as those conducted in the Chesapeake Bay (Breitburg 1999), sampled on subtidal oyster reefs. This study provides useful information from intertidal reefs in one of the six ecoregions that support commercial harvesting of oyster in which abundances are declining (Beck et al. 2011). Previous studies in the area suggest changes in salinity as well as increases in the abundance of carnivorous conchs have contributed to oyster reef deterioration in the Matanzas estuary (Garland and Kimbro 2015).

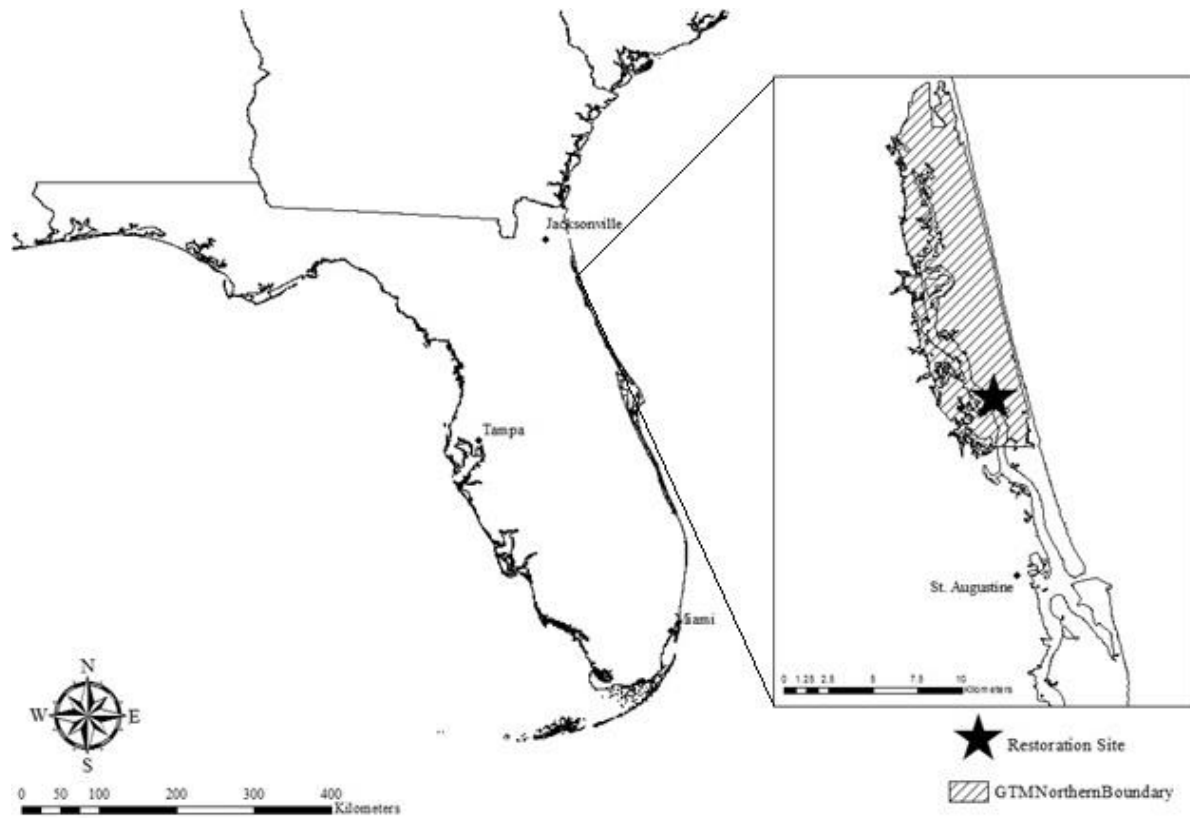
Some previous studies, such as Tolley and Volety (2005), used active sampling gear (i.e., lift nets) to assess the relative use of oyster reefs by fishes and crustaceans. Lift nets provide a more complete sampling of the communities on reefs compared to passive gear like traps or trays since lift nets sample larger areas (even entire sections of patch reefs) and collect everything present at a particular time. Consequently, methods like the lift net also require more effort than passive methods. Using substrate trays provided the opportunity to allow species to settle into the habitat within the trays; however, more mobile species could have left the trays during collections. Substrate trays may target specific groups of organisms, so future studies should address their catch efficiency.

Based on the results of this study, it is likely that elevation within the intertidal zone may play an important role in structuring the benthic communities on restored reefs. Although the role of elevation may be difficult to detect in this study, due to the lack of replication, this is one of the first studies to examine elevational community differences within the intertidal zone. The restoration project in the GTM NERR was installed along the low intertidal zone with no specific species intended as a target for colonization and habitat use. This was a small scale restoration project specifically intended upon mitigating shoreline loss as well as serving as a demonstration site for education and technique. Funding constrained the ability to replicate treatments. However, if elevation is a factor in community structure, this type of information may prove useful for future restoration projects, particularly those designed for habitat enhancement. Future plans include directly addressing the role of elevation on the success of oyster reef construction, examining population structure and size distributions of dominant species, as well as fish utilization of intertidal habitats.

## 1.6 ACKNOWLEDGMENTS

We would like to thank our funding sources: the Atlantic Coastal Fish Habitat Partnership, the Friends of the GTM Research Reserve, and University of North Florida's Coastal Biology Flagship program. Thank you to Drs. Eric Johnson and Nicole Dix who provided guidance in the field, the statistics, and kept our research focus in line with our goals. We could not have done our project without the help of our undergraduates in the Smith Lab at UNF, volunteers of the GTM Reserve, nor the wonderful staff at GTM Reserve. We would especially like to thank Nadja Capps, Brian Alexander, Jen Raabe, Robert Trey Fraley, Marisa Beasley, John Whiting and Sara River Dixon for help in the field collections and identifications of the crab species. Many, many hours were spent sitting at microscopes trying to tell the difference between the various xanthid mud crabs. Lastly, we could not have made many of our natural reef collections without Jason Lynn. Not only did he help us in our collections, but he continuously fixed our boat so that we could be out on the water. All collections were made with approval of the University of North Florida's Institutional Animal Care and Use Committee (IA# 14-003) and under Florida Fish and Wildlife Conservation Commission Special Activity License (SAL-11-1305B-SR).

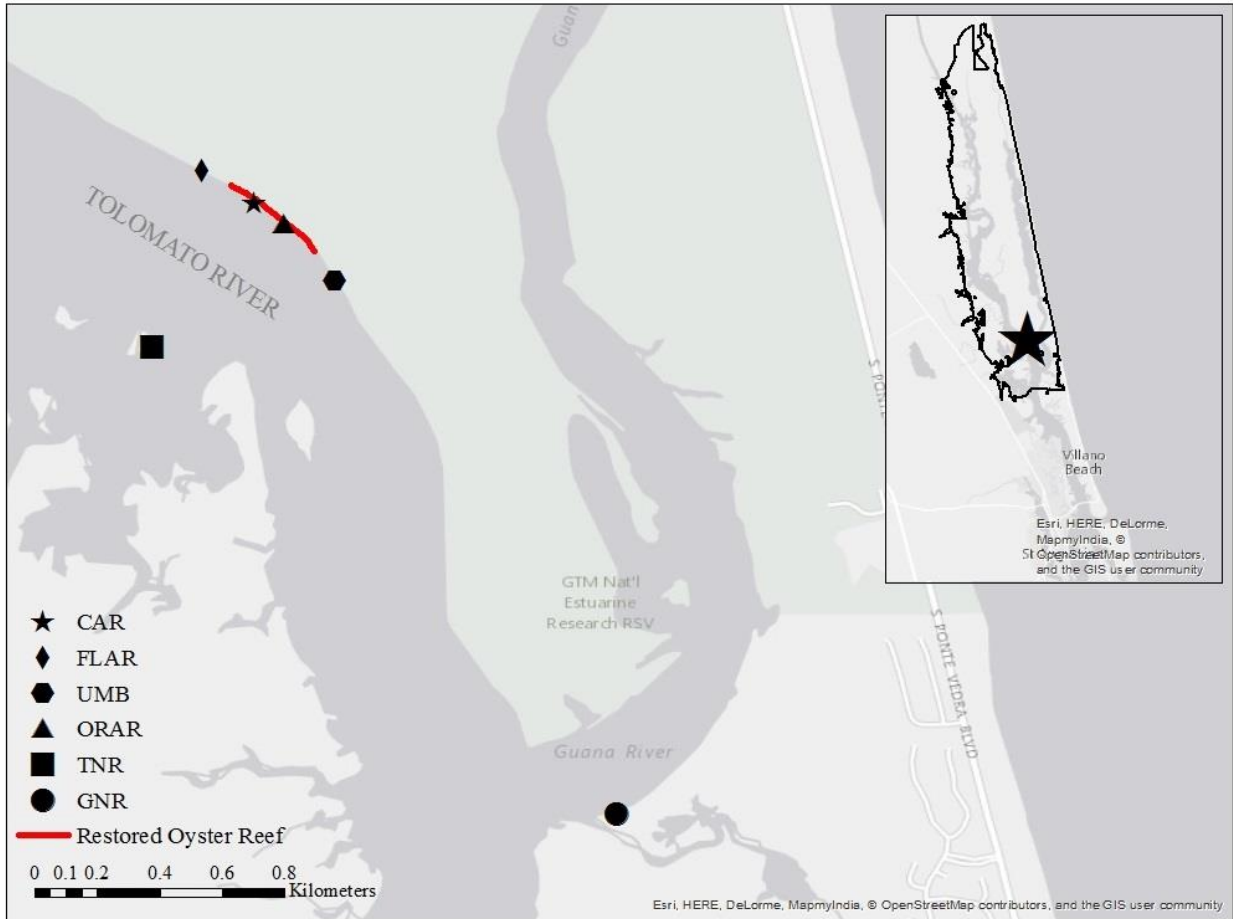




**Figure 1-1** Location map of the study site in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Hatched section represents the northern GTM NERR boundary. Star indicates Wright's Landing, the site of the living shoreline restoration project.



**Figure 1-2** Deployed fiber (coir) logs along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W) Florida, U.S.A. These logs were installed approximately 5 m from the existing *Spartina* marsh edge in the high intertidal zone. Logs were placed in 20-m arcs both behind constructed oyster reefs (pictured), and alone, along eroding shoreline.



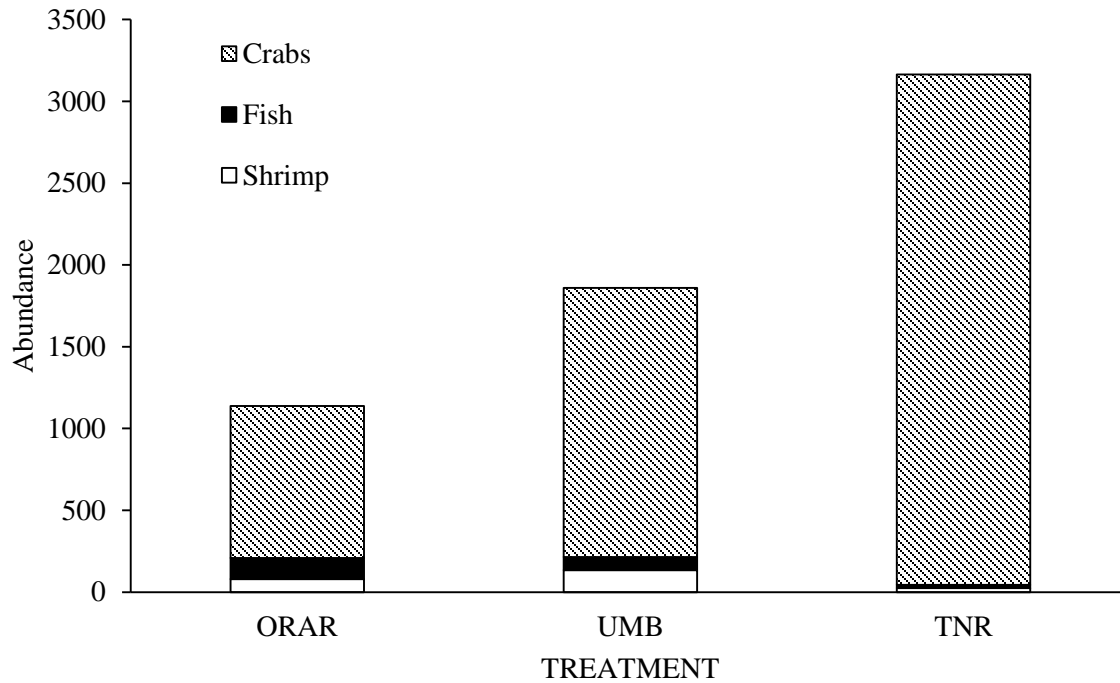
**Figure 1-3** Map of the tray locations along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Four of the tray treatments were within or adjacent to the restored oyster reef along Wright's Landing (indicated in red). ORAR, artificial oyster reef only; FLAR, fiber log only treatment; CAR, combination of fiber log and artificial oyster reef; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River; GNR, natural reef in the Guana River, this site contained both shell trays as well as trays with live oyster.



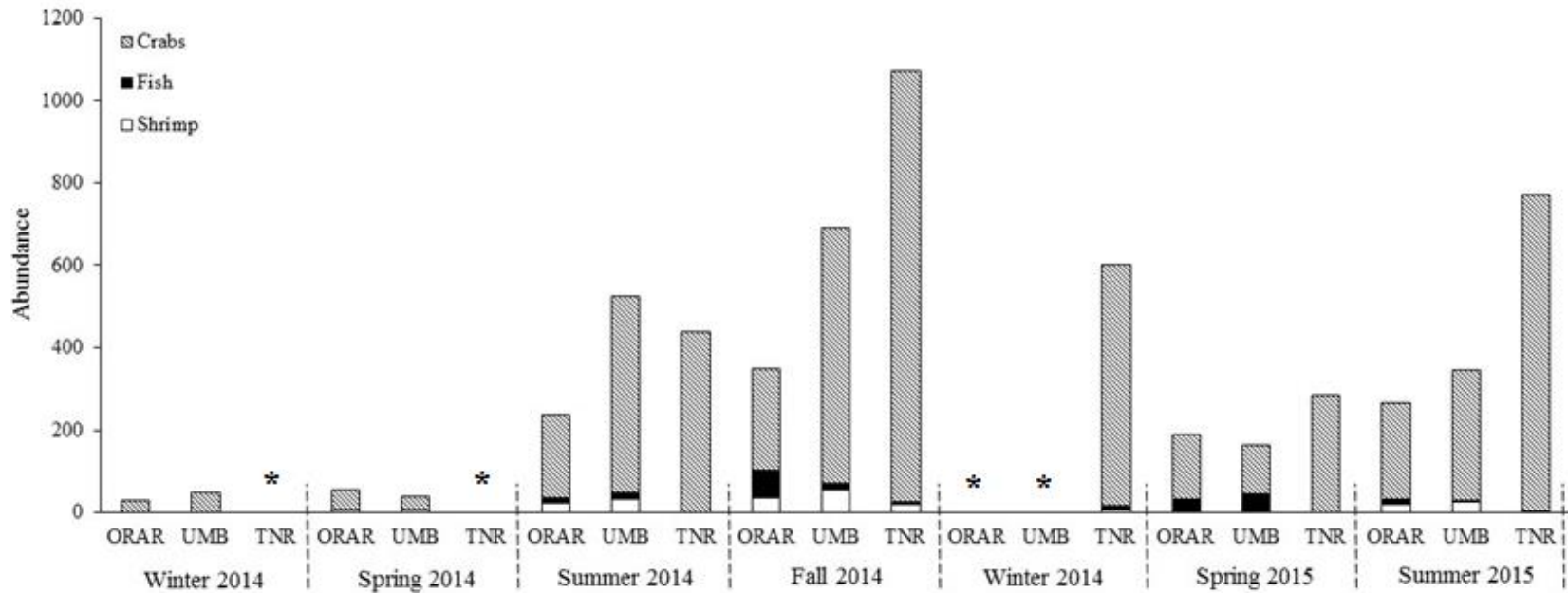
**Figure 1-4** Deployed plastic settlement tray behind one section of the artificial reef installed along the Guana Peninsula in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Trays contained one layer of oyster shell (*Crassostrea virginica*) as well as four bricks for stabilization. They were deployed behind reefs (natural and artificial) as well as 3 m in front of fiber logs and at approximately the same elevation within an unstructured site.

**Table 1-1** Benthic settlement trays summary of effort. This table includes deployment month, deployment completion, months collections were not made, and mean elevation (m) ± standard error. In some cases these omissions were due to deployment delays to avoid conflicts with restoration efforts, or due to collection days due to poor weather. FLAR and CAR were removed prior to elevation equipment became available, therefore elevations were not taken for those trays. Elevation measurements were collected for each tray in May 2015 using an EPOCH 50 GNSS System connected to the Mayport CORS (Continuously Operating Reference Station) by cell phone signal to correct the elevation to centimeter accuracy. Elevations were measured in U.S. Survey Feet and converted to meters afterwards for analysis. Other sites for comparison include unrestored eroding shoreline (UMB), Natural reef habitats (TNR, GNR, and GLNR). GNR was added to NR as a natural “target” site due to concerns that the original TNR site along the Tolomato River might not be representative of other natural reefs. GLNR was added to see if live oyster in the tray would impact fish recruitment to settlement trays.

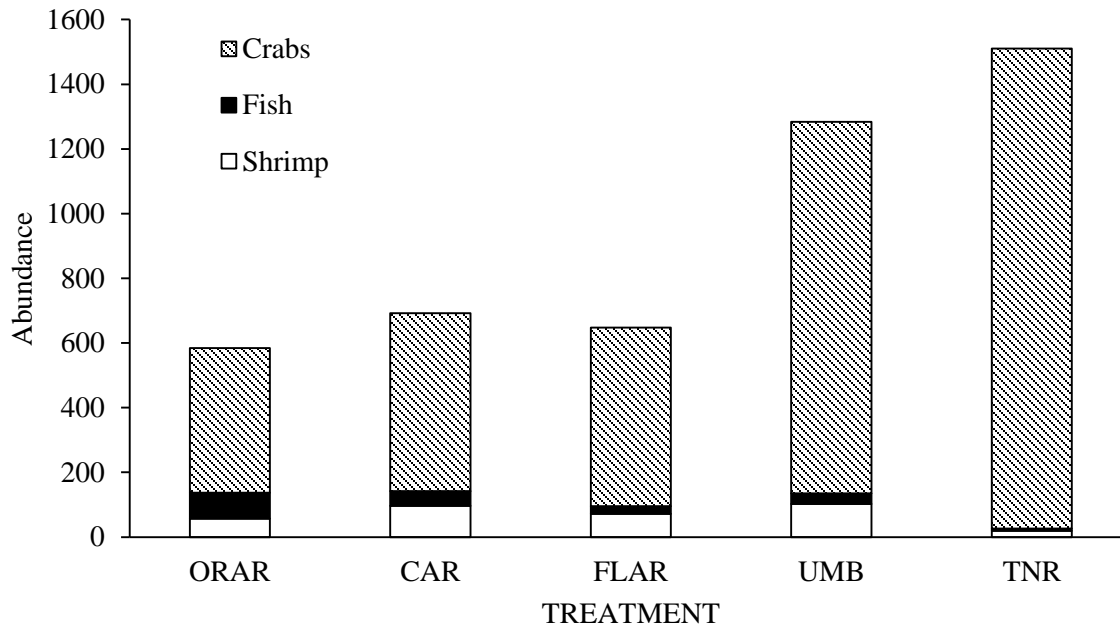
Treatments	Abbrev.	Mean Elevation (m) ± SE	Deployment	Collections missed
Oyster only artificial reef	ORAR	-0.51 ± 0.02	Nov 2013-Jul 2015	Feb 2013, April-May 2014, Dec 2014, Jan-Feb 2015
Combination of artificial oyster and fiber logs	CAR	--	May-Nov 2014	
Fiber log only	FLAR	--	Jul-Nov 2014	
Tolomato River natural reef	TNR	-0.57 ± 0.01	May 2014-Jul 2015	Aug 2014, May 2015
Unstructured mud bottom	UMB	-0.34 ± 0.02	Dec 2013-Jul 2015	Feb 2013, April-May 2014, Dec 2014, Jan-Feb 2015
Guana River natural reef	GNR	-0.33 ± 0.04	Feb 2015-Jul 2015	May 2015
Guana River natural reef with live oyster	GLNR	-0.38 ± 0.04	Feb 2015-Jul 2015	May 2015



**Figure 1-5** Composition of the total abundance of all species collected within restored and unrestored intertidal habitats in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Three trays were deployed in each treatment and sampled on a monthly basis between January 2014 and July 2015. . ORAR, artificial oyster reef; UMB, unstructured mud bottom habitat approximately 50-m south along the same shoreline from the artificial reef; and TNR, natural reef 0.54 km across the Tolomato River from the restored site.

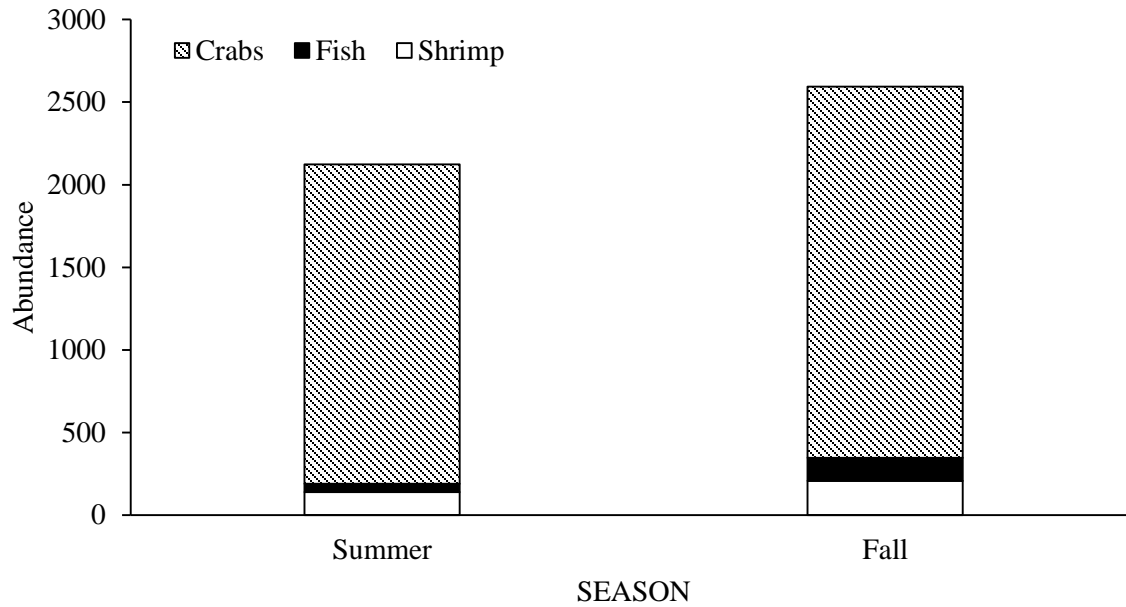


**Figure 1-6** Composition of the total abundance (NPT) of all species collected within restored and unrestored intertidal habitats by season in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Three trays were deployed in each treatment and sampled on a monthly basis between January 2014 and July 2015. ORAR, artificial oyster reef; UMB, unstructured mud bottom habitat approximately 50 m south along the same shoreline from the artificial reef; and TNR, natural reef 0.54 km across the Tolomato River from the restored site. There were variable numbers of trays collected within each season. Asterisks represent treatments not sampled.



**Figure 1-7** Composition of the total abundance of all species collected within restored and unrestored intertidal habitats in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Three trays were deployed in each treatment and sampled on a monthly basis between July and November 2014. Total catch by treatment was divided up into crab, fish and shrimp species. ORAR, artificial oyster reef only (n=18); CAR, combination of artificial oyster and fiber log (n=18); FLAR, fiber log only (n=12); UMB, unstructured mud bottom habitat approximately 50-m south along the same shoreline from the artificial reef (n=18); and TNR, natural reef across the Tolomato River from the restored site (0.54-km) (n=15).





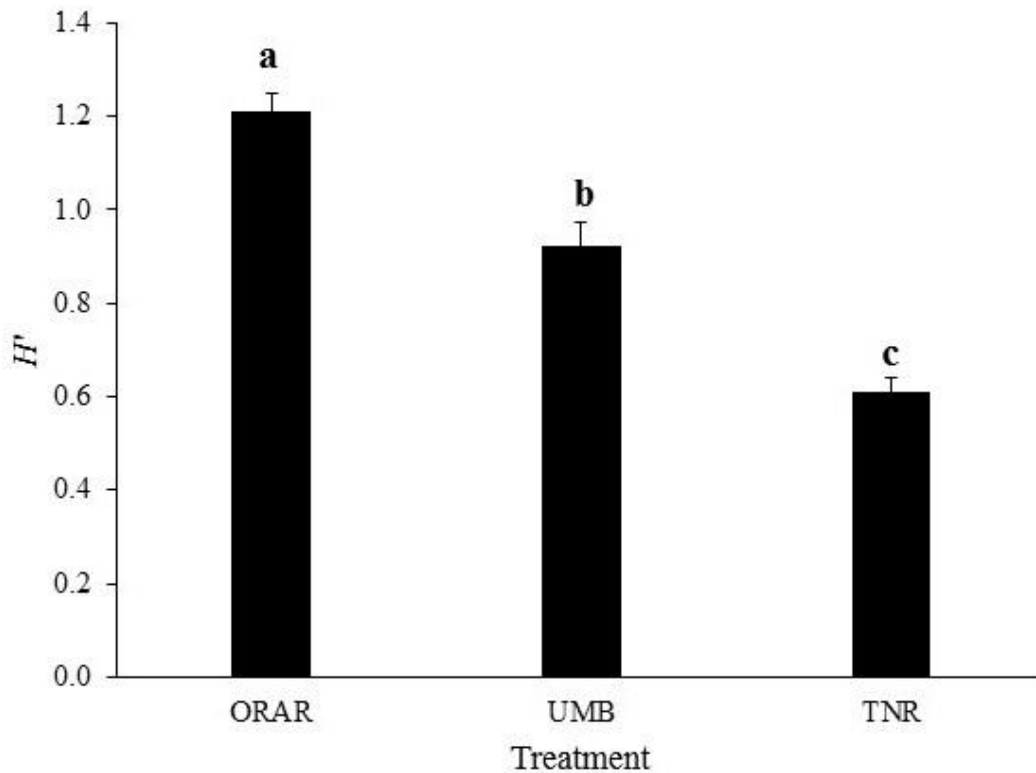
**Figure 1-8** Composition of the total abundance of all species collected within restored and unrestored intertidal habitats by season in the Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. Three trays were deployed in each treatment and sampled on a monthly basis between July and November 2014. Total catch by treatment was divided up into crab, fish and shrimp species. ORAR, artificial oyster reef only; CAR, combination of artificial oyster and fiber log; FLAR, fiber log only; UMB, unstructured mud bottom habitat approximately 50-m south along the same shoreline from the artificial reef; and TNR, natural reef across the Tolomato River from the restored site (0.54-km). Summer (n=39) and Fall (n=42).

**Table 1-2a:** Mean abundance (ind. tray<sup>-1</sup>, NPT ± standard error) of all invertebrates by treatment collected in settlement trays along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef only (n=39); FLAR, fiber log only treatment (n=18); CAR, combination of fiber log and artificial oyster reef (n=12); UMB, unstructured mud bottom (n=38); TNR, natural reef adjacent to restoration site in Tolomato River (n=30); GNR, natural reef in the Guana River (n=12); GLNR, natural reef in the Guana River with live oyster (n=12). FLAR and CAR were only sampled between June and November 2014. GNR and GLNR were added in February 2015.

Species	TREATMENT						
	ORAR	FLAR	CAR	UMB	TNR	GNR	GLNR
<i>Alpheus heterochaelis</i>	2.03 ± 0.37	6.00 ± 1.77	4.94 ± 1.25	3.39 ± 0.68	0.80 ± 0.32	0	0
<i>Callinectes sapidus</i>	0	0	0	0.21 ± 0.08	0	0	0
<i>Callinectes similis</i>	0	0.08 ± 0.08	0	0.13 ± 0.08	0	0	0
<i>Callinectes sp.</i>	0	0	0	0.03 ± 0.03	0	0	0
<i>Charybdis hellerii</i>	0	0	0	0.03 ± 0.03	0	0	0
<i>Dyspanopeus sayi</i>	0.33 ± 0.17	0	0	0	0.03 ± 0.03	0	0
<i>Eurypanopeus depressus</i>	1.49 ± 0.35	0.50 ± 0.34	0.61 ± 0.20	1.66 ± 0.54	5.90 ± 1.36	2.83 ± 1.01	8.58 ± 1.73
<i>Farfantepenaeus aztecus</i>	0.03 ± 0.03	0	0	0.11 ± 0.06	0	0	1.33 ± 1.33
<i>Farfantepenaeus duorarum</i>	0	0	0	0	0	0	0.25 ± 0.25
<i>Hexapanopeus augustifrons</i>	1.25 ± 0.43	0	0.89 ± 0.50	2.00 ± 0.65	0	0	0
<i>Litopenaeus setiferus</i>	0	0	0.39 ± 0.14	0.05 ± 0.05	0	0	1.00 ± 1.00
<i>Menippe mercenaria</i>	0	0.08 ± 0.08	0	0.11 ± 0.05	0	0	0
<i>Pachygrapsus transversus</i>	0.10 ± 0.06	0	0	0	0.03 ± 0.03	0.08 ± 0.08	0
<i>Panopeus herbstii</i>	12.44 ± 1.40	23.92 ± 3.27	16.44 ± 2.71	12.95 ± 1.49	10.57 ± 1.07	9.67 ± 2.71	6.50 ± 1.78
<i>Panopeus occidentalis</i>	0.05 ± 0.05	0	0	0	0	0	0
<i>Panopeus sp.</i>	0.33 ± 0.17	0	0	0.08 ± 0.06	0.03 ± 0.03	0	0
<i>Petrolisthes armatus</i>	8.08 ± 0.90	21.50 ± 3.37	12.44 ± 2.38	26.29 ± 5.47	86.13 ± 11.23	17.83 ± 6.06	25.25 ± 6.99
<i>Rhithropanopeus harrisi</i>	0.26 ± 0.14	0	0	0.53 ± 0.45	1.30 ± 0.80	2.92 ± 1.45	0.83 ± 0.58
<i>Uca minax</i>	0	0	0.06 ± 0.06	0	0	0	0
<i>Uca pugnax</i>	0	0	0.06 ± 0.06	0	0	0	0
<i>Uca sp.</i>	0	0	0.06 ± 0.06	0	0	0.17 ± 0.17	0

**Table 1-2b:** Mean abundance (ind. tray<sup>-1</sup> ± standard error) by treatment of all fish species collected in plastic settlement trays (0.516 m<sup>2</sup>) along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef only (n=39); FLAR, fiber log only treatment (n=18); CAR, combination of fiber log and artificial oyster reef (n=12); UMB, unstructured mud bottom (n=38); TNR, natural reef adjacent to restoration site in Tolomato River (n=30); GNR, natural reef in the Guana River (n=12); GLNR, natural reef in the Guana River with live oyster (n=12) . FLAR and CAR were only sampled between June and November 2014. GNR and GLNR were added in February 2015.

Species	TREATMENT						
	ORAR	FLAR	CAR	UMB	TNR	GNR	GLNR
<i>Bathygobius soporator</i>	0.21 ± 0.10	0.33 ± 0.19	0	0	0.10 ± 0.07	0	0
<i>Ctenogobius boleosoma</i>	0.79 ± 0.20	0.42 ± 0.26	0.28 ± 0.11	0.76 ± 0.31	0.10 ± 0.07	0.58 ± 0.34	0.08 ± 0.08
<i>Ctenogobius smaragdus</i>	0.62 ± 0.19	0	0.11 ± 0.11	0	0.07 ± 0.05	0	0
<i>Diplectrum sp.</i>	0	0	0	0.05 ± 0.05	0	0	0
<i>Eucinostomus sp.</i>	0	0.08 ± 0.08	0	0	0	0	0
<i>Fundulus heteroclitus</i>	0.23 ± 0.11	0.08 ± 0.08	0	0.26 ± 0.21	0	0	0
<i>Gobiosoma bosc</i>	1.38 ± 0.45	0.08 ± 0.08	2.00 ± 0.72	0.39 ± 0.17	0.40 ± 0.16	0	0
<i>Lagodon rhomboides</i>	0	0	0	0.29 ± 0.29	0	0	0
<i>Leiostomus xanthurus</i>	0	0	0	0.11 ± 0.08	0	0	0
<i>Lutjanus campechanus</i>	0	0	0	0	0	0.08 ± 0.08	0
<i>Lutjanus griseus</i>	0.05 ± 0.05	0.75 ± 0.30	0.06 ± 0.06	0.13 ± 0.06	0	0	0
<i>Lutjanus synagris</i>	0	0.08 ± 0.08	0	0.05 ± 0.04	0	0	0
<i>Menidia sp.</i>	0	0	0	0.07 ± 0.04	0	0	0
<i>Opsanus tau</i>	0	0.08 ± 0.08	0	0	0	0	0
<i>Symphurus plagiusa</i>	0	0	0.11 ± 0.08	0	0	0	0

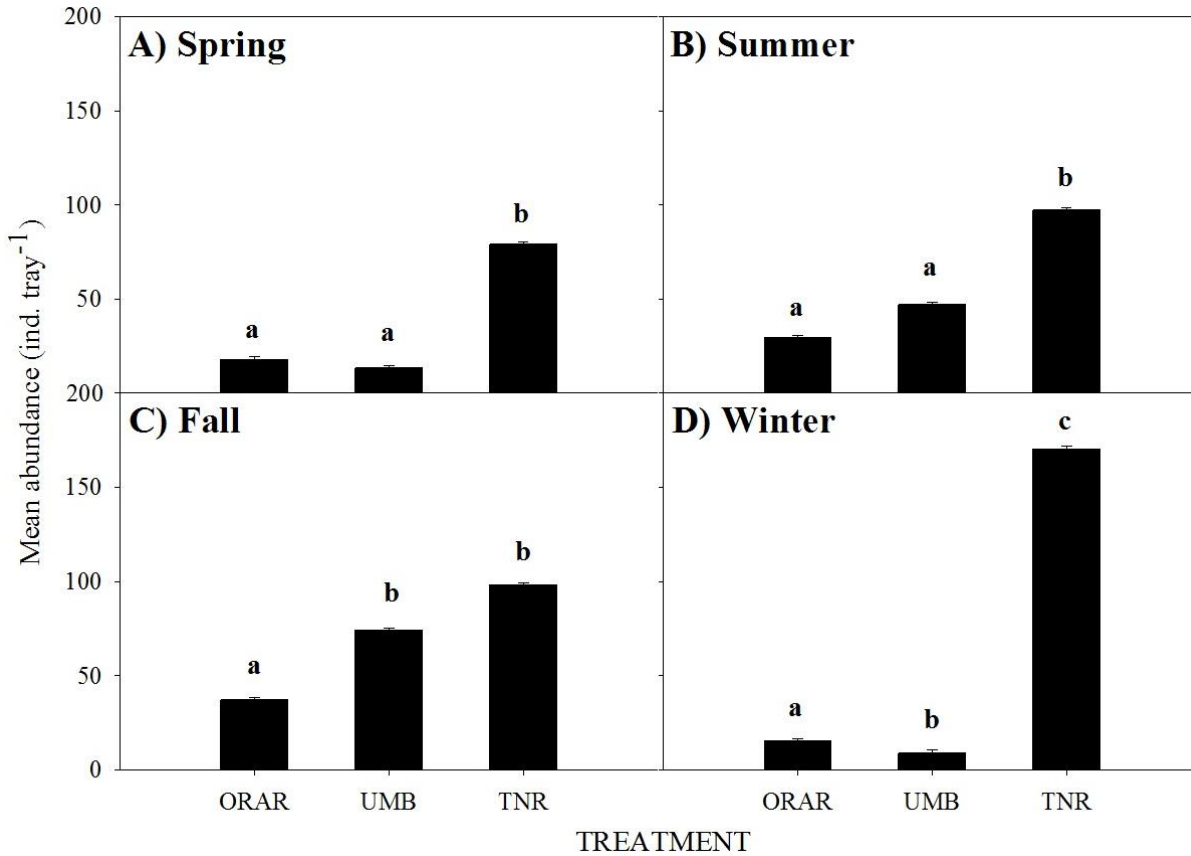


**Figure 1-9** Shannon-Wiener diversity index ( $H'$ ) for settlement trays collected within restored and unrestored habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef; UMB, unstructured mud bottom habitat approximately (distance) south along the same shoreline from the artificial reef; TNR, natural reef across the Tolomato River from the restored site (0.54-km). Each treatment had 39 trays except for TNR (n=27). Significance levels presented as letters above bars are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

**Table 1-3** Summary of means, standard errors and mean differences of the Shannon-Wiener diversity index ( $H'$ ) for settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

Treatment	$n$	Mean $H'$	SE	Mean Differences ( $\bar{X}_i - \bar{X}_j$ )		
				ORAR	UMB	TNR
ORAR	39	1.21	0.04	--		
UMB	39	0.92	0.05	0.29***	--	
TNR	27	0.61	0.03	0.6***	0.31***	--

\*\*\*  $p < 0.001$

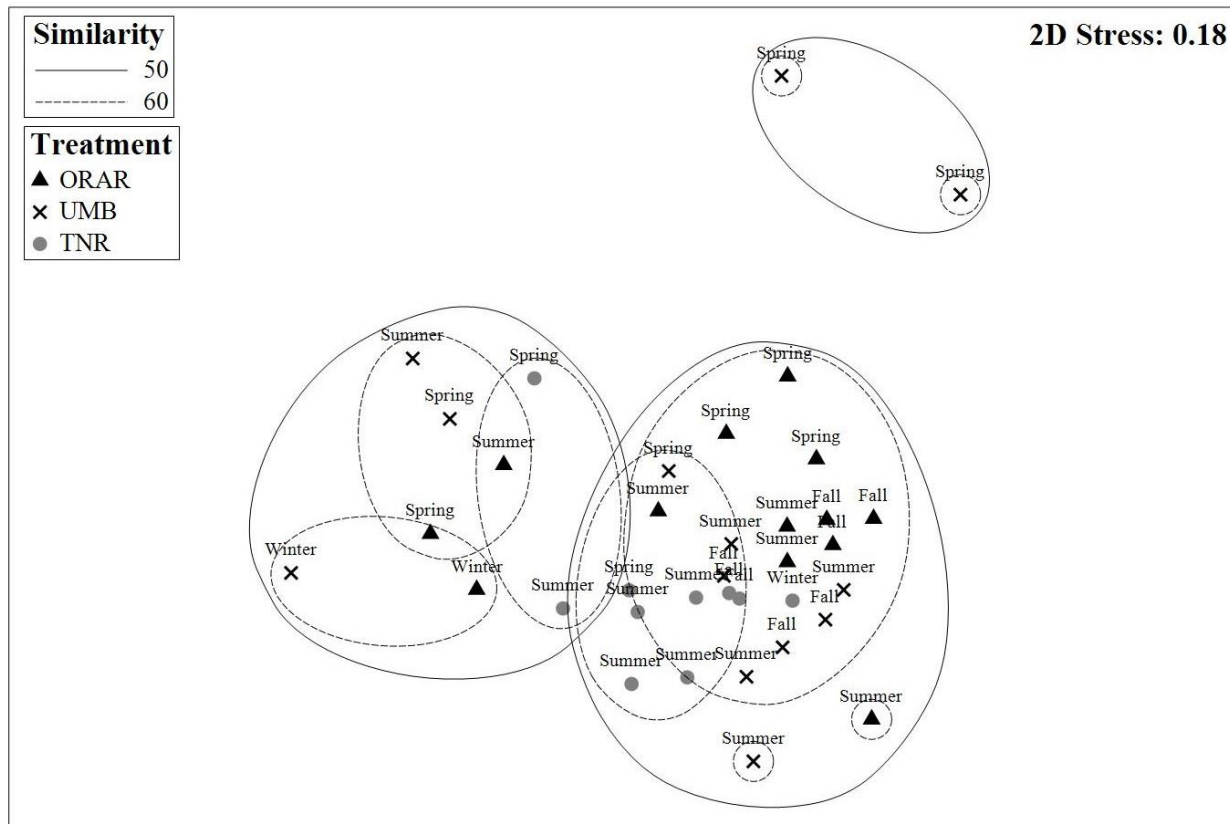


**Figure 1-10:** Mean abundance (ind. tray<sup>-1</sup>) for plastic settlement trays collected within restored and unrestored habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015 across four seasons: A) Spring, B) Summer, C) Fall, and D) Winter. ORAR, artificial oyster reef ; UMB, unstructured mud bottom habitat approximately (distance) south along the same shoreline from the artificial reef; TNR, natural reef across the Tolomato River from the restored site (0.54-km). Each treatment in the spring had 12 trays except for TNR (n=3). All treatments had 15 trays in the summer and three in the winter. There were nine trays in each treatment in fall, except TNR (n=6). Significance levels presented as letters above bars are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

**Table 1-4** Summary of back transformed means, standard errors and mean differences of abundance (ind. tray<sup>-1</sup>) for plastic settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between January 2014 and July 2015. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

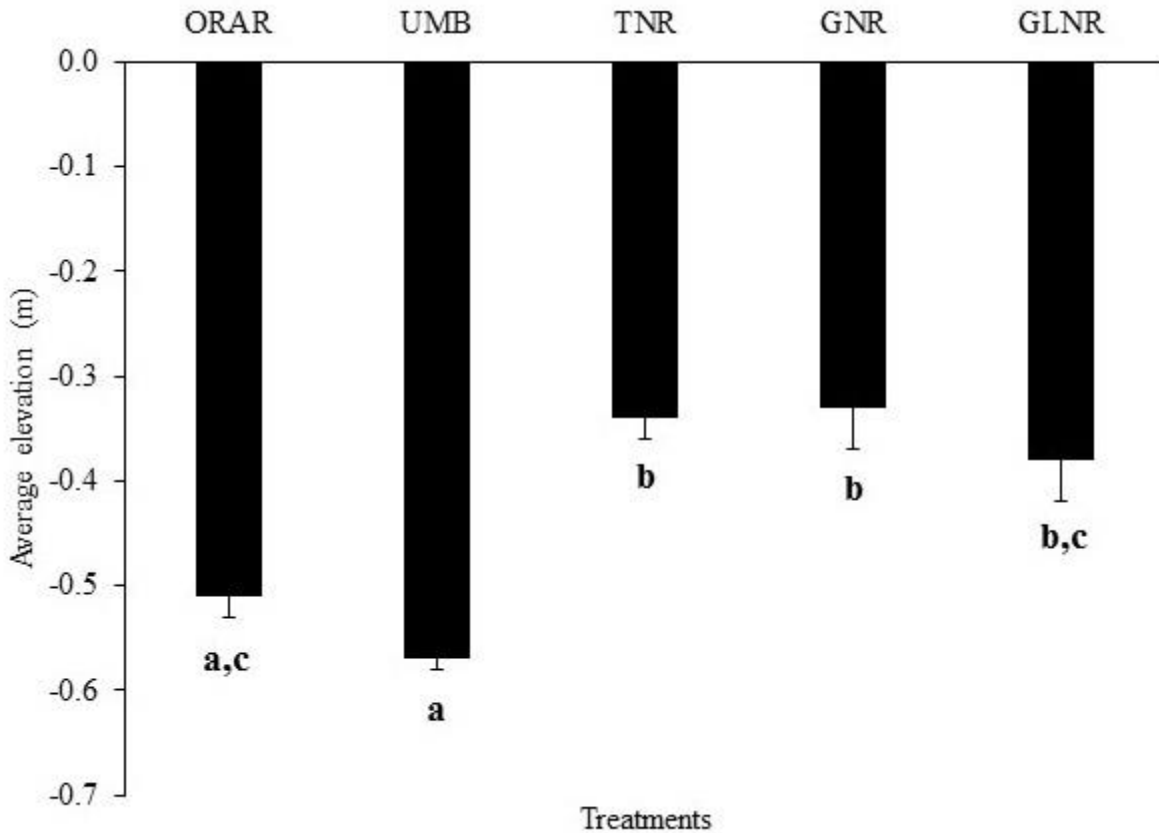
Season	Treatment	<i>n</i>	Mean NPT	SE	Mean Differences ( $\bar{X}_i - \bar{X}_j$ )		
					ORAR	UMB	TNR
Spring	ORAR	12	18	1.2	--		
	UMB	12	14	1.2	0.75	--	
	TNR	3	79	1.3	4.4*	5.85***	--
Summer	ORAR	15	29	1.2	--		
	UMB	15	47	1.2	1.61	--	
	TNR	15	97	1.2	3.31***	2.06*	--
Fall	ORAR	9	37	1.1	--		
	UMB	9	74	1.2	2.01*	--	
	TNR	6	98	1.2	2.66***	1.32	--
Winter	ORAR	3	15	1.2	--		
	UMB	3	9	1.5	1.73*	--	
	TNR	3	170	1.5	11.25*	19.44*	--

\* $p < 0.05$ , \*\*\* $p < 0.001$



**Figure 1-11** Spatial similarity of benthic communities demonstrated with non-metric multidimensional scaling between January 2014 and July 2015. Each point represents the fourth root transformed average species abundance (number tray<sup>-1</sup>) for all three trays collected within each treatment per collection date. Ovals indicate a similarity of 50% (solid) and 60% (dash) as a result of CLUSTER analysis. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef on the Tolomato River across from the restoration site. 2-D stress: 0.18.



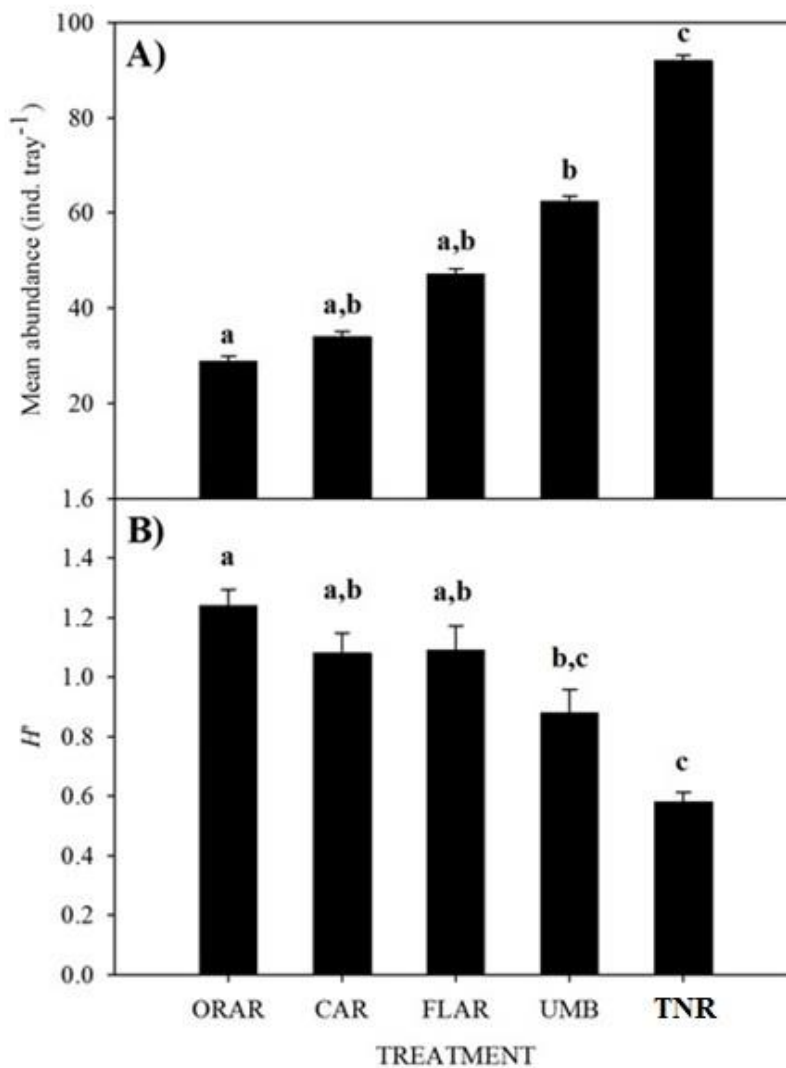


**Figure 1-12** Mean elevation (m) relative to mean sea level (MSL) of settlement trays deployed along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; NR, natural reef adjacent to restoration site in Tolomato River; GNR, natural reef at the mouth of the Guana River; GLNR, Guana natural reef with live oyster. There were three trays in each treatment. Treatments with different letters indicate significant difference using Tukey’s Honestly Significant Difference post-hoc test.

**Table 1-5** Summary of means, standard errors and mean differences of the elevations (m) for plastic settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June 2014 and July 2015. Elevation is based off the Mayport Continuous ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

Treatment	n	Mean Elevation (m)	SE	Mean Differences ( $\bar{X}_i - \bar{X}_j$ )			
				ORAR	UMB	TNR	GNR
ORAR	3	-0.51	0.02	--			
UMB	3	-0.57	0.01	-0.06	--		
TNR	3	-0.34	0.02	-0.16*	-0.23*	--	
GNR	3	-0.33	0.04	-0.17*	-0.23*	0.004	--
GLNR	3	-0.38	0.04	-0.13	-0.19*	0.04	0.04

\* $p < 0.05$



**Figure 1-13** A) Mean abundance (number ind. tray<sup>-1</sup>) and B) Shannon-Weiner diversity index (*H'*) by treatment for all species collected in settlement trays along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. ORAR, artificial oyster reef only (n=18); CAR, combination oyster and fiber log (n=18); FLAR, fiber log only (n=12); UMB, unstructured mud bottom (n=17); TNR, natural reef adjacent to restoration site in Tolomato River (n=15). Different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test.

**Table 1-6** Summary of back transformed means, standard errors and mean differences of abundance (ind. tray<sup>-1</sup>) for plastic settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. ORAR, artificial oyster reef only; CAR, combination oyster and fiber log; FLAR, fiber log only; UMB, unstructured mud bottom; NR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

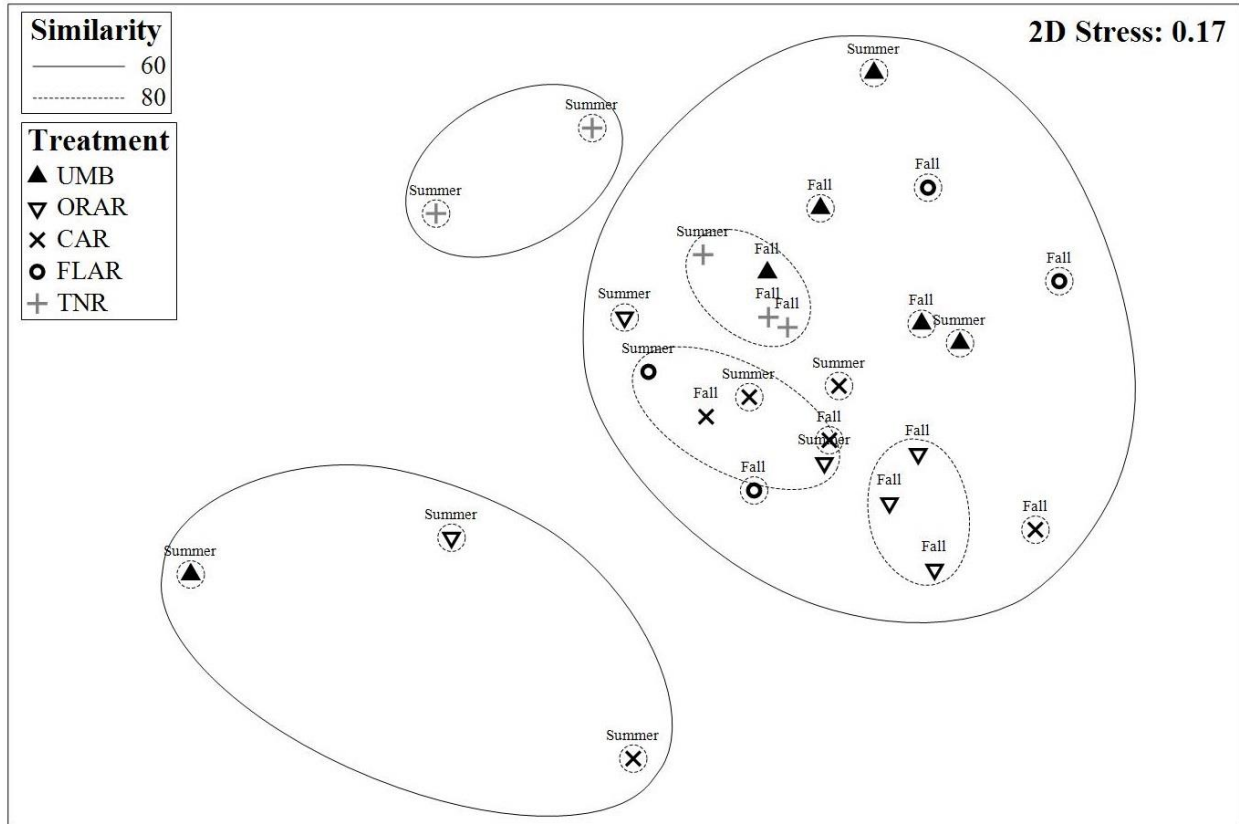
Treatment	n	Mean NPT	SE	Mean Differences ( $\bar{X}_i - \bar{X}_j$ )				
				ORAR	CAR	FLAR	UMB	NR
ORAR	18	29	1.13	--				
CAR	18	34	1.13	1.18	--			
FLAR	12	47	1.19	1.63	1.39	--		
UMB	17	62	1.19	2.16*	1.84*	1.32	--	
NR	15	92	1.13	3.19***	2.71***	1.95*	1.47	--

\* $p < 0.05$ , \*\*\* $p < 0.001$

**Table 1-7** Summary of means, standard errors and mean differences of the Shannon-Wiener diversity index ( $H'$ ) for plastic settlement trays collected within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. ORAR, artificial oyster reef only; CAR, combination oyster and fiber log; FLAR, fiber log only; UMB, unstructured mud bottom; NR, natural reef adjacent to restoration site in Tolomato River. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

Treatment	n	Mean $H'$	SE	Mean Differences ( $\bar{X}_i - \bar{X}_j$ )				
				ORAR	CAR	FLAR	UMB	NR
ORAR	18	1.24	0.06	--				
CAR	18	1.08	0.07	-0.16	--			
FLAR	12	1.09	0.08	-0.15	0.01	--		
UMB	17	0.88	0.08	-0.36*	-0.20	-0.21	--	
NR	15	0.58	0.03	-0.66***	-0.5***	-0.51***	-0.3*	--

\* $p < 0.05$ , \*\*\* $p < 0.001$

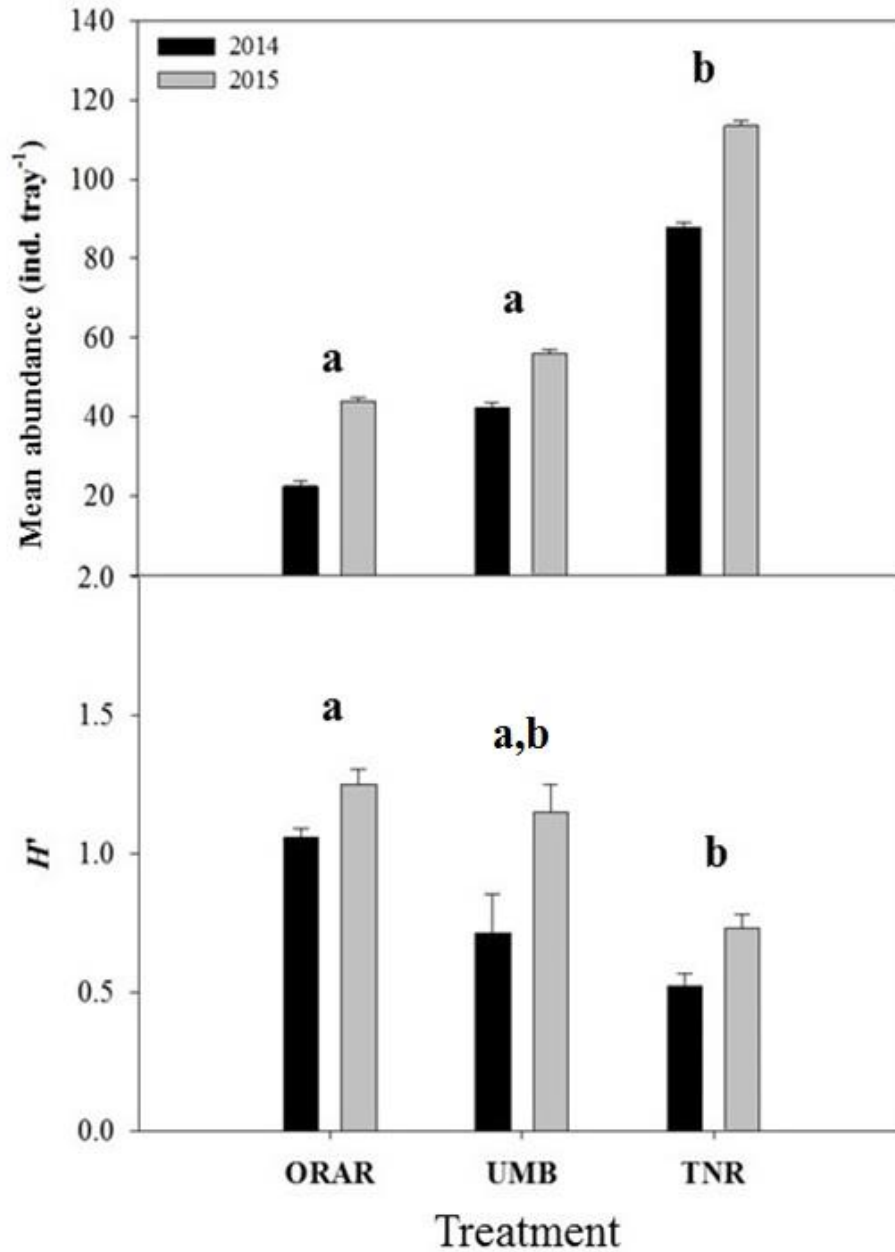


**Figure 1-14** Spatial similarity of benthic communities demonstrated with non-metric multidimensional scaling in 2014. Each point represents the fourth root transformed average species abundance ( $\text{ind. tray}^{-1}$ ) for all three trays collected within each treatment per collection date. Collections were made monthly between June and November 2014. Season each collection took place is indicated next to the point. Ovals indicate a similarity of 60% (solid) and 80% (dash) as a result of CLUSTER analysis. ORAR, artificial oyster reef only; CAR, combined fiber log and artificial oyster; FLAR, fiber log only; UMB, unstructured mud bottom; NR, natural reef on the Tolomato River across from the restoration site. 2-D stress = 0.17.

**Table 1-8** Pairwise R statistic values from the analysis of similarity (ANOSIM) for benthic macrofaunal communities collected in plastic settlement trays within artificial and natural habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. R values range from 0 to 1 with the higher values indicating high separation between the communities. ANOSIM was conducted with 999 permutations. ORAR, artificial oyster reef only; CAR, combination oyster and fiber log; FLAR, fiber log only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River.

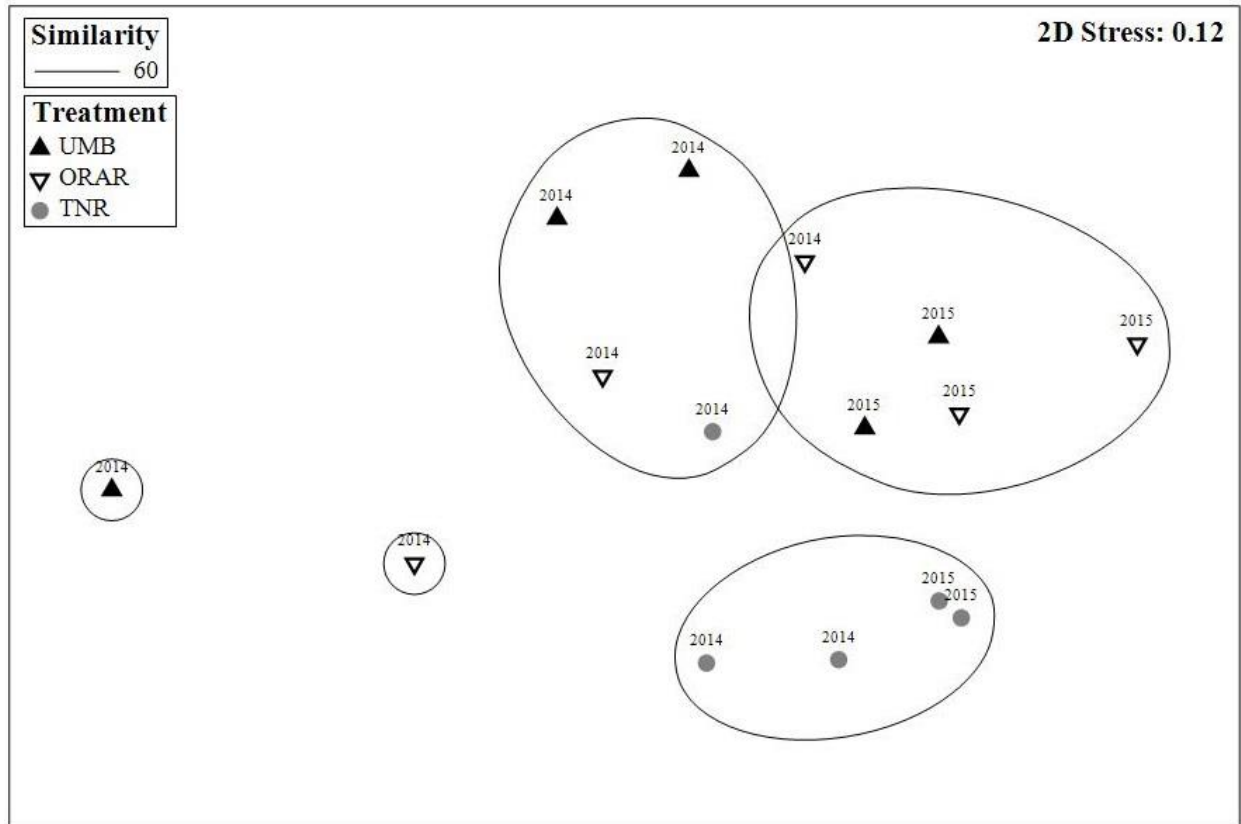
<b>Treatment</b>	<b>ORAR</b>	<b>CAR</b>	<b>FLAR</b>	<b>UMB</b>	<b>NR</b>
ORAR	--				
CAR	0.002	--			
FLAR	0.111	0.27	--		
UMB	0.191	0.176*	0.111	--	
TNR	0.381*	0.387*	0.463*	0.16	--

\*  $p < 0.05$



**Figure 1-15** Mean abundance (ind. tray<sup>-1</sup>) and Shannon-Weiner diversity index ( $H'$ ) by year and treatment for all species collected in plastic settlement trays along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between June and November 2014. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; TNR, natural reef adjacent to restoration site in Tolomato River. There were nine trays in each treatment with the exception of NR in 2015 (n=6). Treatments with different letters indicate significant difference.





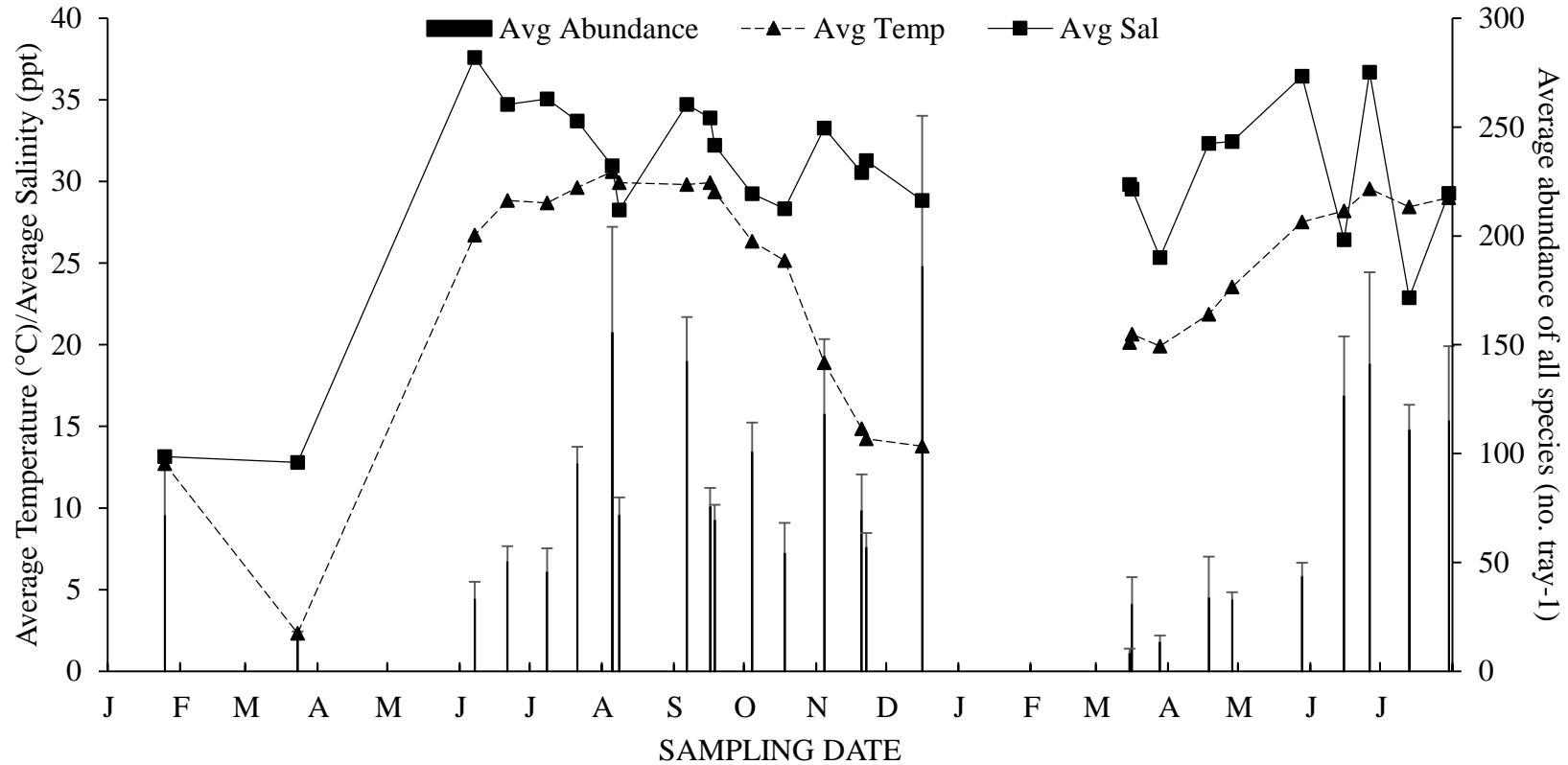
**Figure 1-16** Spatial similarity of benthic communities demonstrated with non-metric multidimensional scaling between 2014 and 2015. Each point represents the fourth root transformed average species abundance (number tray<sup>-1</sup>) for all three trays collected within each treatment per collection date. Only UMB, ORAR, and NR are used because they were collected within the summer season of both years. ORAR, artificial oyster reef only; UMB, unstructured mud bottom; NR, natural reef on the Tolomato River across from the restoration site. Ovals indicate a similarity of 60% (solid) as a result of CLUSTER analysis. 2-D stress: 0.12.

**Table 1-9** Spearman's  $\rho$  (N= 162) between mean abundance (ind. tray-1) and Shannon-Wiener diversity (H') and mean temperature ( $^{\circ}$ C) and salinity (ppt) as well as the maximum and minimum values of each environmental variable taken the nearby Florida Department of Environmental Protection (FLDEP) platform (Station 872-0494 at 29.99472 $^{\circ}$ N, 81.32956 $^{\circ}$ W) 48-hours prior to each collection date.

		<b>Abundance</b>		<b>Diversity</b>	
		$\rho$ (rho)	p-value	$\rho$ (rho)	p-value
Temperature	Mean	0.45	p < 0.0001**	0.199	0.011*
	Max	0.466	p < 0.0001**	0.193	0.014*
	Min	0.419	p < 0.0001**	0.183	0.02*
Salinity	Mean	-0.016	0.840	-0.016	0.841
	Max	0.083	0.294	-0.081	0.304
	Min	-0.025	0.755	0.02	0.799

\*\* Correlation is significant at the 0.01 level (2-tailed).

\* Correlation is significant at the 0.05 level (2-tailed).



**Figure 1-17** Average abundance of all species (number tray<sup>-1</sup>; NPT) for each collection date of benthic settlement trays sampled between January 2014 and July 2015 in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, FL, U.S.A (30.0225250°N, 81.3262806°W). Average abundance includes all species from every treatment sampled on each collection date. Temperature (°C) and salinity (ppt) are presented as the average of data collected every six minutes 48-hrs prior to tray collections from the Florida Department of Environmental Protection Tolomato River water quality data sonde (29.99472°N, 81.32956°W).

## Chapter 2

### Fish assemblages associated with restored and unrestored intertidal habitats

#### 2.1 ABSTRACT

Oyster reefs are declining worldwide and, with the loss of this habitat, many of the ecosystem services derived from these shellfish populations are also lost. Oyster reefs are considered essential fish habitat and provide shelter, foraging grounds, and spawning substrate for many species. Many restoration efforts have been undertaken in hopes of re-establishing these shellfish populations. This study quantified fish assemblages using monthly seine and gill nets set adjacent to restored and unrestored intertidal habitats in northeast Florida to: (1) identify trends in juvenile fish and mobile crustacean assemblages between the artificial reef and unstructured habitat, (2) compare larger nekton abundance associated with restored and unrestored sites, (3) examine spatiotemporal trends in abundance and diversity, and (4) describe relationships between environmental factors and the abundance and diversity of fish assemblages. Diversity was similar between the restored and unrestored habitats, however there was very little species overlap between the two sites. The dominance of post-larval and juvenile spot (*Leiostomus xanthurus*), anchovies (*Anchoa mitchelli* and *A. hepsetus*) and mullet (*Mugil* sp.) led to high density and low diversity in seine collections during the winter months. Fish assemblages differed by season, year, tidal stage, and habitat as indicated by an analysis of similarity (ANOSIM). The largest amount of dissimilarity in community composition was

observed between fall and spring seasonal assemblages (87%) as indicated by a similarity percentage analysis (SIMPER). Overall, the gill net survey did not show any patterns in fish abundance associated with particular habitats in the area, however this is the first assessment in this region using gill netting, and results indicated an abundance of recreationally important species using the estuarine waters adjacent to the restored habitats.

## 2.2 INTRODUCTION

Oyster reefs support highly diverse communities along the South Atlantic and Gulf coasts of the United States, with many species that are either rare or absent from adjacent habitats (Wells 1961; Dame 1979; Burrell Jr. 1986; Zimmerman et al. 1989; Lenihan et al. 2001). The eastern oyster (*Crassostrea virginica*; hereafter oyster) forms three-dimensional reefs which enhance secondary and tertiary productivity within estuaries as juvenile fish and crustaceans recruit to and utilize these reefs as foraging grounds and refuge (Breitburg 1999; Coen and Luckenbach 2000; Harding and Mann 2003; Grabowski et al. 2005; Tolley and Volety 2005; Rodney and Paynter 2006). They are considered essential fish habitat (EFH; SAFMC 1998; Coen et al. 1999) and have been found to serve as foraging grounds for commercially important finfish in regions where seagrasses are not abundant, thereby providing a similar service as submerged aquatic vegetation (Holt and Ingall 2000). Additionally, oyster reefs provide other types of ecosystem services such as water filtration, the prevention of coastal erosion and boat wake mitigation, as well as carbon sequestration (Volety et al. 2014).

An acre of oyster reef habitat with a lifespan of about 50 years is estimated to offer ~\$40,000 of additional value in commercial fisheries (finfish and crustacean) (Grabowski and Peterson, 2007). In fact, many commercially and recreationally important marine fish species depend on estuaries during some portion of their diverse life history such as *Morone saxatilis* (striped bass), *Pomatomus saltatrix* (bluefish), juvenile groupers, snappers, *Cynoscion nebulosus* (spotted seatrout) and *Sciaenops ocellatus* (red drum) (Crabtree and Dean 1982; Wenner et al. 1990; Beck et al. 2001; Harding and Mann 2003; Grabowski et al. 2005; Able and Fahay 2010; McRae and Cowan Jr. 2010; Stunz et al. 2010; Pierson and Eggleston 2014).

Historically, oyster reefs were one of the dominant biogenic habitats found within bays and estuaries around the world. However, it is currently estimated that 85% of the reefs have been lost worldwide as a result of over-fishing, disease, increased sediments loading, pollution and the introduction of nonnative species (Rothschild et al. 1994; MacKenzie et al. 1996; Lenihan and Peterson 1998; Lenihan et al. 2001; Beck et al. 2011). Due to this decline, as well as the economic and ecological value of oysters to their respective systems, many restoration efforts have been undertaken in hopes of re-establishing these shellfish populations.

Several studies have utilized restoration efforts to assess the role of oyster reefs as essential fish habitat, especially for commercially and recreationally important species such as spotted sea trout (*Cynoscion nebulosus*), red drum, and many species of flounder (*Paralichthys* spp.) (Peterson et al. 2003; Scyphers et al. 2011). Fish abundance on recently restored reefs (6-8 months) has been found to resemble natural reefs that were established for at least 4-6 years showing the rapid colonization potential of newly constructed artificial reefs (Pierson and Eggleston 2014).

The Guana Tolomato Matanzas National Estuarine Research Reserve (GTM NERR) constructed a living shoreline of oyster shell bags and fiber logs on the Tolomato River to mitigate shoreline loss along the Guana Peninsula in northeast Florida, U.S.A. Living shorelines, a form of natural stabilization using organic materials, such as oysters and natural vegetation, have been found to cease or reverse coastal erosion as well as provide critical habitats for plants, fishes, and invertebrates (Piazza et al. 2005; Scyphers et al. 2011; Whalen et al. 2011). Unfortunately, not all ecosystem services have been found to develop shortly after a restoration (La Peyre et al. 2014). Additionally, many restoration projects are carried out with little or no

monitoring, which prevents assessment of success and adaptive management strategies from being employed.

Harding and Mann (2001) suggested that oyster reefs provide a greater quantity, quality and diversity of food than adjacent unstructured habitats. Therefore, the goal of this study was to compare nekton use of restored and unrestored intertidal habitats in northeast Florida, U.S.A. In order to achieve this goal several objectives were examined:

1. Identify trends in juvenile fish and mobile crustacean assemblages between the artificial reef and unstructured habitat.

**Hypothesis 1:** There will be greater diversity and abundance within the restored reef than the unstructured habitat.

**Hypothesis 2:** There should be low amounts of similarity between the assemblages within the restored reef and unstructured habitat.

2. Compare larger nekton abundance associated with restored and unrestored sites.

**Hypothesis 3:** Nekton assemblages should be higher on sites with structure than on unstructured sites.

3. Examine spatiotemporal trends in abundance and diversity.
4. Describe relationships between environmental factors and the abundance and diversity of fish assemblages.



## 2.3 MATERIALS AND METHODS

### *Study Area*

Sampling occurred along the Guana Peninsula within the northern GTM NERR, Florida, U.S.A. (30.0225250°N, 81.3262806°W) (Figure 1). The Guana Peninsula is surrounded by the Guana and Tolomato Rivers of the GTM estuary. The GTM estuary is a subtropical, well-mixed, lagoonal estuary consisting of *Spartina alterniflora*-dominated marshes as well as mixed salt marsh-mangrove habitats (Valle-Levinson et al. 2009; Williams et al. 2014). The Tolomato River is a segment of the Atlantic Intracoastal Waterway and shorelines are subject to high wave energies from boat wakes and wind.

The GTM NERR constructed a living shoreline using oyster shell between 2012 and 2013. The artificial oyster reef extends approximately 328 m along the Tolomato bank of the Guana Peninsula. Reefs were constructed of plastic mesh bags filled with oyster shell stacked in 5.5 m long segments within the low intertidal zone. An additional artificial treatment using fiber (coir) logs was installed along the marsh edge in April 2014 at a higher elevation (typically about 30 to 40 cm above the lower oyster reefs). These logs were modeled after the Delaware Estuary Living Shoreline Initiative (DELSI) method used in the Delaware Bay Estuary and installed approximately 5 m from the existing *Spartina* marsh edge (Whalen et al. 2011). Logs were placed in 20-m arcs both behind constructed oyster reefs, and alone, along eroding shoreline (Figure 2). As will be discussed later, the fiber logs did not last more than few months, and most were degraded and removed by winter of 2014 (APPENDIX I). In spring of 2015, upper elevation oyster bags were deployed to replace the footprint of the fiber log arcs. Replacement of the upper elevation habitats was still continuing when this project was concluded.

### ***Collection Methods***

Fish and mobile crustaceans were collected using two gear types to sample juvenile and larger adult assemblages in complimentary habitats. Shorelines within the restored site as well as an unstructured site 50 m south of the artificial reef along the Guana Peninsula, were sampled using a 6.1 m bag seine (3.18-mm mesh) (Figure 3). The seine was pulled 20 m parallel to the shoreline in 25 to 50 cm water depth. Seine poles were kept 3-m apart using a measured line so that each haul sampled approximately 60 m<sup>2</sup> of habitat (Figure 4). The seine was deployed northward along the eastern bank of the Tolomato River within both habitats. No more than 4 seine hauls were able to be completed in a day without the water level changing the sampled habitat, thus the habitat types were alternated each month of sampling. Seining could not be conducted on natural oyster reefs due to restricted access as well as potential snagging on live oyster during collection. Monthly seining occurred between October 2013 and July 2015.

Deeper waters adjacent to sites where seining was performed, as well as nearby natural oyster reefs, were sampled using an experimental monofilament gill net approximately 20-m long with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62 cm). This method was used in order to collect larger, more motile nekton that would either have escaped the seine net during collections, or occupied deeper waters than where seining took place. The gill net survey was conducted between May and December of 2014. Gill nets were set in pairs during daylight hours, on an incoming tide, perpendicular to the shoreline, with 0.5-1 hour soak times depending on ambient conditions. The small mesh panel was anchored next to the shore, primarily on an incoming tide, with the large mesh panel anchored 20 m toward the channel. Site selection for the gill net was haphazard as guided by habitat (unstructured, restored, or natural oyster reef) (Figure 5).

Fishes and crustaceans were identified, and measured (standard length, SL, or carapace width, CW) in the field. All catches in the seine net were placed in aerated buckets, and worked up immediately to be released following collection of the second haul at a site. Small species, such as *Palaemonetes* shrimps, were too small to be quantified in the net. Some taxa could not be identified to species due to lack of distinguishing characters in juveniles (*Eucinostomus* sp.) or likely hybridizing with other species (*Menidia* sp.). Unidentified specimens were returned to the lab for identification.

A handheld YSI Pro 2030 Model multiprobe was used to record environmental conditions (temperature (°C), salinity (ppt), and dissolved oxygen (mg/L)) at each site prior to each seine haul. In addition to these discrete measurements, temperature, salinity and dissolved oxygen were measured throughout the study period by a datasonde deployed at a nearby GTM NERR System-Wide Monitoring Program station, Pine Island (30.05086°N, 81.36747°W) (NERRS). Data was downloaded from this station at the time when handheld measurements were taken for each haul. Environmental parameters were recorded following the deployment of each gill net while it was soaking. As these measurements were taking while the nets were in the water only the handheld measurements were used for further analysis of the gill net catch.

### ***Statistical Analyses***

All data were checked for normality using the Kolmogorov-Smirnov test to evaluate the assumption of the statistical analyses. Logarithmic transformation of the abundance metrics in both surveys was necessary to achieve normality and homogeneity of variance. Tukey Honestly Significant Difference (Tukey HSD) post hoc tests were conducted for all significant interaction and main effects with more than two levels. IBM SPSS Statistics (Windows, Version 22.0. Armonk, NY: IBM Corp) was used for all analyses on abundance and diversity.

### *Seine survey*

Due to low replication (only two seine hauls were possible per treatment per day within a given tide) statistical comparisons by habitat were not able to be performed; therefore, both habitats were analyzed together for seasonal and annual catch differences. Habitat comparisons were made in community analyses. The effects of year, season, and tide (outgoing vs. incoming) on catch standardized to density (catch per unit effort, CPUE, or number of organisms per m<sup>2</sup> sampled, with each seine haul = 60m<sup>2</sup>) and the Shannon-Weiner diversity ( $H'$ ) of each haul were analyzed collectively using multivariate analysis of variance (MANOVA) and then separately using ANOVA for each response variable (Underwood 1981). In some cases, the data remained non-normal (specifically diversity  $H'$ ); these data were still analyzed with analysis of variance (ANOVA) due to its robustness and insensitivity to skewness (Glass et al. 1972).

Because the datasonde measurements were taken 6.95-km (4.32-mi) away from the study site for seine collections, a regression analysis was conducted to estimate conditions at the study site using a subset of paired measurements from both the Pine Island datasonde and handheld YSI measurements collected prior to each seine haul (44 temperature and salinity measurements and 40 dissolved oxygen). The resulting equations for estimating conditions at the study site were: temperature =  $0.987x + 1.293^{\circ}\text{C}$  ( $R^2 = 0.978$ ), salinity =  $0.619x + 9.36$  ppt ( $R^2 = 0.746$ ), and dissolved oxygen =  $0.881x + 1.687$  mg/L ( $R^2 = 0.907$ ). Regression-estimated parameters were used in Spearman's Rank Correlation analysis to describe relationships between density and diversity, temperature, salinity, and dissolved oxygen levels taken during sampling events.

### *Community analyses of seine survey*

Non-metric multidimensional scaling (NMDS) was used to determine similarity of juvenile fish assemblages collected in the seine net by season, habitat, year, and tidal stage. The datasets were

split by sampling gear and analyzed separately. A Bray-Curtis similarity matrix was constructed using the fourth root of the abundance of all species in each net by sampling date and used for the MDS. The transformation reduced the weight of abundant species and enabled the contribution of less abundant or rare species to the overall community structure; however, only species that accounted for more than 5% of the total catch were used in the NMDS (Humphries et al. 2011). The similarity index was also used to conduct a one way analysis of similarity (ANOSIM) on community separation based on season and treatment. A similarity percentage (SIMPER) analysis was conducted to determine which species contributed the most to dissimilarities between the treatments and seasons. All community multivariate analyses were conducted using PRIMER statistical software (version 7.0; Clarke et al. 2014).

#### *Gill net survey*

The effects of season, habitat (natural reef, artificial reef, or unstructured mud bottom), and river (Tolomato vs. Guana) on the CPUE (number of animals per net hour) of nekton sampled by gill nets was tested using a three-way ANOVA. Spearman's rank correlation was used to describe relationships between CPUE and temperature, salinity, and dissolved oxygen levels taken during sampling events.

## 2.4 RESULTS

***Objective 1: Identify trends in juvenile fish and mobile crustacean abundance and diversity between the artificial reef and unstructured habitat.***

A total of 16,061 organisms (12,752 fish; 2,209 invertebrates) from 52 different species (46 fish; 6 invertebrate) were collected in 90 hauls during the entire length of the seine survey (October 2013-July 2015). The dominant species were spot (*Leiostomus xanthurus*), silversides, white shrimp (*Litopenaeus setiferus*), bay anchovy (*Anchoa mitchelli*) and brown shrimp (*Farfantepenaeus aztecus*) which made up 74% of the total catch.

There were several species that were only collected once or twice and primarily as juveniles (Table 1). Bonfish (*Albula vulpes*), Atlantic needlefish (*Strongylura marina*), lookdown (*Selene vomer*), yellowfin mojarra (*Gerres cinereus*), lyre goby (*Evorthodus lyricus*), spotted sea trout (*Cynoscion nebulosus*), whitemouth croaker (*Micropogonias furnieri*), red drum (*Sciaenops ocellatus*), bigeye searobin (*Prionotus longispinosus*), big-clawed snapping shrimp (*Alpheus heterochaelis*), serrated swimming crab (*Scylla serrata*), and the Atlantic brief squid (*Lolliguncula brevis*) were all collected on the artificial reef. There were also several rare species collected in the unstructured site: Crevalle jack (*Caranx hippos*), Atlantic bumper (*Chloroscombrus chrysurus*), bluefish (*Pomatomus saltatrix*), Gulf flounder (*Paralichthys albigutta*), striped searobin (*P. evolans*), and Northern pipefish (*Syngnathus fuscus*).

### *Abundance and diversity*

The results of the MANOVA on the abundance and diversity of juvenile fishes and crustaceans were significant for the effects of season and tide, but not for year (Wilks Lambda test:  $p < 0.05$  for all main effects except year); therefore, separate ANOVAs were conducted of the effects of

season and tide on each of the response variables. Abundance differed by season ( $F(3, 82) = 3.236, p < 0.05$ ) and tidal stage ( $F(1, 82) = 9.274, p < 0.025$ ). More individuals were caught in the spring and winter than the summer and fall (Figure 6, Table 2); however, only catches in the fall and spring were significantly different from one another ( $p < 0.05$ ). Catch was higher during outgoing ( $2.03 \pm 1.17 \text{ m}^{-2}$ ) than incoming tides ( $0.96 \pm 1.21 \text{ m}^{-2}$ )

Diversity also differed by season ( $F(3, 82) = 5.809, p < 0.025$ ) and tidal stage ( $F(1, 82) = 9.109, p < 0.025$ ). Summer and fall were more diverse than the spring ( $p < 0.05$ ). Summer was much more diverse than collections made in the winter ( $p < 0.05$ ) (Figure 7, Table 3). Diversity was significantly higher in collections made during incoming tides ( $H', 1.18 \pm 0.09$ ) than outgoing ( $H', 0.84 \pm 0.07$ ).

#### *Environmental parameters*

Only diversity was found to significantly correlate with environmental parameters (Table 4). Diversity positively correlated with temperature and negatively correlated with dissolved oxygen. There appeared to be no relationship between the catch and the environmental parameters.

#### *Patterns between restored and unrestored habitats*

Fall 2013 (October and November) collections took place before the installation of the fiber log restoration treatment. Overall, there were only 1,062 specimens (510 fishes; 552 invertebrates) from 22 different species (18 fish; 4 invertebrate) collected during these two months. The artificial reef ( $H', 1.49 \pm 0.09$ ) was more diverse than the unstructured site ( $H', 1.04 \pm 0.29$ ). Catches were lower on the artificial reef ( $0.88 \pm 0.09 \text{ m}^{-2}$ ) than the unstructured site ( $3.55 \pm 1.64 \text{ m}^{-2}$ ). The artificial site later became the combination treatment consisting of both artificial oyster

reef and fiber logs while the unstructured site sampled in 2013 became the northern fiber log only restoration treatment.

Much of the difference between the two habitats was due to large catches of white shrimp in the unstructured site ( $2.09 \pm 1.81 \text{ m}^{-2}$ ) compared to the artificial ( $0.16 \pm 0.09 \text{ m}^{-2}$ ). There were also large catches of anchovies (*A. mitchelli* and *A. hepsetus*) in the unstructured site ( $0.5 \pm 0.49 \text{ m}^{-2}$  and  $0.48 \pm 0.43 \text{ m}^{-2}$ , respectively). The artificial site had higher numbers of two flatfishes, bay whiff (*Citharichthys spilopterus*) and black cheeked tonguefish (*Symphurus plagiusa*) ( $0.09 \pm 0.06 \text{ m}^{-2}$  and  $0.05 \pm 0.04 \text{ m}^{-2}$ , respectively) (Table 5).

6,837 individuals (1,241 fishes; 5,596 invertebrates) from 35 species (31 fish; 4 invertebrate) were collected in 46 hauls in 2014. Most of these individuals were collected within the restored reef (5,067 individuals;  $1.25 \pm 0.37 \text{ m}^{-2}$ ) and the least in the unstructured site (1,770 individuals;  $0.34 \pm 0.05 \text{ m}^{-2}$ ) from the unstructured site. There was no apparent difference in the diversity of each site ( $H'$ ,  $0.89 \pm 0.12$  and  $0.85 \pm 0.12$  for the artificial reef and unstructured site, respectively). The most abundant species this year were spot, bay anchovy and silversides (*Menidia* sp.). There were higher catches in the artificial site for every season except winter ( $2.38 \pm 0.97 \text{ m}^{-2}$  in unstructured compared to  $1.37 \pm 0.56 \text{ m}^{-2}$  in the artificial site). In the spring, post-larval and juvenile spot were the most abundant taxa in both habitats ( $1.87 \pm 0.73 \text{ m}^{-2}$  and  $1.35 \pm 1.11 \text{ m}^{-2}$  in the artificial and unstructured sites, respectively). They made up half of the total spring catch on the unstructured site.

Penaeid shrimp were the main catch in the summer and fall months and winter was primarily dominated by silversides and anchovies. Two smooth butterfly rays (*Gymnura micrura*) were caught in the summer in the unstructured habitat. Mummichogs (*Fundulus heteroclitus*) were primarily caught in the restored site, however they were also found in the unstructured site in the



spring. Juvenile mangrove snapper (*Lutjanus griseus*) and spotted sea trout were collected in small abundances within the artificial site in both the summer and spring seasons. Juvenile red drum were only collected on the artificial reef in the winter. Blue crab (*Callinectes sapidus*) were collected throughout the year, except on the unstructured site in the fall. They were in the highest abundance on the artificial reef in the summer ( $0.15 \pm 0.05 \text{ m}^{-2}$ ) and found as juveniles (Table 6).

In only the winter, spring, and summer seasons, a total of 8,162 individuals (6,646 fishes; 1,516 invertebrates) from 32 species (27 fish; 5 invertebrates). The unstructured site ( $H'$ ,  $1.09 \pm 0.1$ ) was more diverse than the artificial reef ( $H'$ ,  $0.98 \pm 0.13$ ); however, the artificial reef had higher catches ( $5.36 \pm 1.55 \text{ m}^{-2}$ ) than the unstructured site ( $1.80 \pm 0.61 \text{ m}^{-2}$ ). Post-larval and juvenile spot were again the most abundant taxa, however they were primarily found on the artificial reef in both the winter ( $4.11 \pm 1.48 \text{ m}^{-2}$ ) and the spring ( $4.65 \pm 3.53 \text{ m}^{-2}$ ). They comprised 76.5% and 80.26% of the catch in the artificial site in both the winter and spring, respectively.

There were higher catches in the artificial site than the unstructured in all the seasons. Spot, darter gobies (*Ctenogobius boleosoma*), and blue crabs, were the only species caught in every season within both habitats. Post-larval mullet (*Mugil* sp.) were the dominant catch in the unstructured site in the winter ( $2.63 \pm 2.58 \text{ m}^{-2}$ ) making up 73.46% of that catch. Small abundances of juvenile bonefish were caught on the artificial reef on one sampling day in the spring ( $0.02 \pm 0.02 \text{ m}^{-2}$ ). Additionally, one Southern flounder (*Paralichthys lethostigma*) was also caught in the artificial reef in the spring. Inshore lizardfish (*Synodus foetens*) were only caught on the unstructured site in the summer ( $0.03 \pm 0.02 \text{ m}^{-2}$ ). Again, mummichogs were only caught in the artificial reef in the winter and spring. Three juvenile Spanish mackerel (*Scomberomorus maculatus*) were collected on the artificial reef in the summer. There were

several juvenile Crevalle jacks also collected in the summer, however they were found in the unstructured site (Table 7).

### *Community differences*

There were differences in the assemblages between the seasons with the spring and fall grouping together more to one another than the winter and summer seasons (Figure 8a). Additionally, the assemblages each year also more closely clustered together (Figure 8b). There did not appear to be any grouping of the habitat types (artificial reef vs. unstructured) or tidal stages (outgoing vs. incoming) (2D stress = 0.14) (Figure 9a, b). Assemblages significantly differed by season ( $r = 0.36, p = 0.001$ ), year ( $r = 0.186, p = 0.001$ ), habitat type ( $r = 0.056, p = 0.01$ ), and tidal stage ( $r = 0.106, p = 0.001$ ).

The two habitats were 74% dissimilar. This was largely driven by the artificial reef having higher abundances of spot and more white shrimp collected on the unstructured site. There was a higher amount of dissimilarity observed between the two tidal stages (75%). There were higher abundances of most species on an outgoing tide, except for brown shrimp (*Farfantepenaeus aztecus*). Comparing each year to one another, 2015 was different from both 2013 ( $r = 0.613, p = 0.001$ ) and 2014 ( $r = 0.171, p = 0.001$ ). Only 2014 and 2015 were examined further as the fall season was not sampled in 2015 and it was the only season sampled in 2013. 2014 and 2015 assemblages were 75% dissimilar primarily due to higher abundances of spot and brown shrimp in 2015 and higher abundances of white shrimp and bay anchovies (*A. mitchelli*) in 2014.

Pairwise comparisons of seasons revealed all the assemblages to significantly differ from one another. The most amount of dissimilarity was found between the fall and spring assemblages (87%). This was driven by large abundances of post-larval and juvenile spot as well striped anchovies (*A. hepsetus*) in the spring months that were not present in the fall months. Secondly,

white shrimp were much more abundant in the fall than the spring. Winter and fall were 82% different due to the spot in the spring as well as more white shrimp and bay anchovies in the winter. Winter and summer assemblages were 81% dissimilar primarily as a result of spot in the winter, however, summer had higher abundances of brown shrimp, white shrimp, and bay anchovies. This same pattern was observed between the spring and summer assemblages (74% dissimilar).

***Objective 2: Compare larger nekton abundance associated with restored and unrestored sites.***

Overall, 429 individuals (28 elasmobranch; 396 bony fish; 5 decapods) were collected in the gill net survey from 28 species (27 fish; 1 invertebrate) between May and December 2014. The dominant taxa were spot, hardhead catfish (*Ariopsis felis*), mojarras, spotted sea trout, and lady fish (*Elops saurus*) (Tables 8, 9).

Nekton abundance was not affected by habitat; however, there was a mild two-way interaction between river and season ( $F(3, 68) = 2.799, p = 0.047$ ). Only catches in the Guana River significantly differed across the seasons ( $F(3, 26) = 3.517, p = 0.029$ ). Additionally, there was only a difference in CPUE between the spring and winter seasons in the Guana River, with a much higher CPUE in the spring ( $16 \pm 1.12 \text{ hr}^{-1}$ ) than the winter ( $2 \pm 1.45 \text{ hr}^{-1}$ ) ( $p = 0.047$ ) (Figure 10, Table 10). None of the environmental variables correlated with CPUE (Table 11).

Only 45 individuals were collected in the spring ( $n = 11$ ) from 10 different species ( $9.4 \pm 3.3 \text{ soak hr}^{-1}$ ). The dominant species in the spring included ladyfish, spotted sea trout, spot, and menhaden (*Brevoortia tyrannus*). More nets were set in the summer months ( $n = 56$ ) and the total catch, 238 individuals, was also the highest ( $5.5 \pm 0.9 \text{ soak hr}^{-1}$ ). Spot and hardhead catfish were primarily caught during the summer, particularly on the natural reef at the Guana River.

Elasmobranchs were also the most abundant during the summer, six young-of-the-year (YOY)

scalloped hammerhead (*Sphyrna lewini*) ranging from 33 to 40 cm fork length were collected. They were collected in each habitat, however more (3 individuals) were collected on the artificial reef. Additionally, 11 YOY Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*), with fork lengths around 30cm, were also collected during the summer. They were primarily found in waters adjacent to natural oyster reefs. Bonnetheads (*S. tiburo*) were caught in all the seasons except winter. The primary catches in the fall (122 individuals total,  $5.7 \pm 1.5$  soak  $\text{hr}^{-1}$ ) were mojarras and Atlantic needlefish.

## 2.5 DISCUSSION

There were seasonal differences in catch and diversity within both surveys. Higher densities in the winter and spring in the seine collections were due to large quantities of post-larval and juvenile spot, mullet, and anchovies. The presence of these species also led to the observed low diversity in the catch during these months due to a few species dominating the assemblages. These species also made up a large portion of the winter catch in a study on ichthyoplankton assemblages in this region (Korsmann 2013). Spot spawn along the continental shelf in cooler months with peak recruitment of larvae in estuaries within the South Atlantic Bight observed between October and March (Taylor et al. 2009).

Although no statistical comparisons were made between the habitat types, the higher diversity of the restored site versus the unstructured site was similar to expectations based on previous studies (Harding and Mann 2001; Scyphers et al. 2011; Piazza et al. 2005; Shervette and Gelwick 2008 ; Humphries et al. 2011; Humphries and La Peyre 2015). There were more rare species collected within the artificial site than the unstructured site, particularly in the summer months. There were seasons in which the difference in the diversity between the sites was not very large; however, examining the assemblages reveal little species overlap between the sites. This suggests that although overall diversity is not all that different, there are species that are associated with each habitat type.

Patterns in abundance and diversity across the seasons may have also been influenced by the degradation of the fiber log restoration treatments and subsequent installation of a new artificial treatment in the spring of 2015. This new treatment consisted of mesh bags filled with oyster shells stacked onto fiber mats where the fiber logs were originally placed. The fiber logs were

found to degrade over time, primarily as a result of high wake energy in this system, which is adjacent to of Florida's Intracoastal Waterway (ICW)(APPENDIX I).

Differences in the assemblages between seasons, tidal stage, year, and habitat were driven primarily by a handful of species: penaeid shrimp, spot and anchovies. These numerically dominant species may serve as important forage fish for larger predatory fishes that are likely to escape the seine net used in this study. The gill net was therefore also used to assess the larger nekton associated with these habitats. The assemblages were similar to those from studies in the Indian River Lagoon and the St. Johns River in Florida (Tremain and Adams 1995; Turtora and Schotman 2010).

Overall, the gill net survey did not show any patterns in fish abundance associated with particular habitats in the area, similar to patterns in other studies (Grabowski et al. 2005; La Peyre et al. 2014). Assessing larger transient fish associated with particular habitat types is difficult as the fish are capable of moving within a short time frame between the habitats. In fact, Pierson and Eggleston (2014) found that fish diversity decreased on control reefs after the construction of a restored reef likely due to the movement of fish from the old habitat to the new habitat.

The gill net survey did, however, show differences in catch between the two rivers. The Tolomato River is part of the ICW and is much deeper and wider than the Guana River. The Guana River also had more complex oyster reefs bordering the channel than the Tolomato. Many of the developed reefs in the Tolomato were much further back in the marsh and were not sampled because the artificial site is along the channel and sampling was standardized to setting nets adjacent to the main channels. It is important to note that the differences observed between the spring and winter seasons may have also been due to the presence of elasmobranchs in the

net during the spring. When a shark, particularly a large adult, hit the gill nets, the nets were immediately removed in order to process the specimens for a quick removal. The nets were then pulled and set in another habitat. This would have resulted in lower soak times in the summer than the winter, where nets were oftentimes empty and left for much longer periods of time.

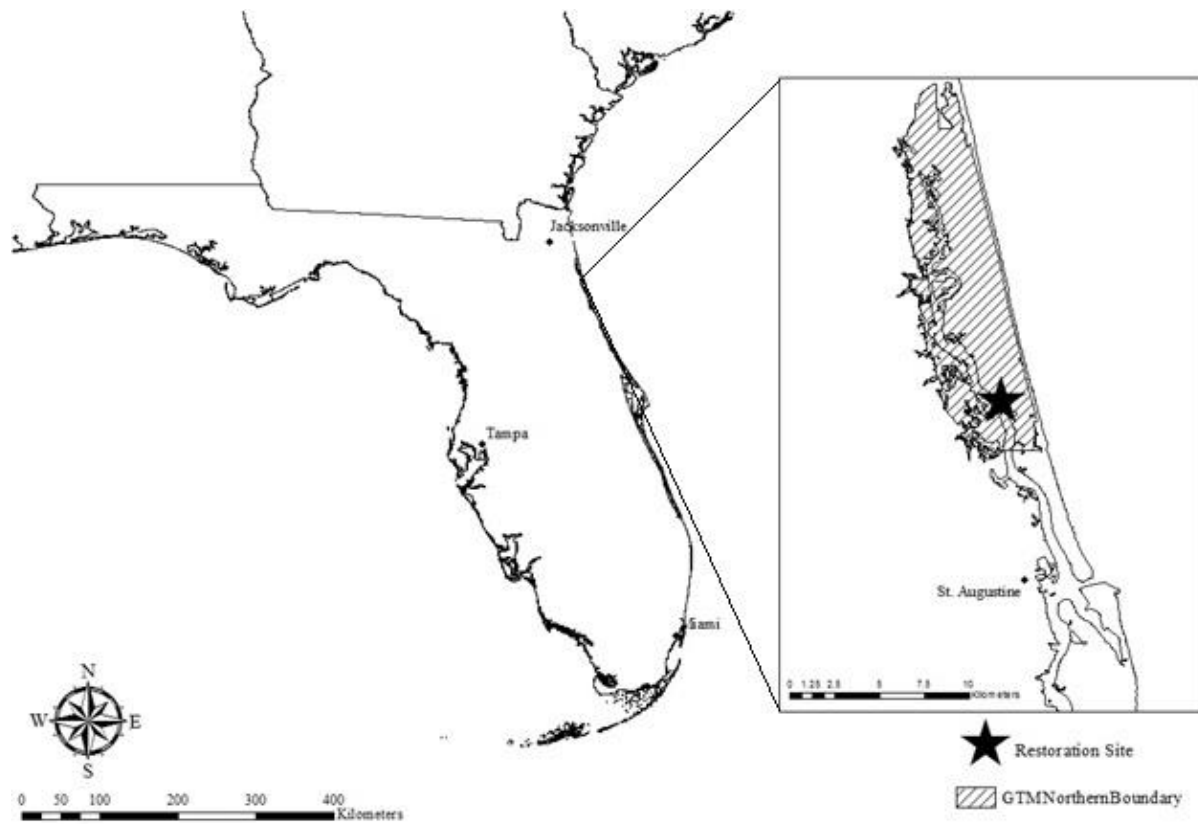
. Oyster reefs are known to be potential nursery and feeding habitat, shelter and spawning substrate for resident fishes and invertebrates, as well as feeding habitat for juvenile commercial and recreational species (Zimmerman et al 1989; Breitburg, 1999; Coen and Luckenbach, 2000; Beck et al. 2001; Lenihan et al. 2001; Harding and Mann, 2001,2003; Peterson et al. 2003; Grabowski et al. 2005; Tolley and Volety 2005; Rodney and Paynter 2006; Scyphers et al. 2011). This study further supports that oyster restoration may enhance fish production, however, it is important to understand that the restoration may target particular species and that a restored reef may not be more diverse than adjacent habitats, but support its own diverse assemblage of species associated with the provided structure.

There have been very few studies conducted in this region that provide information on juvenile and adult estuarine species, regardless of their association with oyster reefs or even restored habitats (Murt and Juanes 2008; Turtora and Schotman 2010; Galleher et al. 2013; Korsman 2013). This study provides necessary baseline information on abundance, diversity, and seasonality of fish species within the Guana Tolomato Matanzas estuary. This is the first assessment in this region using gill netting, and indicates an abundance of recreationally important species using the estuarine waters adjacent to the restored habitats. Future studies include analyzing the data from these collections for size distribution and population patterns of abundant as well as commercially and recreationally important species.

## 2.6 ACKNOWLEDGEMENTS

We would like to thank our funding sources: the Atlantic Coastal Fish Habitat Partnership, the Friends of the GTM Research Reserve, and University of North Florida's Coastal Biology Flagship program. Thank you to Drs. Eric Johnson and Nicole Dix who provided guidance in the field, the statistics, and kept our research focus in line with our goals. We could not have done our project without the help of our undergraduates in the Smith Lab at UNF, volunteers of the GTM Reserve, nor the wonderful staff at GTM Reserve. We would especially like to thank Brian Alexander, Jon Lindenmoyer, Eric Boe, Jordan Baez, Kiersten Masse, Ben Mowbray, Robert "Trey" Fraley, Marisa Beasley, John Whiting and Sara "River" Dixon for help in the field collections and identifications of the fish species. All collections were made with approval of the University of North Florida's Institutional Animal Care and Use Committee (IA# 14-003) and under Florida Fish and Wildlife Conservation Commission Special Activity License (SAL-11-1305B-SR).

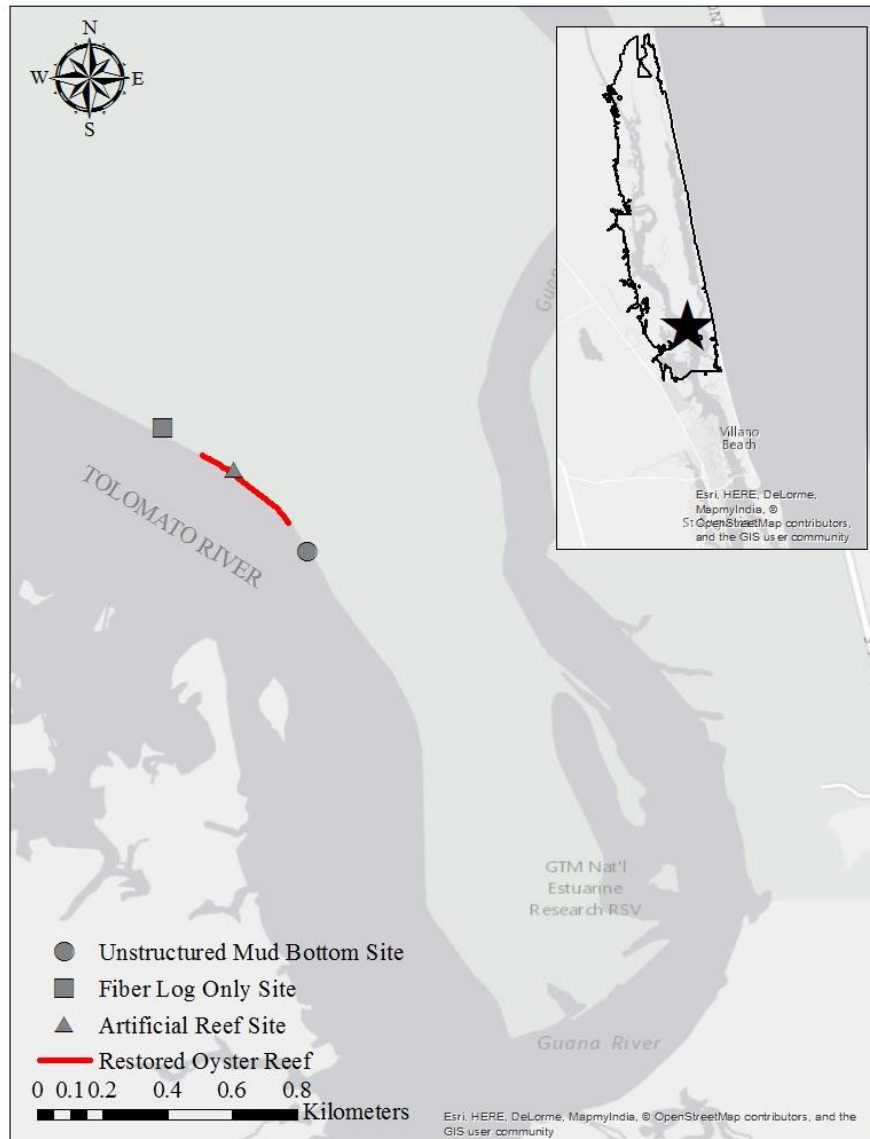




**Figure 2-1** Location map of the study site in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Hatched section represents the northern GTM NERR boundary. Star indicates Wright's Landing, the site of the living shoreline restoration project.



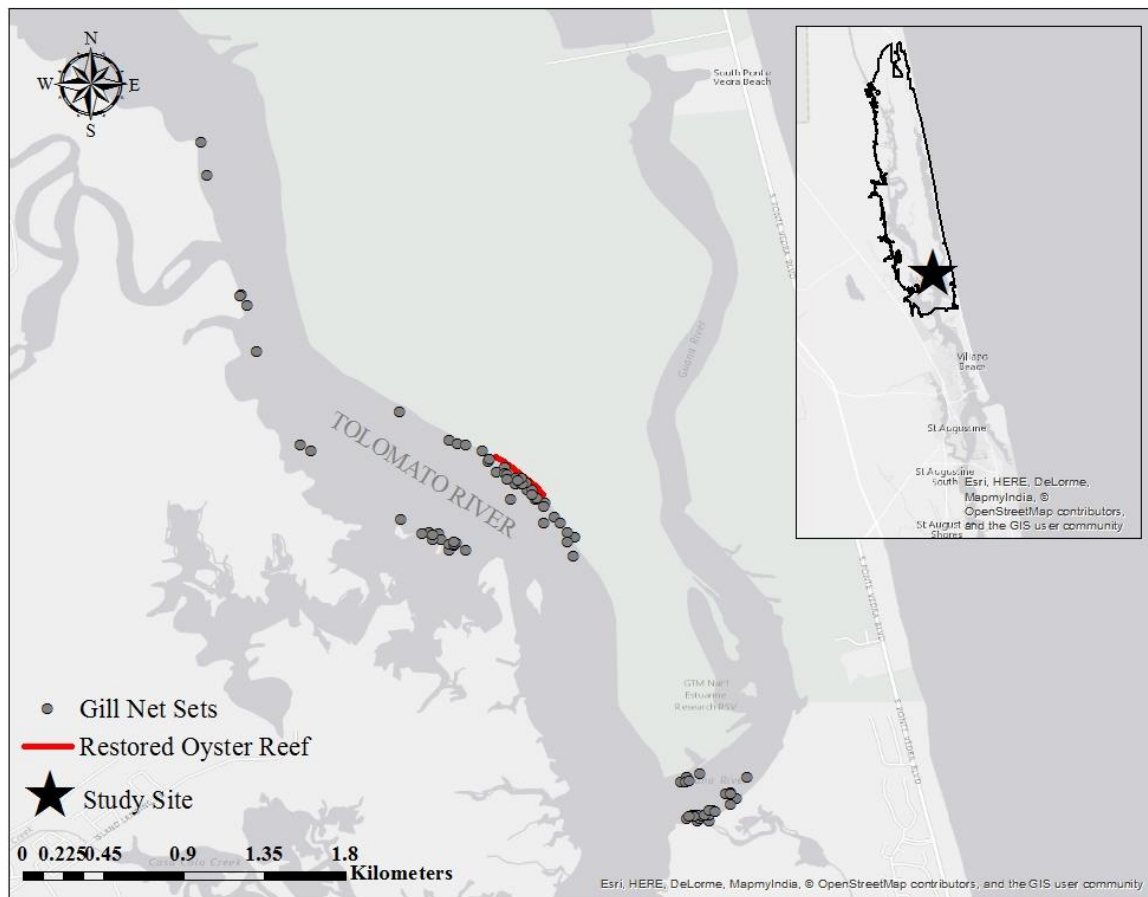
**Figure 2-2** Deployed fiber (coir) logs along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W) Florida, U.S.A. These logs were installed approximately 5-m from the existing *Spartina* marsh edge in the high intertidal zone. Logs were placed in 20-m arcs both behind constructed oyster reefs (pictured), and alone, along eroding shoreline.



**Figure 2-3** Map of the seine locations along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Monthly seining was conducted on restored sites (artificial oyster reef and fiber log reefs) as well as an unstructured mud bottom site 50-m south of the artificial reef between November 2013 and July 2015.



**Figure 2-4** Seining with a 6.1 m bag seine (3.18-mm mesh) within the artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W) Florida, U.S.A. The seine was pulled 20 m parallel to the shoreline in 25 to 50 cm water depth. Seine poles were kept 3 m apart using a measured line so that each haul sampled approximately 60-m<sup>2</sup> of habitat.



**Figure 2-5** Map of the gill net sets along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve, Florida, U.S.A. (30.0225250°N, 81.3262806°W). Monthly seining was conducted on restored sites (artificial oyster reef and fiber log reefs) as well as an unstructured mud bottom site 50-m south of the artificial reef between November 2013 and July 2015. An experimental monofilament gill net approximately 20-m long with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) was used to sample large nekton associated with restored and unrestored intertidal habitats May and December of 2014. Gill nets were set during daylight hours, on an incoming tide, perpendicular to the shoreline, with 0.5-1 hour soak times depending on present conditions.

**Table 2-1** Species list of specimens caught in a 6.1-m bag seine (3.18-mm mesh) bag seine at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between November 2013 and July 2015. Presence in either the restoration site (AR) or adjacent unstructured mud bottom (UMB) habitat is indicated with a P for each sampling year. Species are listed alphabetically, first by order then family and species.

				2013		2014		2015		
	<b>Order</b>	<b>Family</b>	<b>Species</b>	<b>AR</b>	<b>UMB</b>	<b>AR</b>	<b>UMB</b>	<b>AR</b>	<b>UMB</b>	
Vertebrates	<b>Albuliformes</b>	Albulidae	<i>Albula vulpes</i>	--	--		--	P	--	
	<b>Atheriniformes</b>	Atherinopsidae	<i>Menidia</i> sp.	P	P	P	P	P	P	
	<b>Aulopiformes</b>	Synodontidae	<i>Synodus foetens</i>	--	--	P	P	--	P	
	<b>Beloniformes</b>	Belonidae	<i>Strongylura marina</i>	--	--	--	--	P	--	
	<b>Clupeiformes</b>	Clupeidae	<i>Brevoortia smithi</i>	--	--	--	--	P	P	
			<i>Clupea harengus</i>	P	P	--	--	--	--	
		Engraulidae	<i>Anchoa hepsetus</i>	P	P	P	P	P	P	
			<i>Anchoa mitchelli</i>	P	P	P	P	P	P	
	<b>Cyprinodontiformes</b>	Cyprinodontidae	<i>Cyprinodon variegatus</i>	--	--	P	--	P	--	
			<i>Fundulus heteroclitus</i>	--	P	P	P	P	--	
				<i>Fundulus majalis</i>	--	--	P	P	P	--
			Poeciliidae	<i>Poecilia latipinna</i>	--	--	P	--	--	--
	<b>Elopiformes</b>	Elopidae	<i>Elops saurus</i>	--	--	P	P	P	P	
	<b>Mugiliformes</b>	Mugilidae	<i>Mugil curema</i>	--	--	P	--	P	P	
			<i>Mugil</i> sp.	--	--	P	P	P	P	
	<b>Myliobatiformes</b>	Dasyatidae	<i>Dasyatis sabina</i>	--	--	--	--	P	--	
		Gymnuridae	<i>Gymnura micrura</i>	P	--	P	P	P	--	
	<b>Perciformes</b>	Carangidae	<i>Caranx hippos</i>	--	--	--	--	--	--	P
			<i>Chloroscombrus chrysurus</i>	--	P	--	--	--	--	
			<i>Selene vomer</i>	--	--	P	--	--	--	
<i>Trachinotus falcatus</i>			--	--	--	--	P	P		



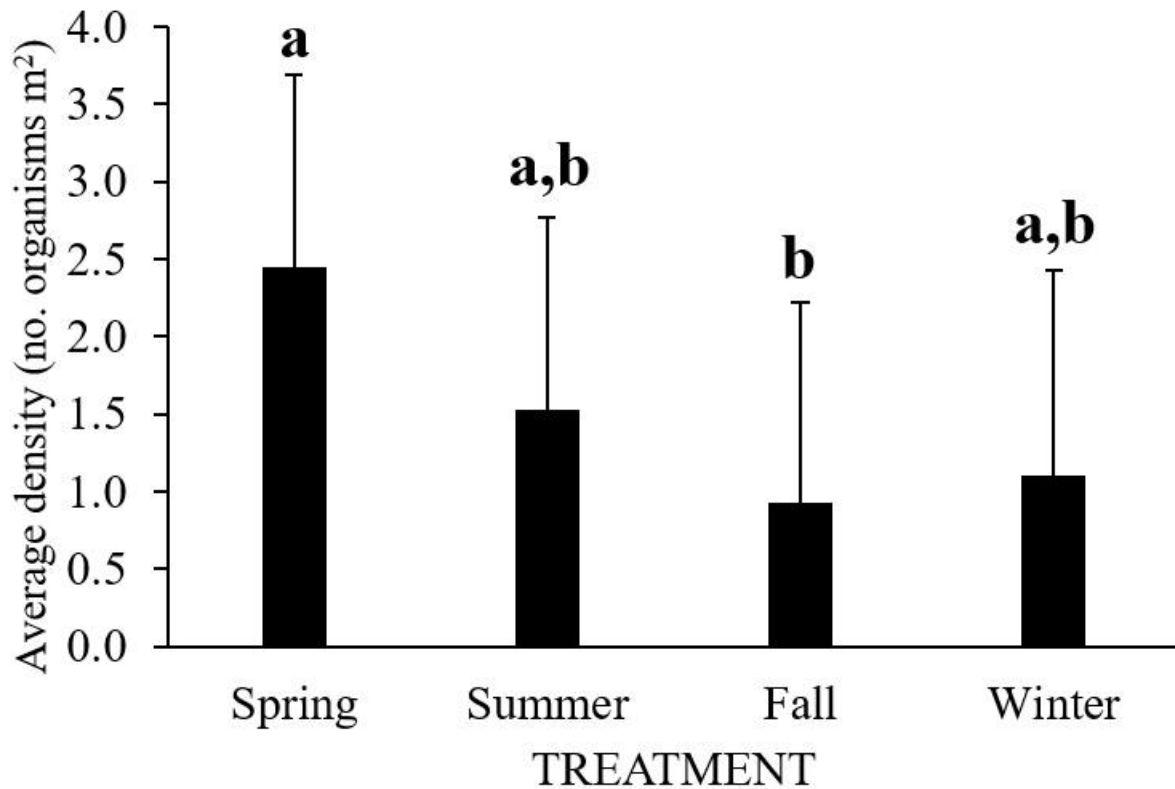
**Table 2-1 (continued)** Species list of specimens caught in a 6.1-m bag seine (3.18-mm mesh) bag seine at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between November 2013 and July 2015. Presence in either the restoration site (AR) or adjacent unstructured mud bottom (UMB) habitat is indicated with a P for each sampling year. Species are listed alphabetically, first by order then family and species.

			2013		2014		2015			
Order	Family	Species	AR	UMB	AR	UMB	AR	UMB		
Vertebrates	<b>Perciformes</b>	Gerreidae	<i>Eucinostomus gula</i>	--	--	P	P	--	--	
			<i>Eucinostomus melopterus</i>	P	P	--	--	--	--	
			<i>Eucinostomus</i> sp.	P	P	P	P	P	P	
			<i>Gerres cinereus</i>	P	--	--	--	--	--	
		Gobiidae	<i>Bathygobius soporator</i>	--	--	P	P	--	--	
			<i>Ctenogobius boleosoma</i>	P	P	P	P	P	P	
			<i>Ctenogobius smaragdus</i>	P	P	P	P	P	--	
			<i>Evorthodus lyricus</i>	--	--	P	--	--	--	
			<i>Gobiosoma bosc</i>	--	--	P	P	P	--	
			Lutjanidae	<i>Lutjanus griseus</i>	--	--	P	--	P	--
			Pomatomidae	<i>Pomatomus saltatrix</i>	--	--	--	P	--	--
		Sciaenidae	<i>Leiostomus xanthurus</i>	--	--	P	P	P	P	
			<i>Cynoscion nebulosus</i>	--	--	P	--	--	--	
			<i>Micropogonias furnieri</i>	--	--	P	--	--	--	
			<i>Micropogonias undulatus</i>	P	--	--	P	--	--	
			<i>Sciaenops ocellatus</i>	--	--	P	--	--	--	
			Serranidae	<i>Diplectrum</i> sp.	--	--	--	--	P	--
		Scombridae	<i>Scomberomorus maculatus</i>	--	--	--	--	P	--	
		Sparidae	<i>Lagodon rhomboides</i>	--	--	--	--	P	P	
		<b>Pleuronectiformes</b>	Achiridae	<i>Trinectes maculatus</i>	P	P	P	--	--	--
Cynoglossidae	<i>Symphurus plagiusa</i>		P	P	P	P	P	P		

**Table 2-1 (continued)** Species list of specimens caught in a 6.1-m bag seine (3.18-mm mesh) bag seine at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between November 2013 and July 2015. Presence in either the restoration site (AR) or adjacent unstructured mud bottom (UMB) habitat is indicated with a P for each sampling year. Species are listed alphabetically, first by order then family and species.

				2013		2014		2015	
	<b>Order</b>	<b>Family</b>	<b>Species</b>	<b>AR</b>	<b>UMB</b>	<b>AR</b>	<b>UMB</b>	<b>AR</b>	<b>UMB</b>
Vertebrates	<b>Pleuronectiformes</b>	Paralichthyidae	<i>Citharichthys spilopterus</i>	P	P	P	P	P	P
			<i>Paralichthys albigutta</i>	--	--	--	P	--	--
			<i>Paralichthys dentatus</i>	--	--	P	P	P	P
			<i>Paralichthys lethostigma</i>	P	--	P	--	P	P
			<i>Paralichthys sp.</i>	--	--	--	--	--	P
	<b>Scorpaeniformes</b>	Triglidae	<i>Prionotus evolans</i>	--	--	--	P	--	--
			<i>Prionotus longispinosus</i>	P	--	--	--	--	--
			<i>Prionotus sp.</i>	--	--	--	P	--	--
	<b>Syngnathidiformes</b>	Syngnathidae	<i>Syngnathus fuscus</i>	--	P	--	--	--	--
			<i>Syngnathus sp.</i>	--	--	--	--	P	P
	<b>Tetradontiformes</b>	Diodontidae	<i>Chilomycterus schoepfii</i>	--	P	--	--	P	--
Tetradontidae		<i>Sphoeroides sp.</i>	--	P	P	--	P	P	
Invertebrates	<b>Decapoda</b>	Alpheidae	<i>Alpheus heterochaelis</i>	--	--	--	--	P	--
		Penaeidae	<i>Farfantepenaeus aztecus</i>	--	--	P	P	P	P
			<i>Litopenaeus setiferus</i>	P	P	P	P	--	P
			<i>Callinectes sapidus</i>	P	--	--	--	--	--
		Portunidae	<i>Callinectes similis</i>	P	P	P	P	P	P
			<i>Callinectes sp.</i>	--	--	P	P	P	P
		<b>Teuthida</b>	Loliginidae	<i>Lolliguncula brevis</i>	P	--	--	--	--



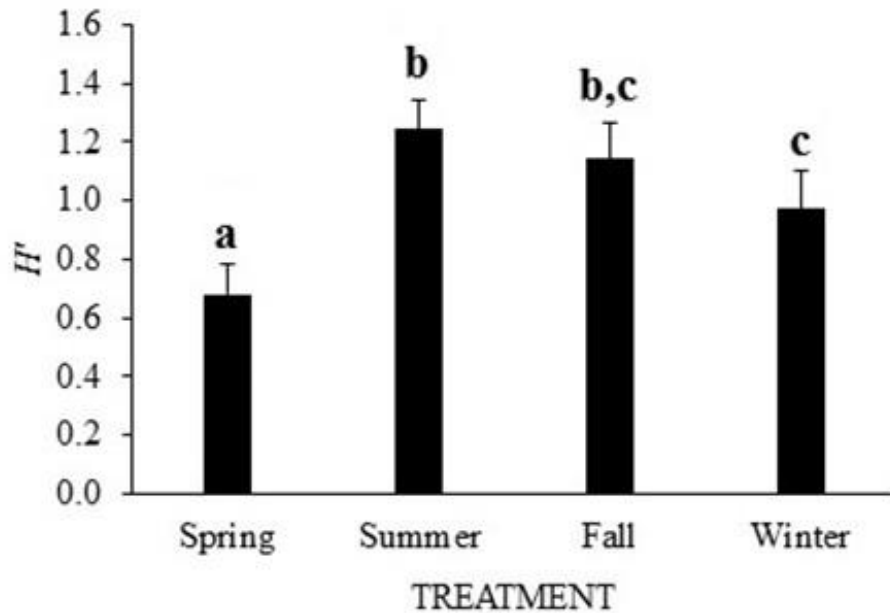


**Figure 2-6** Average density (number of organisms per m<sup>2</sup> sampled, with each seine haul = 60m<sup>2</sup>) of juvenile fish and crustaceans collected in restored and unstructured habitats in a 20-ft bag seine (1/8-in mesh) by season at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A., between November 2013 and July 2015. Spring (n=25); Summer (n=23); Fall (n=16); Winter (n=26). Error bars represent one standard error. Seasons with different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test.

**Table 2-2** Summary of means, standard errors and mean differences of density (number of organisms per m<sup>2</sup> sampled, with each seine haul = 60m<sup>2</sup>) of juvenile fish and crustaceans collected in restored and unstructured habitats in a 20-ft bag seine (1/8-in mesh) by season at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A., between November 2013 and July 2015. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

Season	n	Mean Density (per m <sup>2</sup> )	SE	Mean Differences ( $\bar{X}_i - \bar{X}_j$ )			
				Spring	Summer	Fall	Winter
Spring	25	2.45	1.24	--			
Summer	23	1.53	1.24	0.65	--		
Fall	16	0.93	1.30	0.402*	0.619	--	
Winter	26	1.10	1.33	0.734	1.13	1.825	--

\*  $p < 0.05$



**Figure 2-7** Average Shannon-Weiner ( $H'$ ) diversity indices from seine hauls within restored and unstructured habitats using a 6.1-m bag seine (3.18-mm mesh) of juvenile fish and crustaceans collected by season at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A., between November 2013 and July 2015. Spring (n=25); Summer (n=23); Fall (n=16); Winter (n=26). Error bars represent one standard error. Seasons with different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test.

**Table 2-3** Summary of means, standard errors and mean differences of Shannon-Weiner ( $H'$ ) diversity indices from seine hauls within restored and unstructured habitats using a 6.1-m bag seine (3.18-mm mesh) of juvenile fish and crustaceans collected by season at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A., between November 2013 and July 2015. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

Season	n	Mean Diversity	SE	Mean Differences ( $\bar{X}_i - \bar{X}_j$ )			
				Spring	Summer	Fall	Winter
Spring	25	0.68	0.10	--			
Summer	23	1.24	0.10	0.532*	--		
Fall	16	1.14	0.12	0.423*	-0.109	--	
Winter	26	0.97	0.13	0.121	-0.411*	-0.302	--

\*  $p < 0.05$

**Table 2-4** Spearman's  $\rho$  (N= 90) between density (number of organisms per m<sup>2</sup> sampled, with each seine haul = 60m<sup>2</sup>) and Shannon-Wiener diversity (H') and the regression-estimated parameters of temperature (°C), salinity (ppt), and dissolved oxygen (mg/L) per seine haul. A handheld YSI Pro 2030 Model multiprobe was used to record environmental conditions at each site during each sampling event. Additionally environmental conditions were measured continuously every 15-min throughout the study period by a datasonde deployed at a nearby GTM NERR System-Wide Monitoring Program station, Pine Island (30.05086°N, 81.36747°W). The resulting equations for estimating conditions at the study site were: temperature = 0.987x + 1.293°C (R<sup>2</sup> = 0.978), salinity = 0.619x + 9.36 ppt (R<sup>2</sup> = 0.746), and dissolved oxygen = 0.881x + 1.687 mg/L (R<sup>2</sup> = 0.907).

	Density		Diversity	
	$\rho$ (rho)	p-value	$\rho$ (rho)	p-value
Temperature (°C)	-0.098	0.356	0.334**	0.001
Salinity (ppt)	-0.106	0.322	-0.051	0.632
Dissolved oxygen (mg/L)	0.144	0.175	-0.301**	0.004

\*\* Correlation is significant at the 0.01 level (2-tailed).

**Table 2-5** Summary of CPUE (number of animals per m<sup>2</sup>) for juvenile fishes and mobile crustaceans caught monthly in a 6.1-m bag seine (3.18-mm mesh) by habitat at the Wright's Landing restoration site along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve in October and November 2013. Means (standard error) are presented. Artificial reef (AR) site later became the combination treatment consisting of both artificial oyster reef and fiber logs (n=4) while the unstructured site sampled in 2013 became the northern fiber log only restoration treatment (n=4). Specimens are listed alphabetically by family then species.

	FAMILY	SPECIES	UMB	AR
Vertebrates	Achiridae	<i>Trinectes maculatus</i>	--	0.01 (0.00)
	Atherinopsidae	<i>Menidia</i> sp.	0.22 (0.13)	0.01 (0.00)
	Cynoglossidae	<i>Symphurus plagiusa</i>	0.03 (0.02)	0.05 (0.04)
	Engraulidae	<i>Anchoa hepsetus</i>	0.50 (0.49)	0.11 (0.07)
		<i>Anchoa mitchelli</i>	0.48 (0.43)	0.08 (0.05)
	Fundulidae	<i>Fundulus heteroclitus</i>	--	0.03 (0.02)
	Gerreidae	<i>Eucinostomus melopecterus</i>	--	0.01 (0.01)
		<i>Eucinostomus</i> sp.	0.02 (0.01)	0.12 (0.07)
		<i>Gerres cinereus</i>	0.03 (0.03)	--
	Gobiidae	<i>Bathygobius soporator</i>	--	--
		<i>Ctenogobius boleosoma</i>	0.02 (0.02)	0.15 (0.06)
		<i>Ctenogobius smaragdus</i>	0.06 (0.02)	0.02 (0.02)
	Gymnuridae	<i>Gymnura micrura</i>	0.01 (0.00)	--
	Paralichthyidae	<i>Citharichthys spilopterus</i>	0.03 (0.02)	0.09 (0.06)
		<i>Paralichthys albigutta</i>	--	--
<i>Paralichthys dentatus</i>		--	--	
<i>Paralichthys lethostigma</i>		0.01 (0.00)	--	
Invertebrates	Penaeidae	<i>Litopenaeus setiferus</i>	2.09 (1.81)	0.16 (0.09)
	Portunidae	<i>Scylla serrata</i>	0.01 (0.01)	--
		<i>Callinectes sapidus</i>	0.01 (0.01)	0.08 (0.05)
	Loliginidae	<i>Lolliguncula brevis</i>	0.01 (0.00)	--
		<b>Total</b>	3.55 (1.64)	0.88 (0.09)

**Table 2-6** Summary of CPUE (number of animals per m<sup>2</sup>) for juvenile fishes and mobile crustaceans caught monthly in a 6.1-m bag seine (3.18-mm mesh) by habitat at the Wright's Landing restoration site along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve, January-December 2014. Rare species (only caught once or twice) are not reported in this table. Means (standard error) are presented. Total represents the total for the habitat: all the species included in the entire table. Number of seine hauls represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. Specimens are listed alphabetically by family then species.

FAMILY	SPECIES	Spring (n=12)		Summer (n=12)		Fall (n=8)		Winter (n=14)	
		AR	UMB	AR	UMB	AR	UMB	AR	UMB
Achiridae	<i>Trinectes maculatus</i>	--	--	--	--	0.01 (0.01)	--	--	--
Atherinopsidae	<i>Menidia</i> sp.	1.17 (0.50)	0.19 (0.10)	0.02 (0.01)	--	0.03 (0.03)	0.04 (0.04)	0.35 (0.20)	1.25 (0.47)
Cynoglossidae	<i>Symphurus plagiusa</i>	--	--	0.02 (0.01)	0.02 (0.01)	0.03 (0.00)	0.01 (0.01)	--	0.01 (0.01)
Cyprinodontidae	<i>Cyprinodon variegatus</i>	--	--	--	--	--	--	0.01 (0.00)	--
Elopidae	<i>Elops saurus</i>	0.01 (0.01)	0.01 (0.01)	--	--	--	--	--	--
Engraulidae	<i>Anchoa hepsetus</i>	1.05 (0.67)	0.40 (0.18)	--	0.04 (0.04)	--	--	--	--
	<i>Anchoa mitchelli</i>	0.87 (0.87)	0.53 (0.47)	0.83 (0.57)	0.01 (0.00)	0.03 (0.01)	0.02 (0.01)	--	0.90 (0.61)
Fundulidae	<i>Fundulus heteroclitus</i>	0.06 (0.06)	0.01 (0.01)	0.30 (0.28)	--	--	--	0.44 (0.33)	--
	<i>Fundulus majalis</i>	0.01 (0.01)	0.02 (0.02)	0.04 (0.04)	0.02 (0.01)	--	--	0.03 (0.01)	--
Gerreidae	<i>Eucinostomus gula</i>	--	--	0.01 (0.01)	--	0.03 (0.03)	0.02 (0.02)	--	--
	<i>Eucinostomus</i> sp.	0.01 (0.00)	--	0.12 (0.08)	0.38 (0.29)	0.35 (0.29)	--	--	--
	<b>Total</b>	5.19 (1.33)	2.63 (0.96)	3.37 (0.76)	0.83 (0.25)	1.25 (0.37)	0.34 (0.05)	1.37 (0.56)	2.38 (0.97)

**Table 2-6 (continued)** Summary of CPUE (number of animals per m<sup>2</sup>) for juvenile fishes and mobile crustaceans caught monthly in a 6.1-m bag seine (3.18-mm mesh) by habitat at the Wright's Landing restoration site along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve, January-December 2014. Rare species (only caught once or twice) are not reported in this table. Means (standard error) are presented. Total represents the total for the habitat: all the species included in the entire table. Number of seine hauls represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. Specimens are listed alphabetically by family then species.

FAMILY	SPECIES	Spring (n=12)		Summer (n=12)		Fall (n=8)		Winter (n=14)	
		AR	UMB	AR	UMB	AR	UMB	AR	UMB
Gobiidae	<i>Bathygobius soporator</i>	--	--	--	--	--	--	--	0.01 (0.01)
	<i>Ctenogobius boleosoma</i>	0.03 (0.01)	0.03 (0.01)	0.06 (0.03)	--	0.06 (0.05)	--	0.09 (0.05)	0.02 (0.01)
	<i>Gobiosoma bosc</i>	--	--	--	--	0.01 (0.01)	--	--	--
Gymnuridae	<i>Gymnura micrura</i>	--	--	--	0.01 (0.01)	--	--	--	--
Lutjanidae	<i>Lutjanus griseus</i>	--	--	0.01 (0.01)	--	0.01 (0.01)	--	--	--
Mugilidae	<i>Mugil</i> sp.	0.08 (0.08)	--	0.01 (0.01)	--	--	--	0.27 (0.25)	0.02 (0.02)
Paralichthyidae	<i>Citharichthys spilopterus</i>	--	--	0.01 (0.01)	0.03 (0.02)	0.08 (0.05)	0.04 (0.03)	--	--
	<i>Paralichthys albigutta</i>	--	0.02 (0.01)	--	--	--	--	--	--
	<i>Paralichthys dentatus</i>	--	0.02 (0.02)	0.01 (0.01)	--	--	--	--	--
Poeciliidae	<i>Poecilia latipinna</i>	--	--	0.01 (0.00)	--	--	--	--	--
Pomatomidae	<i>Pomatomus saltatrix</i>	--	0.01 (0.01)	--	--	--	--	--	--
Sciaenidae	<i>Leiostomus xanthurus</i>	1.87 (0.73)	1.35 (1.11)	0.04 (0.02)	--	0.02 (0.02)	--	0.04 (0.03)	0.07 (0.05)
	<i>Cynoscion nebulosus</i>	--	--	0.02 (0.01)	--	0.01 (0.00)	--	--	--
	<i>Micropogonias furnieri</i>	--	--	--	--	0.05 (0.04)	--	--	--
	<i>Sciaenops ocellatus</i>	--	--	--	--	--	--	0.01 (0.01)	--
Synodontidae	<i>Synodus foetens</i>	--	0.01 (0.01)	--	--	--	0.02 (0.02)	--	--
	<b>Total</b>	5.19 (1.33)	2.63 (0.96)	3.37 (0.76)	0.83 (0.25)	1.25 (0.37)	0.34 (0.05)	1.37 (0.56)	2.38 (0.97)



**Table 2-6 (continued)** Summary of CPUE (number of animals per m<sup>2</sup>) for juvenile fishes and mobile crustaceans caught monthly in a 6.1-m bag seine (3.18-mm mesh) by habitat at the Wright's Landing restoration site along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve, January-December 2014. Rare species (only caught once or twice) are not reported in this table. Means (standard error) are presented. Total represents the total for the habitat: all the species included in the entire table. Number of seine hauls represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. Specimens are listed alphabetically by family then species.

FAMILY	SPECIES	Spring (n=12)		Summer (n=12)		Fall (n=8)		Winter (n=14)	
		AR	UMB	AR	UMB	AR	UMB	AR	UMB
Alpheidae	<i>Alpheus heterochaelis</i>	--	--	--	--	--	--	--	--
Penaeidae	<i>Farfantepenaeus aztecus</i>	--	--	0.01 (0.01)	0.04 (0.02)	--	--	--	--
	<i>Litopenaeus setiferus</i>	--	--	1.64 (0.39)	0.22 (0.13)	0.46 (0.39)	0.18 (0.06)	0.05 (0.04)	0.09 (0.05)
Portunidae	<i>Callinectes sapidus</i>	0.02 (0.00)	0.03 (0.01)	0.15 (0.05)	0.05 (0.02)	0.03 (0.03)	--	0.06 (0.03)	0.02 (0.01)
	<i>Callinectes similis</i>	--	--	0.03 (0.02)	--	--	--	0.01 (0.01)	0.01 (0.00)
	<i>Callinectes</i> sp.	--	--	--	--	0.06 (0.04)	0.02 (0.02)	--	--
	<b>Total</b>	5.19 (1.33)	2.63 (0.96)	3.37 (0.76)	0.83 (0.25)	1.25 (0.37)	0.34 (0.05)	1.37 (0.56)	2.38 (0.97)

**Table 2-7** Summary of CPUE (number of animals per 60m<sup>2</sup>) for nekton caught monthly in a 6.1-m bag seine (3.18-mm mesh) by season and habitat at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve in 2014. Means (standard deviations) are presented. Total represents the total for the habitat: all the species included in the entire table. Number of seine hauls represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. Specimens are listed alphabetically by family then species.

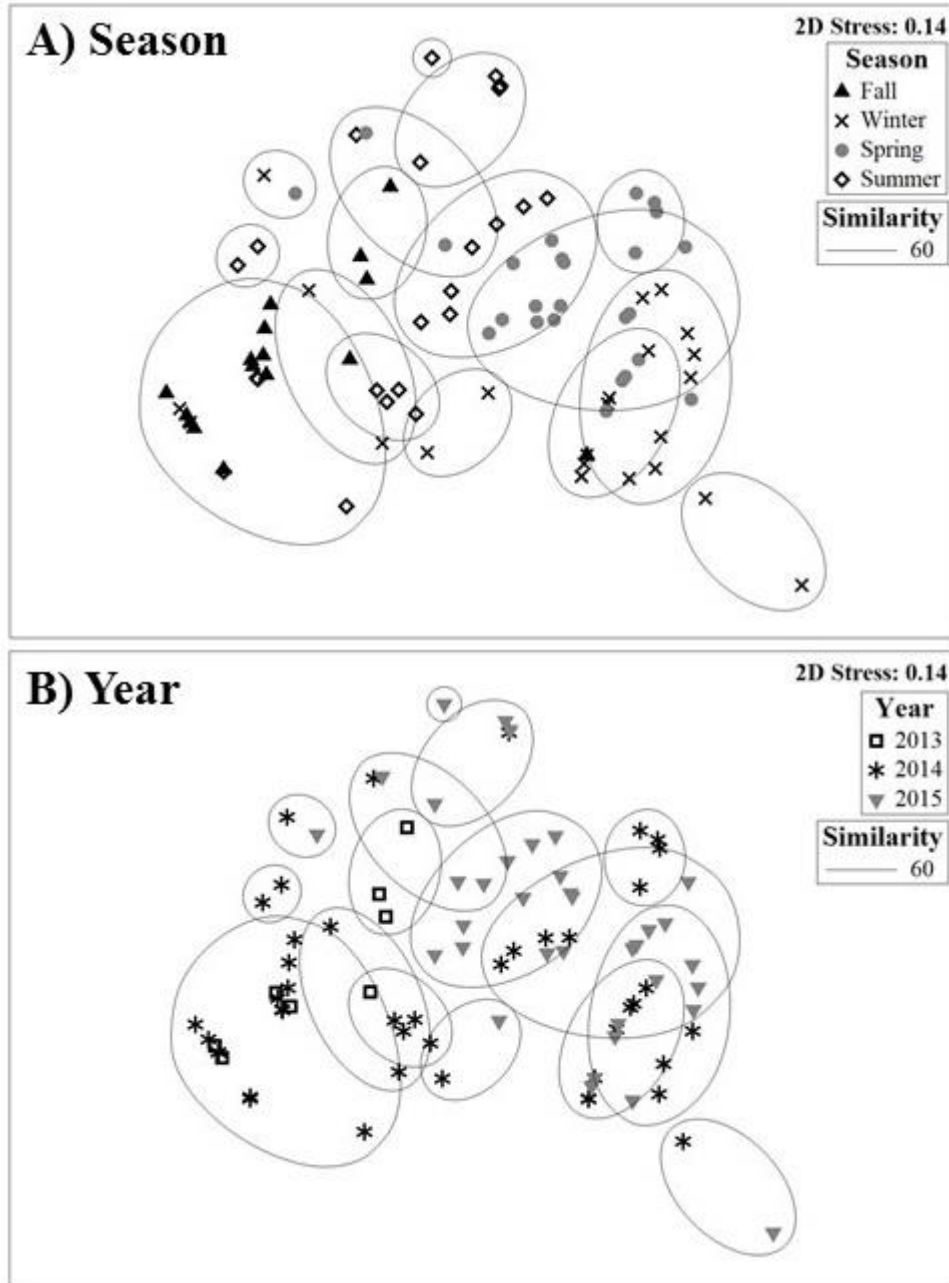
FAMILY	SPECIES	Spring (n=12)		Summer (n=12)		Fall (n=8)		Winter (n=12)	
		AR	UMB	AR	UMB	AR	UMB	AR	UMB
Albulidae	<i>Albula vulpes</i>	0.02 (0.02)	--	--	--	--	--	--	--
Atherinopsidae	<i>Menidia</i> sp.	0.24 (0.20)	0.17 (0.07)	0.84 (0.68)	--	--	--	0.14 (0.05)	0.02 (0.01)
Carangidae	<i>Caranx hippos</i>	--	--	--	0.03 (0.03)	--	--	--	--
Cynoglossidae	<i>Symphurus plagiusa</i>	0.01 (0.01)	--	--	0.01 (0.01)	--	--	--	0.01 (0.01)
Cyprinodontidae	<i>Cyprinodon variegatus</i>	--	--	--	--	--	--	0.02 (0.02)	--
Engraulidae	<i>Anchoa hepsetus</i>	0.30 (0.30)	0.01 (0.01)	0.03 (0.03)	0.02 (0.01)	--	--	--	0.16 (0.15)
	<i>Anchoa mitchelli</i>	0.01 (0.01)	0.11 (0.09)	0.02 (0.01)	0.23 (0.15)	--	--	--	--
Elopidae	<i>Elops saurus</i>	0.01 (0.01)	0.03 (0.01)	--	--	--	--	--	--
Fundulidae	<i>Fundulus heteroclitus</i>	0.02 (0.01)	--	--	--	--	--	0.08 (0.05)	--
	<i>Fundulus majalis</i>	--	--	--	--	--	--	0.03 (0.02)	--
Gerreidae	<i>Eucinostomus</i> sp.	--	--	0.17 (0.08)	0.09 (0.04)	--	--	--	--
Gobiidae	<i>Ctenogobius boleosoma</i>	0.08 (0.04)	0.02 (0.01)	0.14 (0.06)	0.01 (0.00)	--	--	0.23 (0.09)	0.05 (0.02)
	<i>Ctenogobius smaragdus</i>	0.01 (0.01)	--	0.01 (0.00)	--	--	--	--	--
	<i>Gobiosoma bosc</i>	--	--	0.01 (0.01)	--	--	--	--	--
<b>Total</b>		5.79 (4.0)	1.49 (0.36)	4.75 (1.99)	0.93 (0.4)			5.37 (1.67)	3.58 (2.31)

**Table 2-7 (continued)** Summary of CPUE (number of animals per 60m<sup>2</sup>) for nekton caught monthly in a 6.1-m bag seine (3.18-mm mesh) by season and habitat at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve in 2014. Means (standard deviations) are presented. Total represents the total for the habitat: all the species included in the entire table. Number of seine hauls represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. Specimens are listed alphabetically by family then species.

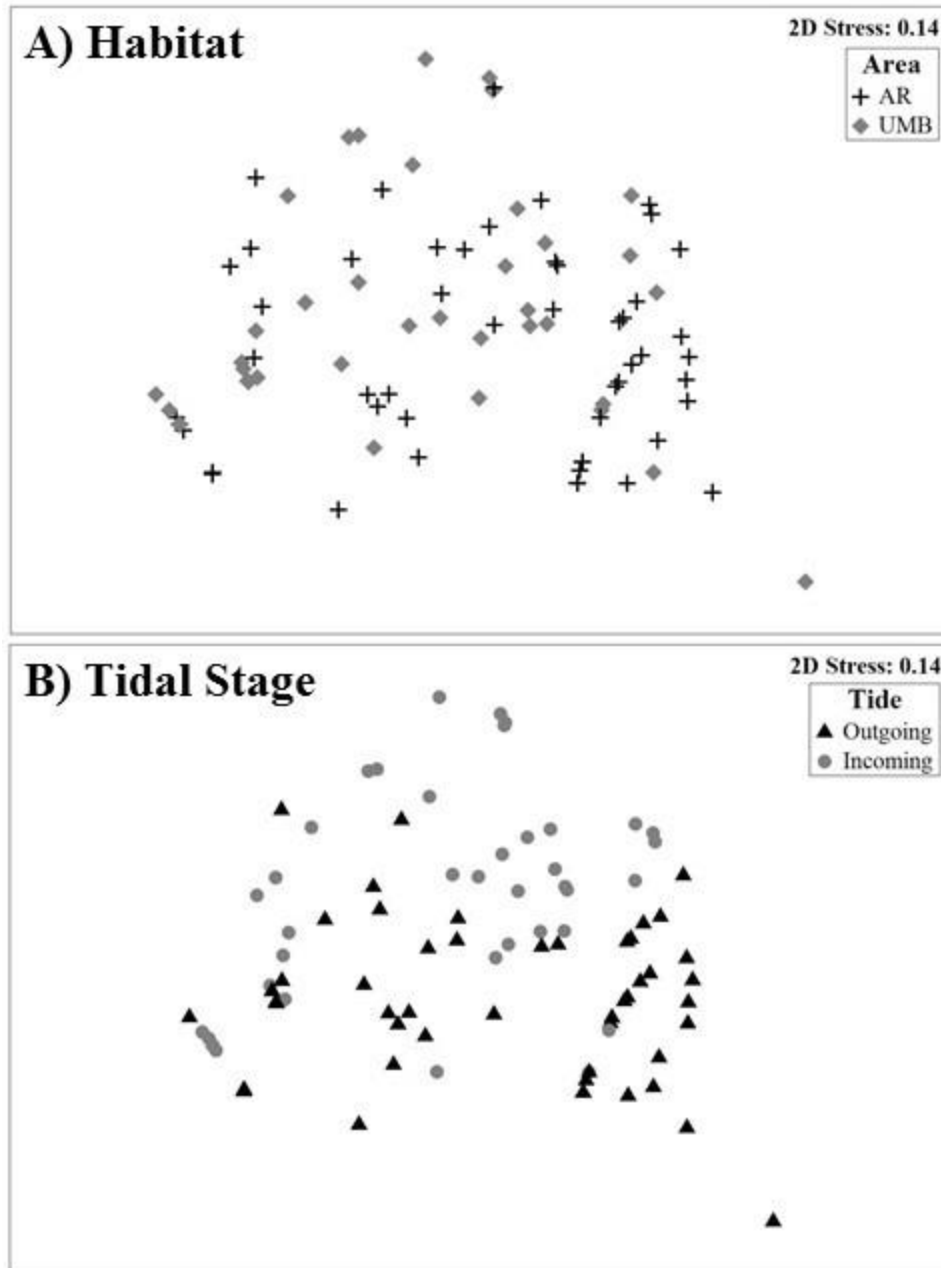
FAMILY	SPECIES	Spring (n=12)		Summer (n=12)		Fall (n=8)		Winter (n=12)	
		AR	UMB	AR	UMB	AR	UMB	AR	UMB
Mugilidae	<i>Mugil curema</i>	--	--	--	--	--	--	0.43 (0.28)	0.01 (0.01)
	<i>Mugil</i> sp.	--	--	--	--	--	--	0.03 (0.03)	2.63 (2.58)
Paralichthyidae	<i>Citharichthys spilopterus</i>	0.02 (0.01)	--	0.03 (0.01)	0.01 (0.01)	--	--	--	--
	<i>Paralichthys dentatus</i>	--	--	0.01 (0.00)	--	--	--	--	--
	<i>Paralichthys lethostigma</i>	0.01 (0.01)	--	--	--	--	--	--	--
	<i>Paralichthys</i> sp.	--	--	--	--	--	--	--	0.01 (0.00)
Sciaenidae	<i>Leiostomus xanthurus</i>	4.65 (3.53)	0.76 (0.35)	0.15 (0.07)	0.23 (0.19)	--	--	4.11 (1.48)	0.40 (0.24)
Scombridae	<i>Scomberomorus maculatus</i>	--	--	0.01 (0.00)	--	--	--	--	--
Serranidae	<i>Diplectrum</i> sp.	0.01 (0.00)	--	--	--	--	--	--	--
Sparidae	<i>Lagodon rhomboides</i>	--	--	--	0.01 (0.01)	--	--	0.04 (0.03)	0.23 (0.12)
Synodontidae	<i>Synodus foetens</i>	--	--	--	0.03 (0.02)	--	--	--	--
Tetradontidae	<i>Sphoeroides</i> sp.	--	--	0.01 (0.00)	0.01 (0.00)	--	--	--	--
	<b>Total</b>	5.79 (4.0)	1.49 (0.36)	4.75 (1.99)	0.93 (0.4)			5.37 (1.67)	3.58 (2.31)

**Table 2-7 (continued)** Summary of CPUE (number of animals per 60m<sup>2</sup>) for nekton caught monthly in a 6.1-m bag seine (3.18-mm mesh) by season and habitat at the Wright's Landing restoration site within the northern Guana Tolomato Matanzas National Estuarine Research Reserve in 2014. Means (standard deviations) are presented. Total represents the total for the habitat: all the species included in the entire table. Number of seine hauls represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. Specimens are listed alphabetically by family then species.

FAMILY	SPECIES	Spring (n=12)		Summer (n=12)		Fall (n=8)		Winter (n=12)	
		AR	UMB	AR	UMB	AR	UMB	AR	UMB
Alpheidae	<i>Alpheus heterochaelis</i>	--	--	0.01 (0.00)	--	--	--	--	--
Penaeidae	<i>Farfantepenaeus aztecus</i>	0.10 (0.06)	0.31 (0.20)	3.19 (2.18)	0.17 (0.04)	--	--	--	--
	<i>Litopenaeus setiferus</i>	--	--	--	0.03 (0.02)	--	--	--	--
Portunidae	<i>Callinectes sapidus</i>	0.28 (0.16)	0.07 (0.03)	0.10 (0.03)	0.05 (0.02)	--	--	0.18 (0.08)	0.05 (0.04)
	<i>Callinectes similis</i>	--	--	--	--	--	--	0.03 (0.02)	0.01 (0.01)
	<i>Callinectes</i> sp.	--	--	--	--	--	--	0.06 (0.04)	--
	<b>Total</b>	5.79 (4.0)	1.49 (0.36)	4.75 (1.99)	0.93 (0.4)			5.37 (1.67)	3.58 (2.31)



**Figure 2-8** Spatial similarity of juvenile fish and mobile crustacean assemblages demonstrated with non-metric multidimensional scaling between October 2013 and July 2015 by A) Season and B) Year. Each point represents the fourth root transformed species abundance (number tray<sup>-1</sup>) for each seine haul (N=89) in both artificially restored and unstructured habitats. Ovals indicate a similarity of 60% as a result of CLUSTER analysis. Sampling took place within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A. 2-D stress: 0.14.



**Figure 2-9** Spatial similarity of juvenile fish and mobile crustacean assemblages demonstrated with non-metric multidimensional scaling between October 2013 and July 2015 by A) Habitat and B) Tidal Stage. Each point represents the fourth root transformed species abundance (number tray<sup>-1</sup>) for each seine haul (N=89) in both artificially restored and unstructured habitats. Habitat AR represents the artificial site consisting of both artificial oyster and fiber log treatments; UMB is an unstructured site 50-m south of the artificial reef. Sampling took place within the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A. 2-D stress: 0.14.

**Table 2-8** Summary of CPUE (number of animals per soak hour) for nekton caught in a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) by season and habitat along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and November 2014. Means (standard deviations) are presented. Number of nets set represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. (NR) are natural oyster reefs. UMB and NR sites were located in both the Guana and Tolomato Rivers. Specimens are listed alphabetically by order, then family and species.

ORDER	FAMILY	SPECIES	Spring (n=11)			Summer (n=56)		
			UMB	NR	AR	UMB	NR	AR
<b>Carcharhiniformes</b>	Carcharhinidae	<i>Carcharhinus limbatus</i>	0	0	0	0	0.03 (0.03)	0
		<i>Rhizoprionodon terranovae</i>	0	0	0	0	0.25 (0.12)	0.16 (0.12)
	Sphyrnidae	<i>Sphyrna lewini</i>	0	0	0	0.15 (0.2)	0.09 (0.07)	0.1 (0.1)
		<i>Sphyrna tiburo</i>	0	0	4.17 (4.17)	0.3 (0.2)	0.25 (0.11)	0
<b>Elopiformes</b>	Elopidae	<i>Elops saurus</i>	0.78 (0.78)	2.46 (1.21)	5.06 (3.73)	0.15 (0.2)	0.39 (0.13)	0.19 (0.11)
<b>Clupeiformes</b>	Clupeidae	<i>Brevoortia tyrannus</i>	0	2.12 (1.42)	0.33 (0.33)	0	0.46 (0.25)	0.15 (0.10)
		<i>Dorosoma petenense</i>	0	0	0	0	0	0.06 (0.06)
	Engraulidae	<i>Anchoa hepsetus</i>	0	0	0	0.13 (0.1)	0	0
<b>Siluriformes</b>	Ariidae	<i>Ariopsis felis</i>	0	0	0.33 (0.33)	0.42 (0.2)	1.26 (0.34)	0.32 (0.14)
<b>Mugiliformes</b>	Mugilidae	<i>Mugil cephalus</i>	0	0	0	0	0.14 (0.07)	0.26 (0.12)
		<i>Mugil curema</i>	0	0.25 (0.25)	0	0	0.03 (0.02)	0.11 (0.08)
		<i>Mugil</i> sp.	0	0	0	0	0	0
<b>Beloniformes</b>	Belonidae	<i>Strongylura marina</i>	0	0	0	0	0.08 (0.05)	0
<b>Pleuronectiformes</b>	Paralichthyidae	<i>Paralichthys dentatus</i>	0	0	0	0	0.03 (0.02)	0
		<i>Paralichthys lethostigma</i>	0	0	0	0	0	

**Table 2-8 (continued)** Summary of CPUE (number of animals per soak hour) for nekton caught in a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) by season and habitat along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and November 2014. Means (standard deviations) are presented. Number of nets set represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. (NR) are natural oyster reefs. UMB and NR sites were located in both the Guana and Tolomato Rivers. Specimens are listed alphabetically by order, then family and species.

ORDER	FAMILY	SPECIES	Fall (n=21)			Winter (n=8)		
			UMB	NR	AR	UMB	NR	AR
<b>Carcharhiniformes</b>	Carcharhinidae	<i>Carcharhinus limbatus</i>	0	0	0	0	0	0
		<i>Rhizoprionodon terranovae</i>	0	0	0	0	0	0
	Sphyrnidae	<i>Sphyrna lewini</i>	0	0	0	0	0	0
		<i>Sphyrna tiburo</i>	0	0.09 (0.11)	0	0	0	0
<b>Elopiformes</b>	Elopidae	<i>Elops saurus</i>	0.11 (0.11)	0.40 (0.21)	0	0	0.24 (0.24)	0
<b>Clupeiformes</b>	Clupeidae	<i>Brevoortia tyrannus</i>	0	0.09 (0.11)	0	0	0.26 (0.26)	0
		<i>Dorosoma petenense</i>	0	0	0	0	0	0
	Engraulidae	<i>Anchoa hepsetus</i>	0	0.09 (0.12)	0	0	0	0
<b>Siluriformes</b>	Ariidae	<i>Ariopsis felis</i>	0	0.83 (0.72)	0	0	0	0
<b>Mugiliformes</b>	Mugilidae	<i>Mugil cephalus</i>	0.10 (0.10)	0.42 (0.28)	2.00 (1.41)	0	0.46 (0.46)	0
		<i>Mugil curema</i>	0.71 (0.48)	0.93 (1.02)	0	0.56 (0.56)	1.25 (0.74)	0
		<i>Mugil</i> sp.	0	0	0	0	0	1
<b>Beloniformes</b>	Belonidae	<i>Strongylura marina</i>	0.61 (0.33)	1.17 (1.25)	0	0	1.28 (1)	0
<b>Pleuronectiformes</b>	Paralichthyidae	<i>Paralichthys dentatus</i>	0	0	0.21 (0.15)	0	0	0
		<i>Paralichthys lethostigma</i>	0	0	0	0	0	0



**Table 2-8 (continued):** Summary of CPUE (number of animals per soak hour) for nekton caught in a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) by season and habitat along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and November 2014. Means (standard deviations) are presented. Number of nets set represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. (NR) are natural oyster reefs. UMB and NR sites were located in both the Guana and Tolomato Rivers. Specimens are listed alphabetically by order, then family and species.

ORDER	FAMILY	SPECIES	Spring (n=11)			Summer (n=56)		
			UMB	NR	AR	UMB	NR	AR
<b>Perciformes</b>	Carangidae	<i>Caranx hippos</i>	0	1.04 (0.75)	0	0	0.35 (0.12)	0.1 (0.1)
	Ephippidae	<i>Chaetodipterus faber</i>	0	0	0	0	0.06 (0.04)	0
	Gerreidae	<i>Eucinostomus</i> spp.	0	0	0	0.16 (0.2)	0.06 (0.04)	0
	Haemulidae	<i>Orthopristis chrysoptera</i>	0	0	0	0	0.06 (0.06)	0
	Pomatomidae	<i>Pomatomus saltatrix</i>	0	0	0.28 (0.28)	0	0.08 (0.05)	0
	Sciaenidae	<i>Bairdiella chrysoura</i>	0	0	0	0	0	0
			<i>Cynoscion arenarias</i>	0	0	0	0	0
		<i>Cynoscion nebulosus</i>	5.68 (0.99)	0.29 (0.29)	0	0.72 (0.4)	0.28 (0.10)	0.55 (0.17)
		<i>Leiostomus xanthurus</i>	0	1.67 (1.67)	0	0.15 (0.1)	2.92 (1.18)	0
		<i>Menticirrhus americanus</i>	0	0	0	0.27 (0.2)	0.15 (0.11)	0.06 (0.06)
		<i>Micropogonias undulatus</i>	0	0	0	0.15 (0.2)	0.16 (0.09)	0
		<i>Sciaenops ocellatus</i>	0	0	0	0	0.12 (0.07)	0
	Scombridae	<i>Scomberomorus maculatus</i>	0	0	0	0	0.10 (0.10)	0
Sparidae	<i>Lagodon rhomboides</i>	0	0	0	0	0.48 (0.18)	0.09 (0.09)	
<b>Decapoda</b>	Portunidae	<i>Callinectes sapidus</i>	0	0	4.17 (4.17)	0.14 (0.1)	0.13 (0.08)	0

**Table 2-8 (continued):** Summary of CPUE (number of animals per soak hour) for nekton caught in a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) by season and habitat along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and November 2014. Means (standard deviations) are presented. Number of nets set represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. (NR) are natural oyster reefs. UMB and NR sites were located in both the Guana and Tolomato Rivers. Specimens are listed alphabetically by order, then family and species.

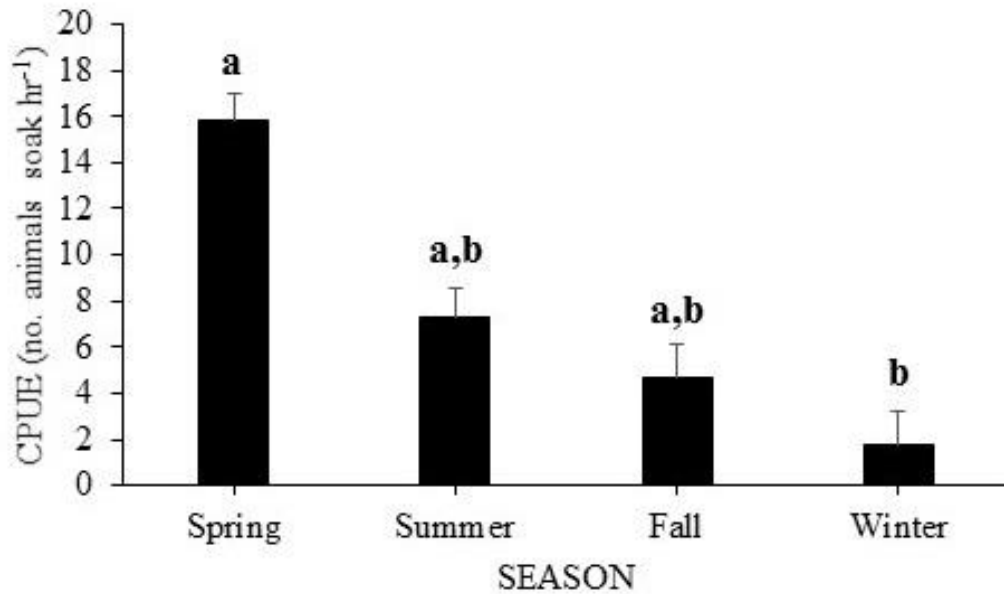
ORDER	FAMILY	SPECIES	Fall (n=21)			Winter (n=8)		
			UMB	NR	AR	UMB	NR	AR
<b>Perciformes</b>	Carangidae	<i>Caranx hippos</i>	0	0.21 (0.18)	0	0	0	0
	Ephippidae	<i>Chaetodipterus faber</i>	0	0	0	0	0	0
	Gerreidae	<i>Eucinostomus</i> spp.	4.24 (4.24)	0	0.21 (0.15)	0	0	0
	Haemulidae	<i>Orthopristis chrysoptera</i>	0	0.19 (0.24)	0	0	0	0
	Pomatomidae	<i>Pomatomus saltatrix</i>	0.13 (0.13)	0	0.69 (0.49)	0	1.49 (0.67)	0
	Sciaenidae	<i>Bairdiella chrysoura</i>	0	0	0.34 (0.24)	0	0	0
		<i>Cynoscion arenarias</i>	0.13 (0.13)	0.17 (0.14)	0	0	0	0
		<i>Cynoscion nebulosus</i>	0	0.10 (0.12)	0.21 (0.15)	0	0.46 (0.46)	0
		<i>Leiostomus xanthurus</i>	0.11 (0.11)	0.52 (0.38)	0	0	0	0
		<i>Menticirrhus americanus</i>	0	0.08 (0.09)	0.34 (0.24)	0	0	0
		<i>Micropogonias undulatus</i>	0	0.10 (0.12)	0.21 (0.15)	0	0	0
		<i>Sciaenops ocellatus</i>	0	0	0	0	0	0
	Scombridae	<i>Scomberomorus maculatus</i>	0	0	0	0	0	0
	Sparidae	<i>Lagodon rhomboides</i>	0.11 (0.11)	0.26 (0.25)	0.00	0	0	0
<b>Decapoda</b>	Portunidae	<i>Callinectes sapidus</i>	0	0	0.34 (0.24)	0	0	0

**Table 2-9** Summary of CPUE (number of animals per soak hour) for nekton caught in a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) by river and habitat along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and November 2014. Means (standard deviations) are presented. Number of nets set represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. (NR) are natural oyster reefs. Specimens are listed alphabetically by order, then family and species.

ORDER	FAMILY	SPECIES	Tolomato River (n=61)			Guana River (n=35)		
			UMB	NR	AR	UMB	NR	AR
<b>Carcharhiniformes</b>	Carcharhinidae	<i>Carcharhinus limbatus</i>	0	0	0	0	0.03 (0.03)	--
		<i>Rhizoprionodon terranovae</i>	0	0	0.12 (0.09)	0	0.26 (0.13)	--
	Sphyrnidae	<i>Sphyrna lewini</i>	0.08 (0.08)	0	0.07 (0.07)	0	0.10 (0.08)	--
		<i>Sphyrna tiburo</i>	0.16 (0.11)	0.17 (0.09)	0.50 (0.50)	0	0.17 (0.10)	--
<b>Elopiformes</b>	Elopidae	<i>Elops saurus</i>	0.20 (0.14)	0.72 (0.36)	0.74 (0.50)	0.13 (0.13)	0.54 (0.17)	--
<b>Clupeiformes</b>	Clupeidae	<i>Brevoortia tyrannus</i>	0	0.23 (0.11)	0.15 (0.08)	0	0.82 (0.40)	--
		<i>Dorosoma petenense</i>	0	0	0.04 (0.04)	0	0	--
	Engraulidae	<i>Anchoa hepsetus</i>	0.07 (0.07)	0.04 (0.04)	0	0	0	--
<b>Siluriformes</b>	Ariidae	<i>Ariopsis felis</i>	0.23 (0.12)	0.16 (0.09)	0.27 (0.11)	0	1.53 (0.40)	--
<b>Mugiliformes</b>	Mugilidae	<i>Mugil cephalus</i>	0	0.17 (0.10)	0.43 (0.25)	0.13 (0.13)	0.23 (0.11)	--
		<i>Mugil curema</i>	0.27 (0.19)	0.17 (0.10)	0.08 (0.06)	0.51 (0.51)	0.58 (0.33)	--
		<i>Mugil</i> sp.	0	0	0.03 (0.03)	0	0	--
<b>Beloniformes</b>	Belonidae	<i>Strongylura marina</i>	0.07 (0.07)	0.25 (0.16)	0	0.55 (0.39)	0.53 (0.38)	--
<b>Pleuronectiformes</b>	Paralichthyidae	<i>Paralichthys dentatus</i>	0	0.04 (0.04)	0.03 (0.03)	0	0	--
		<i>Paralichthys lethostigma</i>	0	0	0.04 (0.04)	0	0	--

**Table 2-9 (continued):** Summary of CPUE (number of animals per soak hour) for nekton caught in a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) by river and habitat along the Guana Peninsula within the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and November 2014. Means (standard deviations) are presented. Number of nets set represented as (n=#). Artificial (AR) includes artificial oyster reefs as well as a combination of artificial oyster reef and fiber-coir log. The unstructured mud bottom (UMB) site was 50-m south of the artificial reef along the Guana Peninsula. (NR) are natural oyster reefs. Specimens are listed alphabetically by order, then family and species.

ORDER	FAMILY	SPECIES	Tolomato River (n=61)			Guana River (n=35)			
			UMB	NR	AR	UMB	NR	AR	
<b>Perciformes</b>	Carangidae	<i>Caranx hippos</i>	0	0.28 (0.14)	0.07 (0.07)	0	0.44 (0.18)	--	
	Ephippidae	<i>Chaetodipterus faber</i>	0	0.08 (0.06)	0	0	0	--	
	Gerreidae	<i>Eucinostomus</i> spp.	0.08 (0.08)	0.08 (0.06)	0.03 (0.03)	4.95 (4.04)	0	--	
	Haemulidae	<i>Orthopristis chrysoptera</i>	0	0.09 (0.09)	0	0	0.07 (0.07)	--	
	Pomatomidae	<i>Pomatomus saltatrix</i>	0.07 (0.07)	0.22 (0.19)	0.12 (0.09)	0	0.08 (0.06)	--	
	Sciaenidae	<i>Bairdiella chrysoura</i>		0	0	0.04 (0.04)	0	0	--
				0.07 (0.07)	0.08 (0.06)	0	0	0	--
				1.26 (0.59)	0.52 (0.16)	0.42 (0.13)	0	0.05 (0.05)	--
				0.08 (0.08)	0.43 (0.32)	0	0.13 (0.13)	3.33 (1.27)	--
				0.14 (0.10)	0.19 (0.16)	0.09 (0.06)	0	0.04 (0.04)	--
				0.08 (0.08)	0.21 (0.13)	0.03 (0.03)	0	0.04 (0.04)	--
				0	0.17 (0.10)	0	0	0	--
	Scombridae	<i>Scomberomorus maculatus</i>	0	0	0	0	0.11 (0.11)	--	
	Sparidae	<i>Lagodon rhomboides</i>	0	0.29 (0.14)	0.07 (0.07)	0.13 (0.13)	0.38 (0.18)	--	
<b>Decapoda</b>	Portunidae	<i>Callinectes sapidus</i>	0.08 (0.08)	0	0.54 (0.50)	0	0.14 (0.09)	--	



**Figure 2-10** Average CPUE (number of animals per soak hour) for a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) sampled along restored and unrestored intertidal habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (30.0225250°N, 81.3262806°W), Florida, U.S.A. between May and December 2014. Error bars represent one standard error. Different letters indicate significant difference using Tukey's Honestly Significant Difference post-hoc test.

**Table 2-10** Summary of back transformed means, standard errors and mean differences of the CPUE (number of animals per soak hour) for a 20-m monofilament gill net with four 5-m panels (stretch-mesh sizes 2.54, 5.08, 6.35, and 7.62-cm) sampled along restored and unrestored intertidal habitats along the Guana Peninsula in the northern Guana Tolomato Matanzas National Estuarine Research Reserve between May and December 2014. Significance levels presented next to mean differences are from Tukey's Honestly Significant Difference (HSD) post hoc tests.

River	Season	n	Mean CPUE	SE	Mean Differences ( $\bar{X}_i - \bar{X}_j$ )			
					Spring	Summer	Fall	Winter
Tolomato	Spring	9	4.43	1.46	--			
	Summer	32	2.54	1.13	-1.75	--		
	Fall	11	3.00	1.23	-1.48	1.18	--	
	Winter	4	2.90	1.72	-1.48	1.18	1.00	--
Guana	Spring	2	15.85	1.12	--			
	Summer	14	7.30	1.22	-2.17	--		
	Fall	10	4.66	1.45	-3.40	-1.57	--	
	Winter	4	1.79	1.45	-8.86*	-4.08	-2.60	--

\*  $p < 0.05$

**Table 2-11** Spearman's  $\rho$  (N= 86) between CPUE (number of animals per soak hour) and temperature ( $^{\circ}\text{C}$ ), salinity (ppt), and dissolved oxygen (mg/L) per seine haul. A handheld YSI Pro 2030 Model multiprobe was used to record environmental conditions at each site during each sampling event.

	<b>CPUE</b>	
	$\rho$ (rho)	p-value
Temperature ( $^{\circ}\text{C}$ )	0.014	0.902
Salinity (ppt)	0.171	0.116
Dissolved oxygen (mg/L)	-0.110	0.315

## APPENDIX I

### The GTM NERR Wright's Landing Living Shoreline Project

In spring 2012, the Guana Tolomato Matanzas National Estuarine Research Reserve (GTM NERR) began the installation of a living shoreline project to mitigate the erosion occurring along the Guana Peninsula in Northeast Florida. The installation of artificial oyster reefs constructed of plastic mesh bags filled with recycled oyster shell was funded through a grant from the Southeast Aquatic Resources Partnership. These reef segments, 28 in total, extend along approximately 1000 linear feet of the Guana Peninsula shoreline (Figures 1,2). Each reef (avg 5.5 L x 1.8 W x 4.3 H m) was approximately 9.8-m<sup>2</sup> and installed in the low intertidal zone within 11.3-m from the *Spartina* marsh edge (minimum 6.6-m, maximum 23-m). The last of the reef segments were completed in the summer of 2013.

Through a grant from the Atlantic Coastal Fish Habitat Partnership, an additional artificial treatment using fiber (coir) logs was installed along the marsh edge in April 2014 (Figures 3, 4). These logs were modeled after the DELSI method used in the Delaware Bay Estuary (Whalen et al. 2013). Each log was approximately 10-ft long and was installed atop a coconut fiber mat with wooden stakes placed every two feet on either side of the log and secured with twine to prevent further movement. Logs were installed in two 20-m arcs along the shoreline with two pairs placed within the original artificial oyster reef and another two pairs installed approximately 100-m north along the same shoreline as a stand-alone treatment.

Biological monitoring on the site began in the summer of 2013 with some specific projects beginning in the fall of 2013. This monitoring has been a collaboration of many researchers from the University of North Florida, Jacksonville, FL, Flagler College, St. Augustine, FL, as well as the GTM NERR staff.



Fiber log movement was observed in the summer following installation (Figure 5). The stakes did not appear to secure the logs enough especially when inundated from boat wakes. The Tolomato River is heavily trafficked as part of the Atlantic Intracoastal Waterway system. Large yachts and pleasure boats frequent this area in the spring and fall seasons and increase the amount of wake energy along the shorelines. As the logs were installed in the middle of the spring season, they endured many wakes and large amounts of wave energy. Additionally, in the summer after installation, shipworms (*Teredo* sp.) colonized the wooden stakes leading to the degradation of the support for the fiber logs (Figure 6). In November 2014, many of the fiber logs came loose from their stakes, degraded, and were found in the high intertidal marsh as wrack. The remaining logs and debris were removed in January 2015 (Figures 7, 8).



**Figure I-1** Map of oyster restoration along Wright’s Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve (GTM NERR). Wright's Landing is along the eastern shoreline of the Tolomato River on th Guana peninsula. Fiber logs were installed within the Benthic habitat 5m from the marsh edge in addition to 100-m north of the reef along the same shoreline. Source: Friends of the GTM Reserve <http://gtmnerr.org/Oyster-Reef-Restoration-Project.php>



**Figure I-2** Installed artificial reef segments along Wright's Landing Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken September 4, 2013 following the installation of the final segments on the southern end.



**Figure I-3** Complete fiber log installation on the southern end of the existing artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken April 26, 2014 following the installation. Logs were placed in 20-m arcs behind the constructed oyster reefs using wooden stakes and twine. Plastic mesh bags filled with oyster cultch were placed in front of the logs for stabilization.





**Figure I-4** Complete fiber log installation 100-m north of the existing artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken July 15, 2014 following the installation. Logs were placed in 20-m arcs approximately five meters in front of *Spartina* marsh grass on unstructured eroding shoreline using wooden stakes and twine. Plastic mesh bags filled with oyster cultch were placed in front of the logs for stabilization.



**Figure I-5** Fiber log movement on the southern installation of the combination of artificial oyster reef and fiber log site along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken July 15, 2014 after the installation of the fiber log only treatment was installed 100-m north of the artificial oyster reef.



**Figure I-6** Evidence of shipworm (*Teredo* sp.) colonization of the wooden stakes securing all the fiber logs installed within the artificial oyster reef as the combination living shoreline treatment along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken July 15, 2014 after the installation of the fiber log only treatment was installed 100-m north of the artificial oyster reef.





**Figure I-7** Degradation and partial removal of the fiber logs installed 100-m north of the existing artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. Photo was taken January 17, 2015. Logs were placed in 20-m arcs approximately five meters in front of *Spartina* marsh grass on unstructured eroding shoreline using wooden stakes and twine in July 2014.





**Figure I-8** After the partial removal of degraded fiber log material off the northern end of the artificial oyster reef along Wright's Landing in the northern Guana Tolomato Matanzas National Estuarine Research Reserve. This was the northern combination living shoreline site with both the artificial reefs and fiber logs. Photo was taken in January 17, 2015.

## REFERENCES

- Able, KW, and MP Fahay. 2010. *Ecology of Estuarine Fishes: Temperate Waters of the Western North Atlantic*. Baltimore, MD: John Hopkins Press.
- Beck, MW, KL Heck Jr, KW Able, L Daniel, DB Eggleston, BM Gillanders, B Halpern, CG Hays, K Hoshino, TJ Minello, RJ Orth, PF Sheridan, and MP Weinstein. 2001. The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates. *BioScience* 51: 633–641.
- Beck, MW, RD Brumbaugh, L Airoidi, A Carranza, LD Coen, C Crawford, O Defeo, GJ Edgar, B Hancock, MC Kay, HS Lenihan, MW Luckenbach, CL Toropova, G Zhang, and X Guo. 2011. Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management. *BioScience* 61: 107–116. doi:10.1525/bio.2011.61.2.5.
- Bertness, MD. 1984. Ribbed mussels and *Spartina alterniflora* production in a New England salt marsh. *Ecology* 65: 1794–1807.
- Breitburg, DL. 1999. Are three dimensional structure and healthy oyster populations the keys to an ecologically interesting and important fish community? In *Oyster reef habitat restoration: a synopsis and synthesis of approaches*, ed. MW. Luckenbach, R. Mann, and JA Wesson, 239–250. Gloucester Point: Virginia Institute of Marine Science Press.
- Coen, LD, RD Brumbaugh, D Bushek, R Grizzle, MW Luckenbach, MH Posey, SP Powers, and SG Tolley. 2007. Ecosystem services related to oyster restoration. *Marine Ecology Progress Series* 341: 303–307.
- Coen, LD, DM Knott, EL Wenner, NH Hadley, AH Ringwood, and MY Bobo. 1999. Intertidal oyster reef studies in South Carolina: design, sampling and experimental focus for evaluating habitat use and function. In *Oyster reef habitat restoration: a synopsis and synthesis of approaches*, ed. Mark W. Luckenbach, R. Mann, and JA Wesson, 133–158. Gloucester Point: Virginia Institute of Marine Science Press.
- Coen, LD, MW Luckenbach, and DL Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. *American Fisheries Society Symposium* 22: 438–454.
- Coen, LD, and MW Luckenbach. 2000. Developing success criteria and goals for evaluating oyster reef restoration: ecological function or resource exploitation? *Ecological Engineering* 15. Elsevier: 323–343.
- Coen, LD. 2002. Annual Report submitted to the South Carolina Sea Grant Consortium, for Funded Project #NA86RG0052, An Examination of Oyster Reefs as Biologically-Critical Estuarine Ecosystems.

- Crabtree, RE, and JM Dean. 1982. The structure of two South Carolina estuarine tide pool fish assemblages. *Estuaries* 5: 2–9.
- Dame, RF. 1979. The abundance, diversity, and biomass of macrobenthos on North Inlet, South Carolina, intertidal oyster reefs. *Proceedings of the National Shellfish Association* 68: 6–10.
- Eash-Loucks, WE, ME Kimball, and KM Petrinec. 2014. Long-term changes in an estuarine mud crab community: evaluating the impact of non-native species. *Journal of Crustacean Biology* 34: 731–738. doi:10.1163/1937240X-00002287.
- Galleher, SN, I Gonzalez, MR Gilg, and KJ Smith. 2013. Abundance and Distribution of Larval and Juvenile *Fundulus heteroclitus* in Northeast Florida Marshes.
- Garland, HG, and DL Kimbro. 2015. Drought Increases Consumer Pressure on Oyster Reefs in Florida, USA. *Plos One* 10: e0125095. doi:10.1371/journal.pone.0125095.
- Geraldi, NR, SP Powers, KL Heck, and J Cebrian. 2009. Can habitat restoration be redundant? Response of mobile fishes and crustaceans to oyster reef restoration in marsh tidal creeks. *Marine Ecology Progress Series* 389: 171–180. doi:10.3354/meps08224.
- Gleason, ML, DA Elmer, NC Pien, and JS Fisher. 1979. Effects of Stem Density Upon Sediment Retention by Salt Marsh Cord grass, *Spartina alterniflora* Loisel. *Estuaries* 2: 271–273.
- Grabowski, JH, AR Hughes, DL Kimbro, and MA Dolan. 2005. How habitat setting influences restored oyster reef communities. *Ecology* 86: 1926–1935.
- Grabowski, JH, and CH Peterson. 2007. Restoring oyster reefs to recover ecosystem services. In *Ecosystem Engineers: Plants to Protists*, ed. K. Cuddington, J. Byers, W. Wilson, and A. Hastings, 281–298. Academic Press.
- Harding, J, and R Mann. 2001. Oyster reefs as fish habitat: opportunistic use of restored reefs by transient fishes. *Journal of Shellfish Research* 20: 951–959.
- Harding, J, and R Mann. 2003. Influence of habitat on diet and distribution of striped bass (*Morone saxatilis*) in a temperate estuary. *Bulletin of Marine Science* 72: 841–851.
- Hillyer, TM, EZ Stakhiv, and RA Sudar. 1997. An Evaluation of the Economic Performance of the U. S. Army Corps of Engineers Shore Protection Program. *Journal of Coastal Research* 13: 8–22.
- Hollebone, AL, and ME Hay. 2007. Population dynamics of the non-native crab *Petrolisthes armatus* invading the South Atlantic Bight at densities of thousands m<sup>-2</sup>. *Marine Ecology Progress Series* 336: 211–223. doi:10.3354/meps336211.
- Hollebone, AL, and ME. Hay. 2008. An invasive crab alters interaction webs in a marine community. *Biological Invasions* 10: 347–358. doi:10.1007/s10530-007-9134-9.

- Holt, SA, and ED Ingall. 2000. Preliminary report: Carbon and Nitrogen sources supporting food webs of spotted sea trout in Galveston Bay and the Laguna Madre. Management Data Series Number 174. Austin, TX.
- Humphries, AT, MK La Peyre, and GA Decossas. 2011. The effect of structural complexity, prey density, and “predator-free space” on prey survivorship at created oyster reef mesocosms. *PloS one* 6: e28339. doi:10.1371/journal.pone.0028339.
- Humphries, AT, and MK La Peyre. 2015. Oyster reef restoration supports increased nekton biomass and potential commercial fishery value. *PeerJ* 3: e1111. doi:10.7717/peerj.1111.
- Humphries, AT., MK La Peyre, ME Kimball, and LP Rozas. 2011. Testing the effect of habitat structure and complexity on nekton assemblages using experimental oyster reefs. *Journal of Experimental Marine Biology and Ecology* 409. Elsevier B.V.: 172–179. doi:10.1016/j.jembe.2011.08.017.
- Kennedy, VS, DL Breitburg, MC Christman, MW Luckenbach, KT Paynter, J Kramer, KG Sellner, J Dew-Baxter, C Keller, and R Mann. 2011. Lessons learned from efforts to restore oyster populations in Maryland and Virginia, 1990 to 2007. *Journal of Shellfish Research* 30: 1–13.
- Korsman, B. 2013. The spatial and temporal community structure of ichthyoplankton in a Northeast Florida estuary: a study of ingress at a faunal boundary. (Master’s thesis). University of North Florida, Jacksonville, FL. Available from UNF Theses and Dissertations. (Paper 452)
- Kuhlmann, ML. 1998. Spatial and temporal patterns in the dynamics and use of pen shells (*Atrina rigida*) as shelters in St. Joseph Bay, Florida. *Bulletin of Marine Science* 62: 157–179.
- Lee, SY, and RT Kneib. 1994. Effects of biogenic structure on prey consumption by the xanthid crabs *Eurytium limosum* and *Panopeus herbstii* in a salt marsh. *Marine Ecology Progress Series* 104: 39–47.
- Lehnert, RL, and DM Allen. 2002. Nekton use of subtidal oyster shell habitat in a southeastern US estuary. *Estuaries* 25: 1015–1024.
- Lenihan, HS, and CH Peterson. 1998. How Habitat Degradation Through Fishery Disturbance Enhances Impacts of Hypoxia on Oyster Reefs. *Ecological Applications* 8: 128–140.
- Lenihan, HS, CH Peterson, JE Byers, JH Grabowski, GW Thayer, and DR Colby. 2001. Cascading of habitat degradation: oyster reefs invaded by refuge fishes escaping stress. *Ecological Applications* 11: 764–782.
- MacKenzie Jr., CL. 1983. To increase oyster production in the northeastern United States. *Marine Fisheries Review* 45: 1–22.

- MacKenzie Jr., CL. 1996a. Management of natural populations. In *The Eastern Oyster: Crassostrea virginica*, ed. VS Kennedy, RIE Newell, and AF Eble, 707–721. College Park, MD: Maryland Sea Grant.
- MacKenzie Jr., CL. 1996b. History of oystering in the United States and Canada, featuring the eight greatest oyster estuaries. *Marine Fisheries Review* 58: 1–87.
- MacRae, PSD, and JH Cowan Jr. 2010. Habitat Preferences of Spotted Seatrout, *Cynoscion nebulosus*, in Coastal Louisiana: A Step Towards Informing Spatial Management in Estuarine Ecosystems. *The Open Fish Science Journal* 3: 154–163. doi:10.2174/1874401X01003010154.
- Manley, J, A Power, and R Walker. 2008. Wild eastern oyster, *Crassostrea virginica*, spat collections for commercial grow-out in Georgia. *Occasional Papers of the University of Georgia Marine Extension Service* 2: 16 pp.
- Meyer, DL. 1994. Habitat partitioning between the xanthid crabs *Panopeus herbstii* and *Eurypanopeus depressus* on intertidal oyster reefs (*Crassostrea virginica*) in southeastern North Carolina. *Estuaries* 17: 674–679.
- Meyer, DL, and EC Townsend. 2000. Faunal utilization of created intertidal eastern oyster (*Crassostrea virginica*) reefs in the southeastern United States. *Estuaries* 23: 34–45.
- Milbrandt, EC, M Thompson, LD Coen, RE Grizzle, and K Ward. 2015. A multiple habitat restoration strategy in a semi-enclosed Florida embayment, combining hydrologic restoration, mangrove propagule plantings and oyster substrate additions. *Ecological Engineering* 83. Elsevier B.V.: 394–404. doi:10.1016/j.ecoleng.2015.06.043.
- Murt, J, and F Juanes. 2008. Cohort-specific winter growth rates of YOY bluefish, *Pomatomus saltatrix*, in northeast Florida estuaries: Implications for recruitment. *Journal of Northwest Atlantic Fishery Science* 41: 221–231. doi:10.2960/J.v41.m629.
- Nestlerode, JA, MW Luckenbach, and FX O’Beirn. 2007. Settlement and Survival of the Oyster *Crassostrea virginica* on Created Oyster Reef Habitats in Chesapeake Bay. *Restoration Ecology* 15: 273–283. doi:10.1111/j.1526-100X.2007.00210.x.
- NOAA National Estuarine Research Reserve System (NERRS). 2015. System-wide Monitoring Program. Data accessed on October 1, 2015 from the NOAA NERRS Centralized Data Management Office website: <http://www.nerrsdata.org/>
- Oliveira, E, and S Masunari. 1995. Estrutura populacional de *Petrolisthes armatus* (Gibbes) (Decapoda, Anomura, Porcellanidae) da Ilha do Farol, Matinhos, Parana, Brasil. *Revista Brasilia Zoologica* 12: 355–371.

- Peterson, CH, JH Grabowski, and SP Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation. *Marine Ecology Progress Series* 264: 249–264.
- La Peyre, MK, AT Humphries, SM Casas, and JF La Peyre. 2014. Temporal variation in development of ecosystem services from oyster reef restoration. *Ecological Engineering* 63. Elsevier B.V.: 34–44. doi:10.1016/j.ecoleng.2013.12.001.
- Piazza, BP, PD Banks, and MK La Peyre. 2005. The potential for created oyster shell reefs as a sustainable shoreline protection strategy in Louisiana. *Restoration Ecology* 13: 499–506.
- Pierson, KJ, and DB Eggleston. 2014. Response of Estuarine Fish to Large-Scale Oyster Reef Restoration. *Transactions of the American Fisheries Society* 143: 273–288. doi:10.1080/00028487.2013.847863.
- Posey, MH, TD Alphin, CM Powell, and E Townsend. 1999. Use of oyster reefs as habitat for epibenthic fish and decapods. In: M. W. Luckenbach, R. Mann & J. A. Wesson, editors. *Oyster reef habitat restoration: a synopsis and synthesis of approaches*. Gloucester Point: Virginia Institute of Marine Science Press, pp. 229–237.
- Rodney, WS, and KT Paynter. 2006. Comparisons of macrofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland. *Journal of Experimental Marine Biology and Ecology* 335: 39–51. doi:10.1016/j.jembe.2006.02.017.
- Rothschild, BJ, JS Ault, P Gouletquer, and M Heral. 1994. Decline of the Chesapeake Bay oyster population: a century of habitat destruction and overfishing. *Marine Ecology Progress Series* 111: 29–39.
- SAFMC. 1998. Final habitat plan for the South Atlantic Region: Essential fish habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. Charleston, SC.
- Scyphers, SB, SP Powers, KL Heck Jr, and D Byron. 2011. Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. *PloS one* 6: e22396. doi:10.1371/journal.pone.0022396.
- Shervette, VR, and F Gelwick. 2008. Seasonal and Spatial Variations in Fish and Macroinvertebrate Communities of Oyster and Adjacent Habitats in a Mississippi Estuary. *Estuaries and Coasts* 31: 584–596. doi:10.1007/s12237-008-9049-4.
- Stunz, Gw, TJ Minello, and LP Rozas. 2010. Relative value of oyster reef as habitat for estuarine nekton in Galveston Bay, Texas. *Marine Ecology Progress Series* 406: 147–159. doi:10.3354/meps08556.
- Taylor, JC, WA Mitchell, JA Buckel, HF Walsh, KW Shertzer, GB Martin, and JA Hare. 2009. Relationships between Larval and Juvenile Abundance of Winter-Spawned Fishes in North

- Carolina, USA. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 1: 12–21.
- Tolley, SG, and AK Voley. 2005. The role of oysters in habitat use of oyster reefs by resident fishes and decapod crustaceans. *Journal of Shellfish Research* 24: 1007–1012.
- Tremain, DM, and DH Adams. 1995. Seasonal variation in species diversity, abundance and composition of fish communities in the northern Indian River Lagoon, Florida. *Bulletin of Marine Science* 57: 171–192.
- Turtora, M, and EM Schotman. 2010. Seasonal and spatial distribution patterns of finfish and selected invertebrates in coastal lagoons of northeastern Florida, 2002-2004. *Scientific Investigations Report 2010-5131*: 1–100.
- Valle-Levinson, A, G Gutierrez de Velasco, A Trasviña, AJ Souza, R Durazo, and AJ Mehta. 2009. Residual exchange flows in subtropical estuaries. *Estuaries and Coasts* 32: 54–67.
- Voley, AK., L Haynes, P Goodman, and P Gorman. 2014. Ecological condition and value of oyster reefs of the Southwest Florida shelf ecosystem. *Ecological Indicators* 44. Elsevier Ltd: 108–119. doi:10.1016/j.ecolind.2014.03.012.
- Wells, HW. 1961. The fauna of oyster beds, with special reference to the salinity factor. *Ecological Monographs* 31: 239–266.
- Wenner, CA, WA Roumillat, JR Moran Jr., MB Maddox, LB Daniel III, and JW Smith. 1990. *Investigations on the life history and population dynamics of marine recreational fishes in South Carolina: part 1*. Charleston, SC.
- Whalen, L, D Kreeger, D Bushek, J Moody, and A Padeletti. 2011. *Practitioner's Guide to Shellfish-Based Living Shorelines for Salt Marsh Erosion Control and Environmental Enhancement in the Mid-Atlantic. Report No. 11-04*.
- Williams, AA, SF Eastman, WE Eash-Loucks, ME Kimball, ML Lehmann, and D Parker. 2014. Record northernmost endemic mangroves on the United States Atlantic coast with a note on latitudinal migration. *Southeastern Naturalist* 13: 56–63.
- Williams, SL. 1993. Shoreline Erosion at Mad Island Preserve, Matagorda City, Texas. *Texas Journal of Science*: 299–309.
- Zimmerman, R, TJ Minello, T Baumer, and M Castiglione. 1989. Oyster reef as habitat for estuarine macrofauna. *NOAA Tech. Memo. NMFS-SEFC-*: 16 p.

## VITA

### EDUCATION

M.Sc. Biology, University of North Florida, Jacksonville, FL, December 2015

B.Sc. Biological Science, Florida State University, Tallahassee, FL, December 2012

### RESEARCH EXPERIENCE

August 2013-2015 -GTM NERR Restoration Project

February-April 2015 -Guana River Dam American Eel (*Anguilla rostrata*) Sampling

Summer 2013 -NOAA Shark Population Assessment Group Internship

Spring 2013 -Mote Marine Laboratory Ecotoxicology Internship

Summer 2012 -Research Internship in Marine Ecology

### WORK EXPERIENCE:

June-August 2015, Archer Western Contractors, Jacksonville, FL

*Manatee Observer*

Summer 2014, 2015 –Friends of the GTM Reserve, Ponte Vedra Beach, FL

*Graduate Student Field Researcher*

Fall 2013-2015 –University of North Florida, Department of Biology, Jacksonville, FL

*Graduate Teaching Assistant*

July-December 2012 –Florida State University Campus Recreation, Tallahassee, FL

*Aquatic Head Student Supervisor*

January-December 2012 –Florida State University Campus Recreation, Tallahassee, FL

*Aquatic Student Supervisor*

May 2011-December 2012 –Florida State University Campus Recreation, Tallahassee, FL

*Lifeguard*

### SCIENTIFIC PRESENTATIONS

**Dunnigan, S** and K Smith. The role of habitat in faunal communities in a northeast Florida estuary. *Southeastern Estuarine Research Society Spring 2015 Meeting*, March 14, 2015: Jacksonville, FL

**Dunnigan, S** and K Smith. The role of habitat in faunal communities in a northeast Florida estuary. *Guana Tolomato Matanzas National Estuarine Research Reserve State of the Reserve 2015: From Science to Management, February 6, 2015*: Ponte Vedra Beach, FL

**Dunnigan, S**, J Raabe, and N Dix. *Mesodinium rubrum* bloom within a northeast Florida estuary: comparing a decade of weather and water quality measurements. *Guana Tolomato Matanzas National Estuarine Research Reserve State of the Reserve 2015: From Science to Management, February 6, 2015*: Ponte Vedra Beach, FL



**Dunnigan, S** and KJ Smith. Through the grass, on the reef: a preliminary investigation of a combination living shoreline treatment as potential fish habitat in Guana Peninsula, FL. *Guana Tolomato Matanzas National Estuarine Research Reserve State of the Reserve 2014: Changing Tides, February 2014: Ponte Vedra, FL*

**Dunnigan, S** and AR Hughes. Effect of multiple consumers, *Tozeuma carolinense* and *Lagodon rhomboides*, on the sub-tropical seagrass *Thalassia testudinum*. *Florida State University Undergraduate Marine Certificate Research Symposium, November 2012: Tallahassee, FL*

**Dunnigan, S**, K Lawrence, MA Kolmann, C Peterson, and RD Grubbs. Preliminary examination of diet composition in two coastal ariid catfish. *Florida State University Undergraduate Research Symposium, March 2012: Tallahassee, FL*

### **GRANTS AND AWARDS**

Summer 2014 -University of North Florida Coastal Biology Program Summer stipend  
Fall 2013 -University of North Florida Coastal Biology Travel Grant  
Spring 2013 -Mote Marine Aquarium Internship Scholarship  
2009-2012 -Florida State University Freshman Scholarship