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Fish Assemblages Associated with a Newly Deployed Eco-Engineered Artificial Seawall in the Intercoastal Waters of Port Everglades

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FISH ASSEMBLAGES ASSOCIATED WITH A NEWLY DEPLOYED ECO-ENGINEERED ARTIFICIAL SEAWALL IN THE INTERCOASTAL WATERS OF PORT EVERGLADES

By

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ABSTRACT

As the demand for urbanization of coastal areas increases, there is a strong interest to create new infrastructures that would replace natural habitats (Airoldi & Beck, 2007; Dugan et al., 2011). These infrastructures, due to their differences in composition and structure, are often associated with decreasing biodiversity, and proliferation of invasive species (Firth et al., 2014; Moschella et al., 2005). To minimize or attenuate these negative effects of hardening shorelines eco-engineering can be implemented. This kind of approach focuses on the modification of artificial habitats to enhance services that would not be otherwise obtained (Barbier et al., 2011; Mayer-Pinto et al., 2017; Strain et al., 2017). In this study, I examined the effect of four eco-engineered concrete mattresses, designed to replace standard rock armors and concrete erosion systems, on the fish assemblages of the intercoastal waterway of Port Everglades, Florida. The specific design of these artificial structures did not result in a clear ecological enhancement of fish assemblages compared to the surrounding urbanized habitats, but it did show the potential to increase suitable habitat for native fish over invasive ones. This study could also provide new elements for future development of eco-engineering solutions.

KEYWORDS

Artificial system, urbanization, coastal management, blenny, intercoastal waters.

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I thank ECOncrete® Tech Ltd. for funding this project and managing all development end deployment logistics, allowing me to collect data on their Bio-Enhanced Drycast Mattresses. I thank Nova Southeastern University and my professors that taught me and guided me through the years. I thank my friends and family for supporting me through all the good and bad times that brought me to this point. And most of all, I want to thank my father, Roberto Cinti, which without I would not have even had the chance of starting this career.

Table of Contents

INTRODUCTION

Rapid human expansion and climate change are major factors in habitat destruction and fragmentation, which is the first cause of animal extinctions (Airoldi & Beck, 2007). This is particularly true for coastlines, which are areas of high human concentration. Coastlines host two-thirds of the human population (Creel, 2003), so as demand for urbanization of coastal areas increases and sea levels rise there is a stronger interest to create artificial infrastructures that replace natural habitats (Airoldi & Beck, 2007; Dugan et al., 2011). These infrastructures create great quantities of hard substrate open to colonization, though it is often colonized by nuisance and invasive species. This occurs because man-made structures have different compositions and designs than natural environments. High habitat homogeneity, low habitat complexity, and high inclination percentage are some of the physical properties that lead to changes in species richness, assemblages, and biodiversity, which favor the proliferation of invasive species (Connell, 2000; Dugan et al., 2011; Firth et al., 2014; Lam et al., 2009).

A species becomes invasive when it is introduced into places outside its natural range, negatively impacting native biodiversity, ecosystem services or human well-being (NOAA; IUCN). To succeed in becoming an invasive species an organism must pass through 3 phases: transport from the original donor ecosystem and along a dispersal pathway, introduction and survival in the new environment, and establishment to form a population capable of reproducing (Wonham et al., 2000). Hull fouling and boring, aquarium trade, recreational water users, construction industries, and ballast waters are some of the transportation vectors that organisms can use to disperse into new systems (Bax et al., 2003; Wonham et al., 2000).

Artificial and natural system are different due to differences in composition and structure (Bulleri and Chapman, 2004; Chapman and Bulleri, 2003; Firth et al., 2013a; Gacia et al., 2007; Firth et al., 2014; Pister, 2009; Vaselli et al., 2008). Artificial systems have lower heterogeneity and habitat complexity than natural systems and are associated with lower biodiversity (Moschella et al., 2005).

Concrete is one of the most common building materials and is used in the construction of artificial systems that are associated with human expansion. Globally it accounts for over 50% of the materials used in coastal and marine environments due to its longevity and low cost (Kampa and Laaser, 2009). Due to the lack of heterogeneity in construction design, and unique surface chemistry, which impairs settlement of marine larvae, concrete is considered a poor substrate for biological recruitment (Luken and Selberg, 2004).

On a microscale (<1cm) the composition and surface roughness of an artificial system have a significant impact on assemblages of colonizing biotas (Coombes et al., 2011; Green et al., 2012; Firth et al., 2014). This is especially true when building materials used for artificial systems differs from the natural system, which could result in a reduction of species survival and settlement (Davis et al., 2002; Moreira et al., 2006; Coombes et al., 2011; Green et al., 2012; Firth et al. 2014).

On a centimeter to meter scale (<10 cm to 1 m) the lack of habitat complexity (holes, cracks, crevices, and pools), which offer protection for smaller animals, results in lower biodiversity and exclusion of many species in natural systems of near habitats (Bracewell et al., 2012; Cartwright and Williams, 2012; Chapman and Johnson, 1990; Firth and Crowe, 2008, 2010; Firth and Williams, 2009; Firth et al., 2009; Firth et al., 2014; Goss-Custard et al., 1979; Johnson et al., 1998; Skov et al., 2011).

Higher disturbances are also associated with artificial systems (e.g. maintenance work, trampling, pollution) resulting in lower habitat quality and higher colonization rates from opportunistic and invasive species (Airoldi and Bulleri, 2011; Airoldi et al., 2005; Bracewell et al., 2012, 2013; Bulleri and Airoldi, 2005; Bulleri et al., 2006; Firth et al., 2011; Firth et al. 2014).

Furthermore, artificial systems, such as seawalls, can reduce intertidal habitats by reducing or eliminating the transition from low to high water that is present in gently sloping coastlines (Chapman, 2003; Firth et al., 2014).

With more than 75% of the population living in coastline counties, Florida is a prime example for the need to create infrastructure to satisfy high demand that comes with high population densities (Wilson & Fischetti, 2010). To mitigate the hardening of shorelines soft engineering can be implemented. This approach focuses on modification of natural habitats to enhance services that would not be otherwise obtained building artificial structures. Prime examples are restoration or establishment of sandy beaches, mangroves forests, and oyster reefs to enhance fisheries productivity and sequestration of carbon and diminish wave energy and storm surge (Barbier et al., 2011; Mayer-Pinto et al., 2017; Strain et al., 2017).

When soft engineering is not an option like Port Everglades (FL), the need for infrastructure reduces natural habitats. The use of Eco-engineering is strongly advised. Marine infrastructure, such as seawalls and jetties that replace natural habitats, have been designed by engineers with the purpose of protecting the coastline from erosion and their homogeneous surfaces tend to host low diversity assemblages, but through eco-engineering these infrastructures can be designed to be multifunctional, benefiting both humans and nature (Chapman & Underwood, 2011; Dafforn et al., 2015; Firth et al., 2016).

Eco-engineering is defined by Bergen, Bolton, & Fridley, 2001 as the inclusion of ecological principles in the design of infrastructure to enhance its ecological value. Eco-engineering can be implemented either in the design of artificial systems, to ensure greater effects and construction of infrastructures with more environmentally friendly structures, or later through a modification or addition of already built artificial structures. This could provide multiple end-user benefits on small and large scales, such as mitigating environmental impacts and recovering neglected ecosystem services (Chapman & Blockley, 2009; Dugan et al., 2011; Mayer-Pinto et al., 2017; Strain et al., 2017).

One company that has been embracing the concept of eco-engineering through research and development of innovative solutions to reduce the ecological footprint of urbanized areas is ECOncrete®. ECOncrete® was founded by Dr. Shimrit Perkol-Finkel and Dr. Ido Sella in 2012. They are marine ecologists that have been developing and studying ways to improve urbanized areas through ecological enhancement and green engineering technologies all around the world. ECOncrete® claims that their products work through a combination of concrete composition, complex surface texture, and macro-designs that mimic natural features, enhance biological recruitment by modifying small scale hydrodynamics, and focus on desirable biological features. This study could confirm or deny these claims for fishes associated with this specific artificial system structure and design.

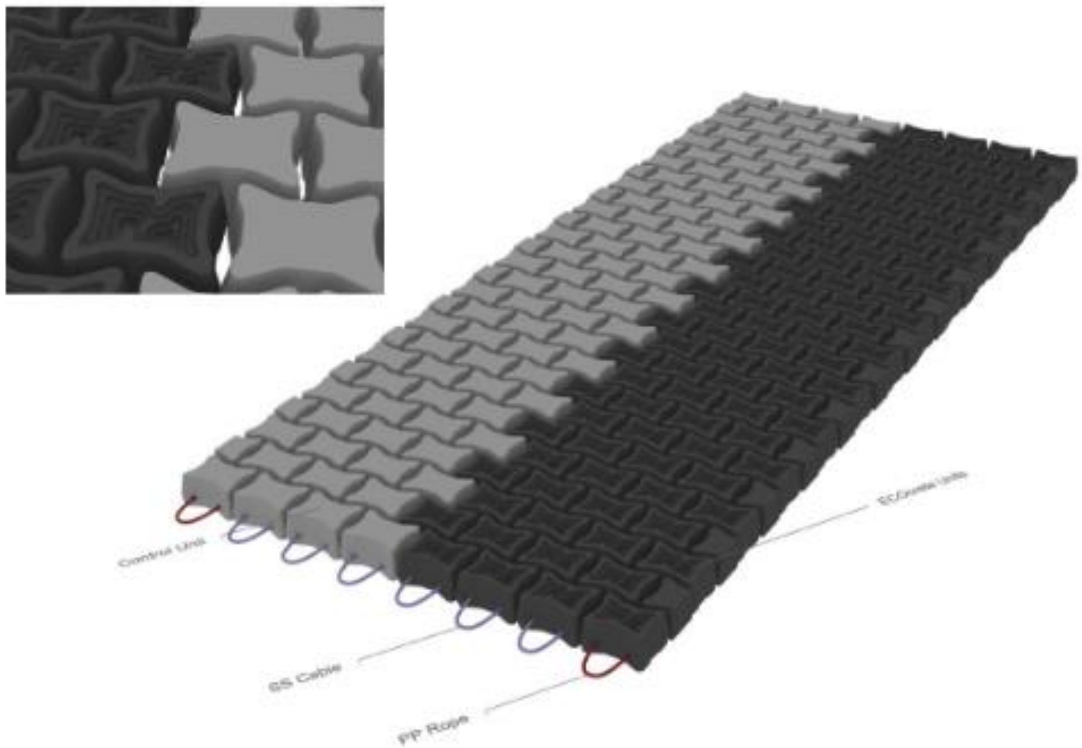
The primary objective of this study was to examine the effect of ECOncrete® Bio-Enhanced Drycast Mattress on fish assemblages in the intertidal zone and compare them with surrounding urbanized habitats. The articulated concrete mattress is an ECOncrete® product designed as an alternative to rock armor and standard concrete erosion systems by providing shoreline and bank stabilization, erosion control and protection to offshore pipelines and cables while enhancing biodiversity by supporting the growth of flora and fauna. Looking at the effect that this specific concrete composition, texture, and design have on fish populations could improve development of infrastructure to provide ecological advantages mitigating the negative effects that come with coastline urbanization and creating fish nurseries (Perkol-Finkel and Sella, 2014; Perkol-Finkel and Sella, 2015; Sella and Perkol-Finkel, 2015).

Because of the scale of rugosity on ECOncrete®, I expect to find a difference in number of cryptic species, such as *Blennies* and *Gobies*, between ECOncrete® and control treatments. This hypothesis is predicated on the idea that the presence of cryptic species can be determined by the scale of topographic features of the ECOncrete® units that can mimic their natural environment. I also expect the frequency of invasive species, such as lionfish (*Pterois volitans*) and tessalated blenny (*Hypsoblennius invemar*), to be higher on ECOncrete® relative to unaltered concrete. The reason behind this hypothesis is that the lionfish would predate on the fish colonizing the mattresses, and the tessalated blenny would be carried in the ballast water of the many commercial vessels passing by Port Everglades (Benkwitt, 2013; Wonham et al., 2000; Box et al., 2003).

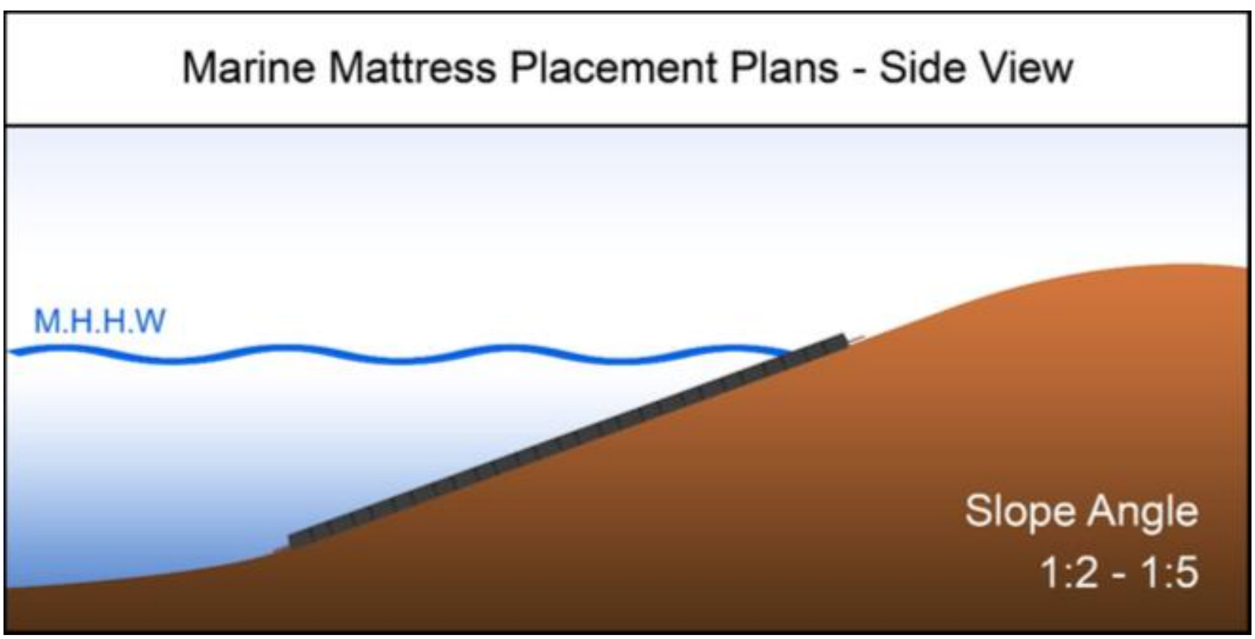
MATERIAL AND METHODS

Experimental Setup

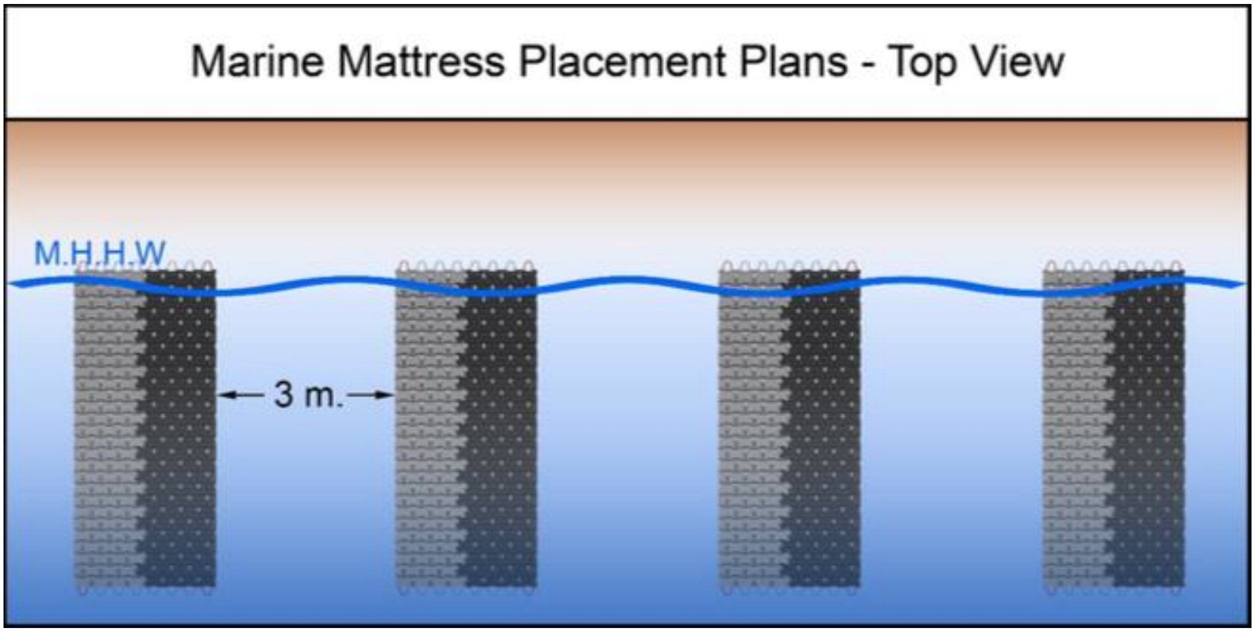
Four 2.4x5.7 m marine mattresses, each composed of 203 articulated units (30x24x15 cm), and 26 half units (15x24x15), connected with stainless steel cables/polypropylene rope (Fig. 1) with a total weight of approximately 3950 Kg were used in the experiment. Half of each mattress was composed of textured ECOncrete® units and the other half was composed of featureless Control units prepared from standard Portland cement-based concrete mix. Four replicated mattresses were placed in the lower intertidal zone of the intercoastal waters of Port Everglades, Florida (Figures 1, 2 and 3) (Perkol-Finkel and Sella, 2016).



(Figure 1) ECOncrete® Bio-Enhanced Marine Mattress design composed by the control and ECOncrete® units. The cable provides structural backbone and allows for quick deployment.



(Fig. 2) Side view of deploying ECOncrete® Bio-Enhanced Marine Mattress



(Fig. 3) Top view of deploying ECOncrete® Bio-Enhanced Marine Mattress

Structural Modification

At months 6 and 12, six units per mattress were removed (3 from the top of each mattress and 3 from the bottom) as a sample to examine structural integrity over time and to measure biomass in the laboratory for a different study.

Data Acquisition

Mattresses were deployed in April of 2017 and data was recorded from June 2017. Data was collected in two ways; 1) on site through visual censuses every one to two weeks, and 2) recorded on a GoPro mounted on a movable station at months 3, 6, and 12 from deployment date. The site of the study is located in Port Everglades, Florida between the Halmos College of Natural Sciences and Oceanography campus and the adjacent US Naval Reservation. Visual census data was collected for 10 minutes on each mattress and each surrounding area to be later analyzed. GoPro videos were taken for 10 minutes on each mattress to analyze patterns between the control and ECOncrete®. Photos of fishes on the mattresses and surrounding areas were taken for species identification. All surveys were done snorkeling.

(Fig. 4) Satellite Map of the different study sites. Each MAT is composed of ECOncrete® Bio-Enhanced units and control units. The locations are MAT 1 (M1E, M1C), MAT 2 (M2E, M2C), MAT 3 (M3E, M3C), MAT 4 (M4E, M4C), limestone boulders water breaker (NS), and construction site remnants (AS).

(Fig. 5) Deployment of one of the ECOncrete® Bio-Enhanced Marine Mattresses used for this study.

In order to avoid disturbances to fish communities in the area, monitoring using GoPros was always performed prior to visual monitoring surveys that were done at months 3, 6, and 12. During each visual survey, the snorkeler started the survey by viewing fish from a distance in order to map fish around the units with minimal disturbance. After this stage, the snorkeler approached the units and conducted a count of cryptic species (Sella and Perkol-Finkel, 2015).

(Fig. 6) Left: Divers during fish counts approaching the mattress from a distance to reduce disturbance.. (Fig. 7) Right: Divers during a fish count looking for cryptic species.

Differently than shown in Figure 2 and 3, during low tides mattresses become exposed at different rates, with mattress 1 being the most exposed, with almost half of units out of the water and mattress 4 being the least exposed with only a few units out of the water. For this reason, to avoid differences of the surveyable areas between the sites all fish surveys were done when all the mattresses were completely underwater.

To avoid species misidentification of a fish or their life stage, identification and life stages were assessed using dichotomous keys and scientific names were confirmed using ITIS (*Integrated Taxonomic Information System)*.

Statistical Analysis

Data collected through visual census on the mattresses was compared to visual data collected on adjacent urbanized sites to assess if there were significant differences with established habitats. These 2 comparison sites are construction material residuals site (AS) and limestone boulder waterbraker seawall (NS).

Species were classified into three categories: residents (R), visitors (V), or transient (T) according to the same criteria used by Russell et al. (1974), Talbot et al. (1978), and Bohnsack and Talbot (1980). Resident species are those that tend to remain at one site and are observed on one or more consecutive surveys, while visitors and transients tend to move in and out of sites (Thanner et al., 2006). To reduce variability only resident species were used for statistical analysis (Thanner et al., 2006).

Data were first transformed using the square root in order to account for less common species, then the Bray-Curtis Similarity Index was calculated. Based on the Bray-Curtis Similarity Index (nMDS) Non-metric Multi-Dimensional Scaling plots were created to visually represent the data. Then ANOSIM - Analysis of Similarities was run in order to explore separation among the groups. The ANOSIM test is limited in the ability to test for the interaction of the 2 factors in the design, so a PERMANOVA - Permutational multivariate analysis of variance test was run in order to address the possibility of interactions between the factors: location and treatment. In order to look at the contribution that each taxa exert into separate the groups the SIMPER Similarity Percentages - species contributions test was performed as well. Post hoc pair-wise tests were implemented if relevant. All data was analyzed using the statistical analysis programs PRIMER-e, Version 7.0.13. and PERMANOVA+1 (Anderson et al., 2008; Clarke et al., 2014).

Diversity: Shannon Diversity Index for fishes $H' = -p_i \sum \ln p_i$ where p_i is the proportion of individuals found in species i, $p_i = n_i/N$, where n_i is the number of individuals in species i and N is the total number of individuals in the community (Shannon & Weaver, 1949).

The Bray Curtis dissimilarity is used to quantify the differences in species populations between two different sites. It’s used primarily in ecology and biology, and can be calculated with the following formula: $BC_{ij} = 1 – (2C_{ij} /(S_i+S_j))$

Where: i & j are the two sites, S_i is the total number of specimens counted on site i, S_j is the total number of specimens counted on site j, C_{ij} is the sum of only the lesser counts for each species found in both sites (Bray and Curtis, 1957).

RESULTS

During the 35 surveys on the Mattresses and 5 surveys on the limestone boulders site (AS), and construction residues site (NS) performed in the study, a total of 10269 fishes belonging to 26 families and 48 species were observed on the Mattresses and at the compared urbanized sites. 5093 fishes were found at the ECOncrete® side of Mattresses (M1E, M2E, M3E, M4E), 4577 fishes were found at the control side of Mattresses (M1C, M2C, M3C, M4C), 226 fishes were found at the construction residues site (NS), and 373 fishes were found at the limestone boulders site (AS). Of the 48 species recorded during this study, 43 species were found at the Mattresses and classified as 13 residents (30.2%), 17 visitors (39.6%), and 13 transient (30.2%) species. Of the 13 resident species 2 were found only at the AS (Table 1).

The PERMANOVA test shows a significant difference in resident fish assemblages (P-value <0.05) between location groups (M1, M2, M3, M4, AS, NS) but not between treatments (E, C), nor between the interaction of these two factors (Table 2). The ANOSIMS results show the same difference in fish assemblages between locations as well as significant differences between treatment groups. Though, the R value being so low results in the treatment group having a small effect on the fish assemblages. The pair-wise test shows significant differences between all locations but looking at the R values and comparing them with the results of the SIMPER test makes it possible to estimate which locations may have stronger effects on the fish assemblages.

(Table 1) Total number of resident fish collected through visual censuses for each location. ECOncrete® side of the Mattresses (M1E, M2E, M3E, M4E), control side of the Mattresses (M1C, M2C, M3C, M4C), construction residues site (NS), and limestone boulders water breaker (AS).

Sum of TOT	Column Labels										
Row Labels	AS	M1C	M1E	M2C	M2E	M3C	M3E	M4C	M4E	NS	Grand Total
Abudefduf saxatilis	42	218	206	249	231	341	361	110	171	12	1941
Acanthurus chirurgus	10	15	56	45	74	12	23	13	31	15	294

Anisotremus virginicus	17	32	34	17	11	32	41	11	8	0	203
Eucinostomus melanopterus	45	24	28	53	63	14	10	145	102	17	501
Gymnothorax funebris	3	0	0	0	0	0	0	0	0	0	3
Haemulon aurolineatum	117	205	301	20	31	180	149	190	197	8	1398
Haemulon flavolineatum	13	161	156	151	152	201	267	188	206	33	1528
Halichoeres bivittatus	6	52	62	55	65	51	71	31	51	8	452
Kyphosus sectatrix	6	36	47	45	52	25	25	12	16	4	268
Lutjanus apodus	13	147	80	94	99	55	53	39	50	4	634
Lutjanus griseus	29	96	33	39	49	44	44	20	8	9	371
Lutjanus synagris	0	0	1	0	1	0	2	30	51	7	92
Pomacanthus paru	9	0	0	0	0	0	0	0	0	0	9
Scartella cristata	0	95	216	5	3	0	0	0	0	5	324

Stegastes adustus	7	80	100	97	98	90	104	84	92	8	760
Grand Total	**317**	**1161**	**1320**	**870**	**929**	**1045**	**1150**	**873**	**983**	**130**	**8778**

The SIMPER test showed that fish assemblages, at and within each location (M1C, M2C, M3C, M4C, M1E, M2E, M3E, M4E, AS, NS), showed high similarity ranging from 66.22% in group M1C to 48.19% in group NS. Similar results appeared when looking at the treatment (C, E), showing a high similarity between each group, with similarity of 61.79% in group E and 60.76% in group C. When comparing the different location groups within each treatment, the similarity percent ranged from 58.15% (M1C - M3C) to 46.18% (M1C - M4C) for the control group and 56.89% (M1E - M2E) and 47.19% (M1E - M4E) for the ECOncrete® group. The similarity was the lowest when groups are compared with mattress 4, with similarity percent of 46.18% (M1C - M4C), 47.41% (M2C - M4C),and 47.15% (M3C - M4C) for the control group, and 47.19% (M1E - M4E), 50.77% (M2E - M4E), and 49.34% (M3E - M4E) for the ECOncrete® group (Table 4).

When comparing the control treatment against the ECOncrete treatment within each mattress, it showed that all adjacent locations had high similarity (M1C - M1E, M2C - M2E, M3C - M3E, and M4C - M4E) ranging from 66.16% (M2C - M2E) to 53.72% (M4C - M4E). When comparing the AS with the NS it showed the highest difference between locations with a 36.23% similarity (Table 2).

The 2D MDS plot clearly showed the differences in fish assemblages by location and treatment (Fig. 7) and the different species superimposition by vectors showed the species-specific preferences for each location. E.g. *Lutjanus synagris* and the *Eucinostomus melanopterus* have a stronger presence on M4 than M1 independently by the treatment (Fig.7).

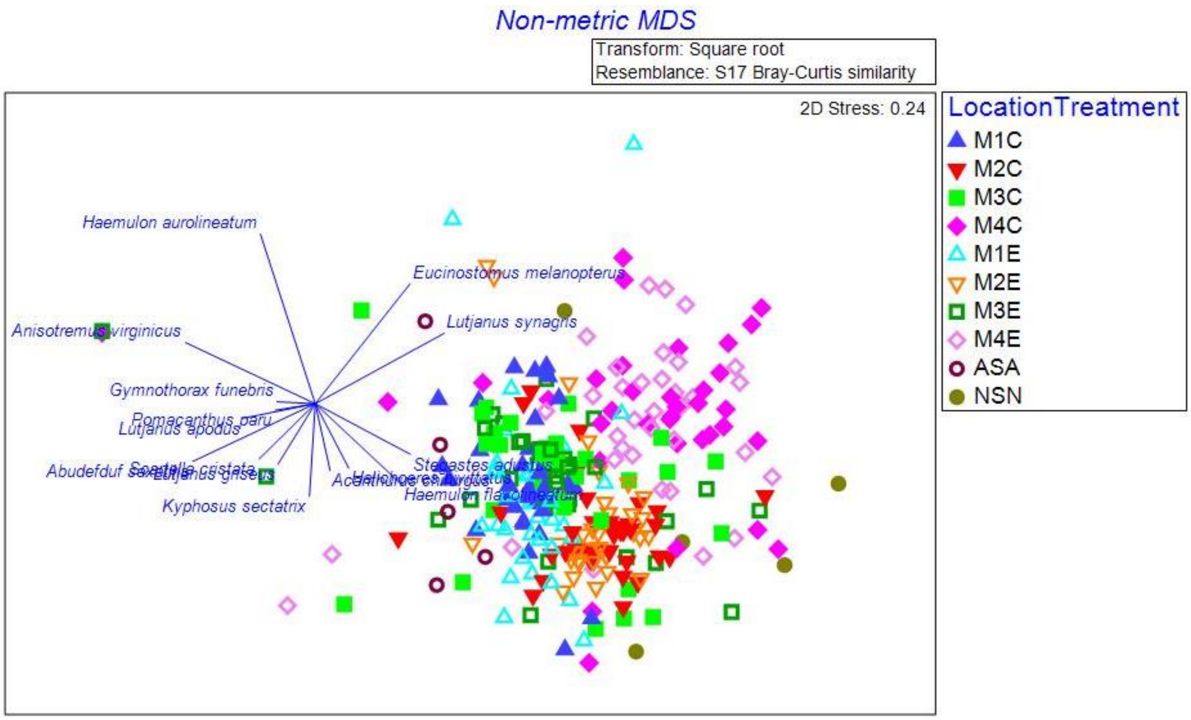
(Table 2) PERMANOVA results for differences between locations (Lo) with 6 levels Mattress 1 (M1), Mattress 2 (M2), Mattress 3 (M3), Mattress 4 (M4), construction site remnants (AS), and limestone boulders water breaker (NS), and differences between treatments (Tr) with 2 levels Econcrete® (E), and control (C).

PERMANOVA table of results						
Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Tr	1	1298.6	1298.6	1.4155	0.232	999
Lo	3	73192	24397	26.594	0.001	999
TrxLo	3	3164.6	1054.9	1.1498	0.314	999
Res	280	2.5687E+05	917.41			
Total	289	3.4579E+05				

(Table 3) Shows the differences in fish assemblages between the locations of this study Mattress 1 (M1), Mattress 2 (M2), Mattress 3 (M3), Mattress 4 (M4), construction site remnants (AS), and limestone boulders water breaker (NS). The significant level is the p-value (Sig. Lev. / 100) and R Statistic is the strength in which the factor location creates differences in the fish assemblages.

Pairwise Tests Table of results					
Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
M1, M2	0.427	0.1	Very large	999	0
M1, M3	0.271	0.1	Very large	999	0
M1, M4	0.513	0.1	Very large	999	0
M1, AS	0.629	0.1	17259390	999	0
M1, NS	0.793	0.1	17259390	999	0
M2, M3	0.304	0.1	Very large	999	0

M2, M4	0.451	0.1	Very large	999	0
M2, AS	0.688	0.1	17259390	999	0
M2, NS	0.722	0.1	17259390	999	0
M3, M4	0.319	0.1	Very large	999	0
M3, AS	0.389	1.1	17259390	999	10
M3, NS	0.671	0.2	17259390	999	1
M4, AS	0.609	0.2	17259390	999	1
M4, NS	0.395	1.3	17259390	999	12
AS, NS	0.648	1.6	126	126	2



(Fig. 7) The 2D MDS shows the separation between the different locations, where each location is represented by different colors and shapes. The resident species correlated to the similarity between the locations are superimposed as vectors on the plot. Location and treatment are in the legend as Mattress 1 Control (M1C), Mattress 2 Control (M2C), Mattress 3 Control (M3C), Mattress 4 Control (M4C), Mattress 1 ECOncrete® (M1E), Mattress 2 ECOncrete® (M2E), Mattress 3 ECOncrete® (M3E), Mattress 4 ECOncrete® (M4E), construction site remnants (ASA), and limestone boulders water breaker (NSN).

The fish assemblages, at each location (M1C, M2C, M3C, M4C, M1E, M2E, M3E, M4E, AS, NS), showed high similarity ranging from 66.22% in group M1C to 48.19% in group NS. Similar results appeared when looking at the treatment (C, E), showing a high similarity between each group, with similarity of 61.79% in group E and 60.76% in group C. When comparing the different location groups within each treatment, the similarity percent ranged from 58.15% (M1C - M3C) to 46.18% (M1C - M4C) for the control group and 56.89% (M1E - M2E) and 47.19% (M1E - M4E) for the ECOncrete® group. The similarity is the lowest when groups were compared with mattress 4, with similarity percent of 46.18% (M1C - M4C), 47.41% (M2C - M4C),and 47.15% (M3C - M4C) for the control group, and 47.19% (M1E - M4E), 50.77% (M2E - M4E), and 49.34% (M3E - M4E) for the ECOncrete® group (Table 4).

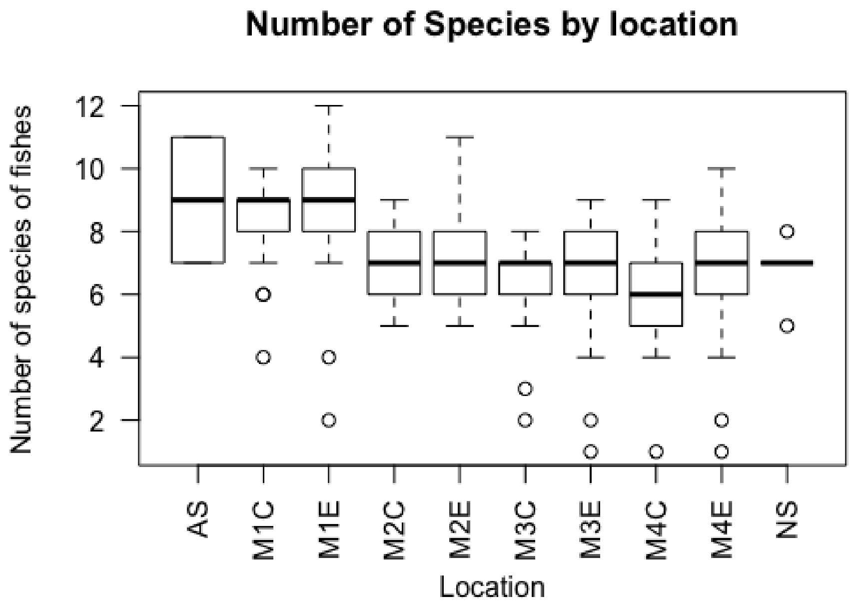
(Table 4) Average similarity of fish communities between/within the different locations and treatment. Mattress 1 (M1), Mattress 2 (M2), Mattress 3 (M3), Mattress 4 (M4), ECOncrete® treatment (E), Control treatment (C), Mattress 1 Control (M1C), Mattress 2 Control (M2C), Mattress 3 Control (M3C), Mattress 4 Control (M4C), Mattress 1 ECOncrete® (M1E), Mattress 2 ECOncrete® (M2E), Mattress 3 ECOncrete® (M3E), Mattress 4 ECOncrete® (M4E), construction site remnants (AS), and limestone boulders water breaker (NS).

SIMPER Table of Results							
Groups	Av.Sim %	Groups	Av.Sim %	Groups	Av.Sim %	Groups	Av.Sim %
M1C-M2C	56.74	M1E-M2E	56.89	M1C-M1E	63.45	M3-M4	48.25
M1C-M3C	58.15	M1E-M3E	54.51	M2C-M2E	66.16	M2-M4	49.09
M1C-M4C	46.18	M1E-M4E	47.19	M3C-M3E	60.59	AS	55.81
M2C-M3C	56.59	M2E-M3E	53.37	M4C-M4E	53.72	M4	53.58
M2C-M4C	47.41	M2E-M4E	50.77	AS-NS	36.23	C-E	60.98
M3C-M4C	47.15	M3E-M4E	49.34	M2-M3	56.48	M4C	51.13
M1-M2	56.81	M1-M3	56.33	M1-M4	46.69	M4E	56.03
M1	65.60	M2	65.68	M3	60.23		
NS	48.19	C	60.76	E	61.79		
M1C	66.22	M2C	65.76	M3C	59.93		
M1E	64.98	M2E	65.61	M3E	60.52		

When comparing the control treatment against the ECOncrete treatment within each mattress, it showed that all adjacent locations had high similarity (M1C - M1E, M2C - M2E, M3C - M3E, and M4C - M4E) ranging from 66.16% (M2C - M2E) to 53.72% (M4C - M4E). When comparing the AS with the NS it showed the strongest difference between locations with a 36.23% similarity (Table 2).

Resident Species contribution in similarity across locations

There was a significant difference in the number of species by location, and in their fish assemblages (Fig 7 and 8).



(Fig. 8) Boxplot of the number of species of fish for each location. The dark middle bar represents the median, the box represents the upper and lower 25% inner quartiles and the whiskers represent the outer 25% quartiles (n=2093). The Y-axis shows the number of species of fishes, the x-axis shows the location and treatment; Mattress 1 Control (M1C), Mattress 2 Control (M2C), Mattress 3 Control (M3C), Mattress 4 Control (M4C), Mattress 1 ECOncrete® (M1E), Mattress 2 ECOncrete® (M2E), Mattress 3 ECOncrete® (M3E), Mattress 4 ECOncrete® (M4E), construction site remnants (AS), and limestone boulders water breaker (NS).

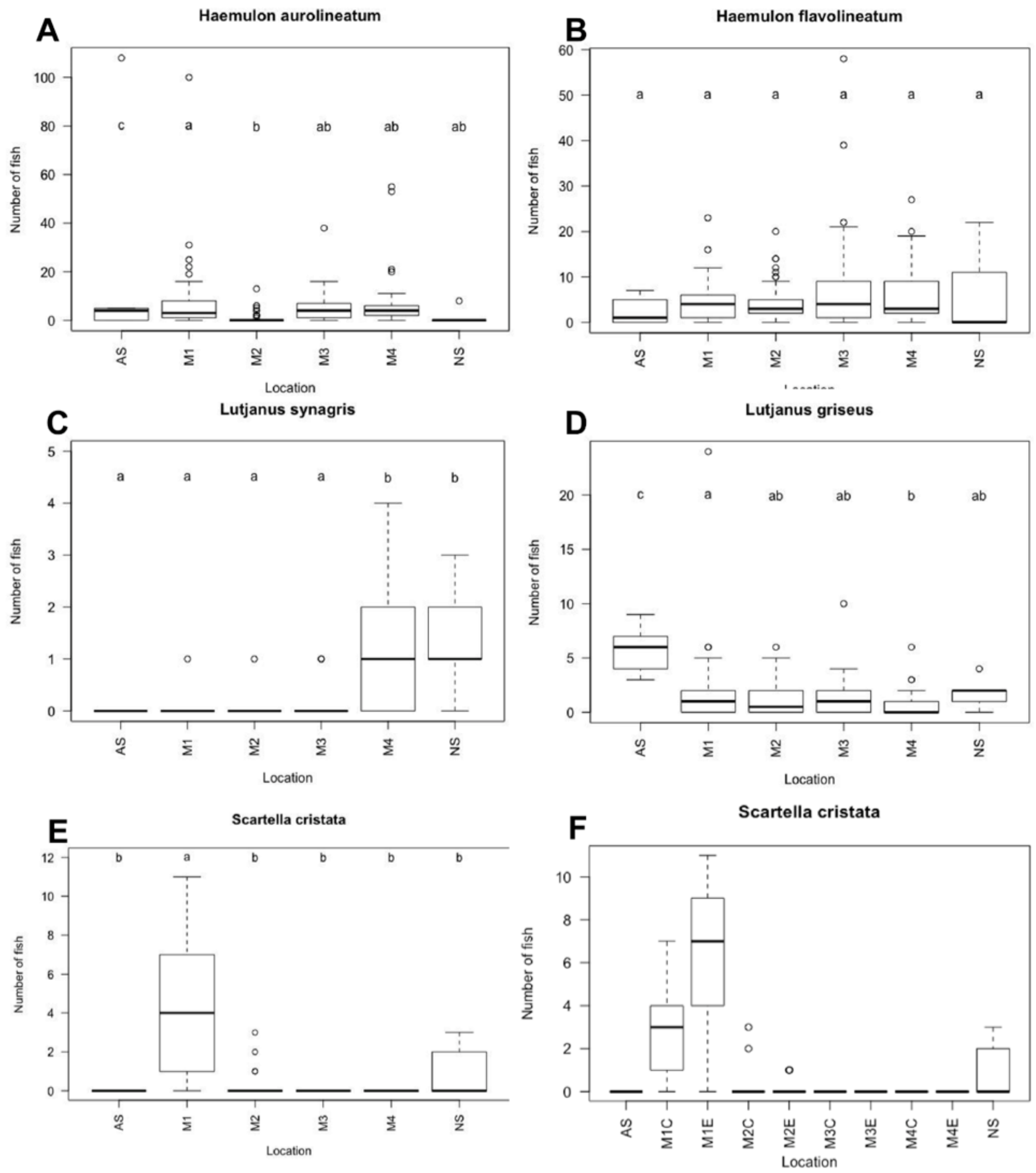
Haemulon aurolineatum represented 15.93 % of all the resident fishes and it changed significantly by location (Table 5). *Haemulon aurolineatum* showed a preference in locations M1, M3, M4 and NS, independently by the treatment (E, C) and it contributed to describe between 10.54% (M1E) and 19.07% (M4C) of the average similarity in species assemblages of these locations (Table 4 and Fig. 9A).

Haemulon flavolineatum represented 17.41% of all resident fishes and it did not change by location (Table 5). *Haemulon flavolineatum* did not show a preference in locations nor treatment (E, C) and it contributed to describe between 11.64% (M1E) and 18.71% (M2C) of the average similarity in species assemblages between locations (Table 4 and Fig. 9B).

Lutjanus synagris represented 1.05% of the resident fishes and it was predominant on M4 and NS, with a significant difference in location but not treatment preference (Table 5). *Lutjanus synagris* contributed to describe 9.12% (M4E) and 10.84% (NS) of the average similarity in species assemblages between the predominant locations (Table 4 and Fig. 9C).

Lutjanus griseus represented 4.23% of all resident fishes and it was most predominant at AS, and the least at M4. *Lutjanus griseus* distribution was explained by the letters in Fig.12., where each letter represents a statistically different location group. *Lutjanus griseus* shows a preference in location (Table 5) and it contributes to explain between 20.40% (AS) and 11.54% (NS) of the average similarity of the resident fish populations (Table 4 and Fig. 9D).

Scartella cristata represented 3.69% of all resident fishes and it was found at the highest abundance at M1, with a significant preference in treatment E (Table 5). *Scartella cristata* contributed to describing 16.45% (M1E) and 9.44% (M1C) of the average similarity in species assemblages of this mattress (Table 4, Fig. 9E and F).



(Fig. 9) Boxplot of the abundance of the species (A) *Haemulon aurolineatum*, (B) *Haemulon flavolineatum*, (C) *Lutjanus synagris*, (D) *Lutjanus griseus*, (E) *Scartella cristata* at each location. The dark middle bar represents the median, the box represents the upper and lower 25% inner quartiles and the whiskers represent the outer 25% quartiles ((A) n=1398, (B) n=1528, (C) n=92, (D) n=371, (E,F) n=324). The Y-axis shows the number of fishes, the x-axis shows the location and treatment; Mattress 1 (M1), Mattress 2 (M2), Mattress 3 (M3), Mattress 4 (M4), Mattress 1 Control (M1C), Mattress 2 Control (M2C), Mattress 3 Control (M3C), Mattress 4 Control (M4C), Mattress 1 ECOncrete® (M1E), Mattress 2 ECOncrete® (M2E), Mattress 3 ECOncrete® (M3E), Mattress 4 ECOncrete® (M4E), construction site remnants (AS), and limestone boulders water breaker (NS). Letters represent the statistical similarities/differences between locations. (F) shows all sites and all treatments, while (E) shows only sites.

Anisotremus virginicus represented 2.31% of all resident fishes and it shows differences in abundance depending on location rather than treatment (Table 5). It was predominantly found at AS then at M1 and M3 and finally at M2 and M4. *Anisotremus virginicus* contributed to describe 12.80% of the average similarity in species assemblages of the AS location (Table 4 and Fig. 10 A).

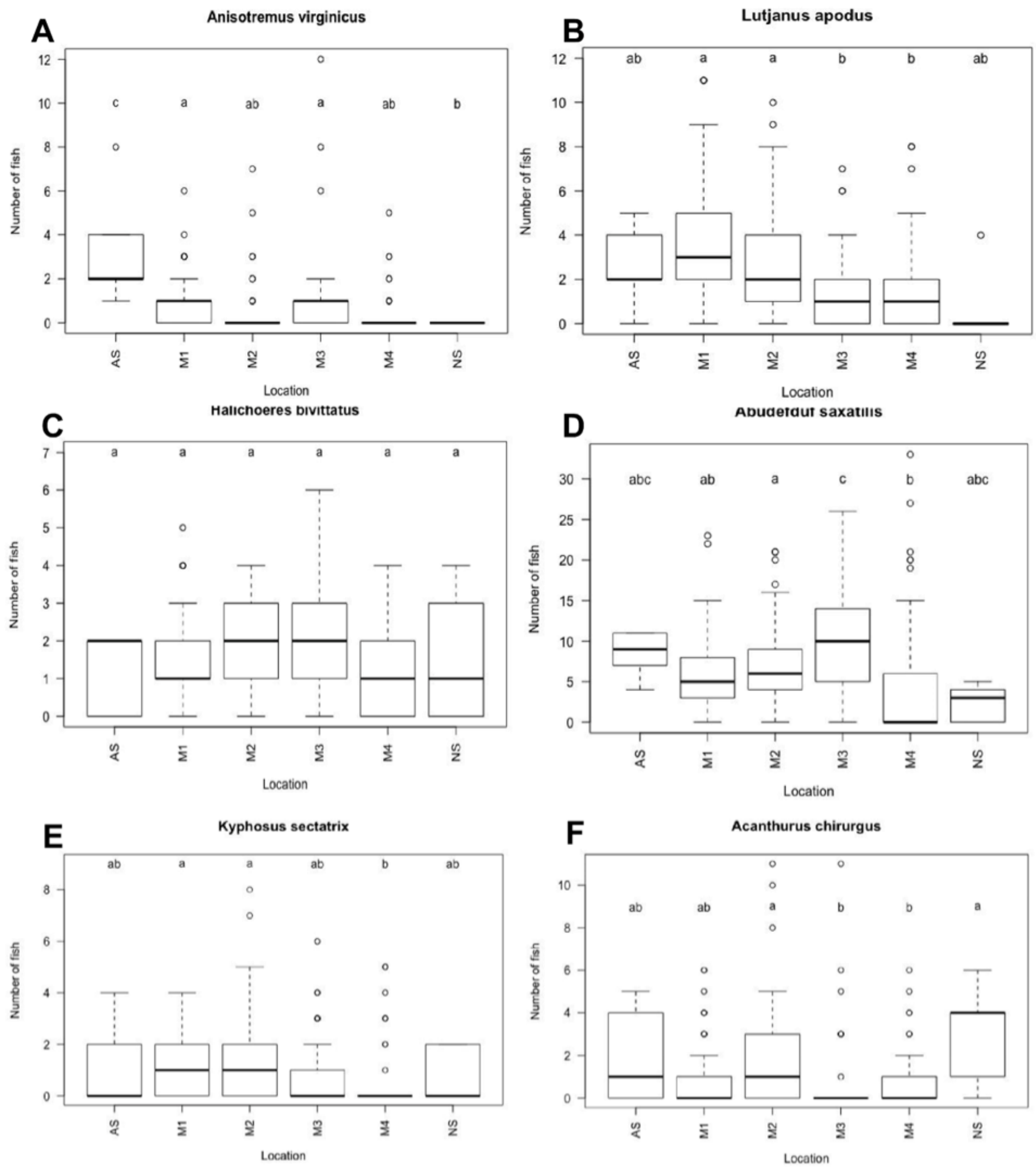
Lutjanus apodus represented 7.22% of all resident fishes and its distribution was significantly dependent on location but not treatment (Table 5). It showed predominance on M1, and M2. *Lutjanus apodus* contributed to describing between 15.18% (M2E) and 10.54% (M1E) of the average similarity in fish populations between locations (Table 4 and Fig. 10 B).

Halichoeres bivittatus represented 5.15% of the resident fishes and there was no difference in this species' abundance between location or treatment (Table 5). *Halichoeres bivittatus* was found at every location and it was only a small contributor to the average similarity in species assemblages between locations (Table 4 and Fig.10 C).

Abudefduf saxatilis represented 22.11% of all resident fishes and it was the most abundant species recorded in this study. Its abundance differed between locations but not treatments (Table 5) and its frequency fell into 3 distinct groups (a, b , and c). *Abudefduf saxatilis* offered the highest contribution in the average similarity in species assemblages of all locations in which it is predominant, (M1, M2, M3, and AS) ranging from 15.47% at M1C to 27.55% at M3C (Table 4, and Fig. 10 D).

Kyphosus sectatrix represented 3.35% of all resident fishes and its abundance differed by location and not treatment (Table 5). It was found at every location, with the exception of M4. This species offered only a small contribution to explain the average similarity of resident fish populations between locations (Table 4 and Fig. 10 E).

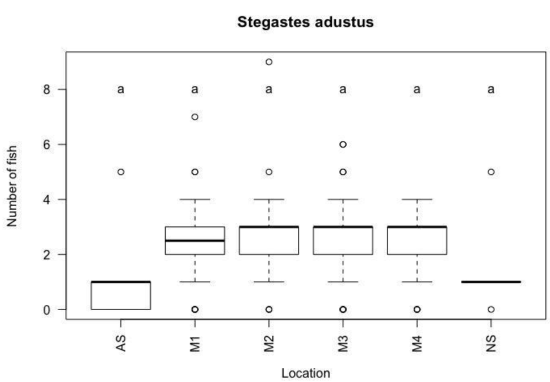
Achanturus chirurgus represented 3.35% of the resident fishes and it differed in abundance by locations and treatments (Table 5). It showed a strong preference in NS and M2 contributing to explain 16.37% of the average similarity in species assemblages at this site (Table 4 and Fig. 10 F).

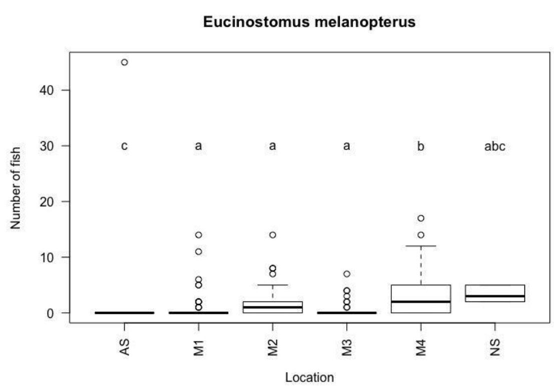


(Fig. 10) Shows a boxplot of the abundance of the species (A) *Anisotremus virginicus*, (B) *Lutjanus apodus*, (C) *Halichoeres bivittatus*, (D) *Abudefduf saxatilis*, (E) *Kyphosus sectatrix*, and (F) *Acanthurus chirurgus* at each location. The dark middle bar represents the median, the box represents the upper and lower 25% inner quartiles and the whiskers represent the outer 25% quartiles ((A) n=203, (B) n=634, (C) n=452, (D) n=1941, (E) n=268, and (F) n=294). The Y-axis shows the number of fishes, the x-axis shows the location; Mattress 1 (M1), Mattress 2 (M2), Mattress 3 (M3), Mattress 4 (M4), construction site remnants (AS), and limestone boulders water breaker (NS). Letters represent the statistical similarities/differences between locations.

Stegastes adustus represented 8.66% of the resident fishes and its abundance did not differ by location nor treatment (Table 5). It contributed to explain the average similarity in species assemblages of each location by a range that goes from 9.75% (AS) to 20% (M4E) (Table 4 and Fig. 20).

Eucinostomus melanopterus represented 5.71% of all resident fishes and its abundance differed between locations but not treatments (Table 5). It showed predominance on M4 and NS, and it contributed to describe between 12.80% (M4E) and 26.4% (NS) of the average similarity of resident fish assemblages at these locations (Table 4 and Fig. 21).





(Fig. 11) Boxplot of the abundance of the species *Stegastes adustus* and *Eucinostomus melanopterus* at each location. The dark middle bar represents the median, the box represents the upper and lower 25% inner quartiles and the whiskers represent the outer 25% quartiles (*S. adustus* (n=760) and *E. melanopterus* (n=452)). The Y-axis shows the number of fishes, the x-axis shows the location and treatment; Mattress 1 (M1), Mattress 2 (M2), Mattress 3 (M3), Mattress 4 (M4), construction site remnants (AS), and limestone boulders water breaker (NS). Letters represent the statistical similarities/differences between locations.

(Table 5) Shows the differences between location and treatment for each resident species.

Two-Way ANOVA (P-values) for each resident species, ns = (p-value > 0.05)			
Species	Location	Treatment	Location : Treatment
H. aurolineatum	1.59e-05	ns	ns
H. flavolineatum	ns	ns	ns
L. synagris	< 2e-16	ns	ns
L. griseus	1.41e-06	ns	ns
S. cristata	< 2e-16	4.84e-07	1.52e-15
A. virginicus	1.44e-05	ns	ns
L. apodus	2.09e-14	ns	ns
H. bivittatus	ns	ns	ns
A. saxatilis	8.67e-08	ns	ns
K. sectatrix	2.51e-05	ns	ns
A. chirurgus	5.11e-06	6.46e-05	ns
S. adustus	ns	ns	ns
E. melanopterus	7.58e-13	ns	ns

DISCUSSION

There is a significant difference between the composition of resident fish assemblages between different locations but not treatments, although there was a species-specific preference in the ECOncrete® units at side M1 by *Scartella cristata* (Fig. 9 F). Also, when found, there was no preference by invasive species at any location or treatment.

The hypothesis of a difference in number of species on the ECOncrete® side of the mattresses was predicated on the idea that cryptic species, such as those in the *gobidae* and *blennidae* families, can be defined by topographic features, such as the terrace-like shape and depressions of the ECOncrete® treatment units, which have the capacity of retaining water, and offer protection from predation like natural rock pools (Syms, 1995; Sella & Perkol-Finkel, 2015; Morris et al., 2017). The results showed that the cryptic species, *Scartella cristata*, was found only on M1 and limestone boulders breakwater (NS), with a significant difference between the ECOncrete® units and control units of the mattress. This species of *blennidae* is found on shallow rocky systems and tide pools (Randall, 1967), and it is frequently seen hiding only on the most shallow parts of each location, almost always at the water line (pers. obs.). The reason for this result may be caused by environmental factors and the complexity of M 1. This location is at a slightly shallower depth than the other mattresses and the degree of complexity on the ECOncrete® is similar to the small holes and crevices of the limestone boulders (NS) offering a suitable microhabitat needed by this cryptic species.

(Fig. 12) A *Scartella cristata* hiding in one of the microscale depressions of the ECOncrete® unit.

Similarly, *Lutjanus synagris* and *Eucinostomus melanopterus* were found predominantly on mattress 4 and NS (Fig. 9 C, and 11), but without showing a significant difference between the treatments. The habitat preference by these species may be connected to the substrate on which sites lay rather than the structures. I suggest this explanation because I noticed that these 2 species were predominantly utilizing part of the sites closer to the sandy bottom. This would make sense given the dietary habits of these two species (Allen, 1985; Randall,1967).

(Fig.13) A *Scorpaena plumieri* waiting in ambush between two units of the ECOncrete® Bio-Enhanced Marine Mattress.

The effects of complex microhabitats are mostly positive but they can differ between different taxa, locations, and environmental conditions and need to be extensively taken into consideration when planning eco-engineering (Toft et al., 2013; Sella & Perkol-Finkel, 2015; Strain et al., 2017). For example, in this study, the small size fish *Scartella cristata* could utilize small topographic depressions in the terrace-like structure of ECOncrete® units as habitat (Fig. 12), but larger size fishes preferred to use larger depressions such as the space in between different units (pers. obs., Fig.13). Similar observations were recorded for the large body size species *Pomacanthus paru and Gymnothorax funebris* found only at AS, which had larger crevices between all sites. This size specific habitat preference could be the reason behind the fish assemblage similarities between the control side and ECOncrete® units side of mattresses, as only fish that are smaller in size can utilize the small topographical features of the ECOncrete® units (Nash et al., 2013). This is a result of this project being developed primarily with the goal of enhancing colonization by algae and calcium carbonate invertebrates rather than for larger teleosts (Perkol-Finkel & Stella, 2016). Therefore, structures that were developed with the idea of enhancing habitat for multiple sizes of taxa showed a greater response in increasing biodiversity (Chapman & Underwood, 2011; Browne & Chapman, 2014; Firth et al., 2014; Morris et al., 2017; Sella & Perkol-Finkel, 2015). For example, an eco-engineered enhanced shoreline, in Seattle, incorporated habitats over hundreds of meters and it was shown to enhance recruitment and feeding in juveniles of salmon (Toft et al., 2013). Sella and Perkol-Finkel (2015) used enhanced breakwater units of 1 m^3 with small, medium, and large topographic features resulting in higher biodiversity than the surrounding standard breakwaters.

Depending on the goal of eco-engineered habitats, it may change taxon assemblages through a knock-off effect. A focus to change predator assemblages by implementing more habitat will result in a change of the benthic community structure through a top-down effect. The previously discussed study by Teoft et al. (2013) is an example of this case. On the other hand, the primary goal of this project was to enhance benthic biodiversity by increasing microscale habitat, enhancing algal growth and invertebrate retention changing the larger taxon assemblages through a bottom-up effect (Browne & Chapman, 2014; Chapman & Underwood, 2011; Firth et al., 2014; Morris et al., 2017; Perkol-Finkel & Sella, 2016; Sella & Perkol-Finkel, 2015).

It is important to understand and mimic natural features when enhancing or developing urbanized habitats by eco-engineering in order to support and maintain the natural biota and reduce the risk of proliferation of invasive species, which are often associated with concrete based coastal marine infrastructures (Glasby et al., 2007; Sella & Perkol-Finkel, 2015). An Invasive species is an organism that is introduced into places outside its natural range, negatively impacting native biodiversity, ecosystem services or human well-being.(NOAA; IUCN). During this project the only recorded presence of an invasive species was by *Pterois volitans*, which is largely distributed in Florida (Benkwitt, 2013). It was recorded on 2 different occasions while transiting the mattress and it did not stop at these locations for long (pers. obs.). No invasive species of the families *Gobidae* and *Blennidae,* such as the tessalated blenny (*Hypsoblennius invemar*), which is the only reported invasive blenny in Florida (FWC), were observed in any of the surveys. The hypothesis that these families would have been seen during this study was predicated because in Wonham et al., (2000) Gobies were the most often reported fish taxa of invaders and dispersers in ballast waters. Gobies and blennies were found in the crevices of the ballast intake grates of ship hulls that resembled their natural habitat in which they seek refuge and lay eggs (Rainer, 1995; Wonham et al., 2000). They also hypothesized that upon arrival and discharge of ballast waters in a new port the cryptic nature of these fishes would increase the likelihood of them surviving by hiding in artificial systems, such as dock piling and bottom debris, commonly found in urbanized areas (Wonham et al., 2000).

This finding shows that even if there is the possibility for the ECOncrete® to attract invasive species, it seems to be better suited as habitat for native species. This result is particularly important to improve marine infrastructure such as harbors, marinas, and breakwaters that facilitate the spreading of these harmful species by linking shorelines that were previously isolated (Bulleri & Airoldi, 2005; Vaselli et al., 2008; Airoldi et al., Sella & perkol-Finkel, 2015).

CONCLUSION

Even though some factors within the experimental array were not completely identical, like some local variation in placement depth due to underwater construction limitations, the ECOncrete® design did not result in a clear ecological enhancement of fish assemblages compared to the surrounding locations and treatments. It did show some species specific habitat preference by a species of blenny, which may be attributed to habitat complexity and environmental factors. Further studies with special focus on fish sizes and life stages associated with this particular ECOncrete® design could quantify the importance of those factors and further improve further mattress designs. Also, the absence of invasive species suggests that this design is more suited for native species instead. As urbanized areas will continue to replace natural habitats, more eco-engineering solutions are needed and the results of this study could assist in finding them.

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