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ECOncrete Pile Encasement Project - Brooklyn Bridge Park, NY
Biological and Ecological Aspects

Mid Term Report II

Dec 2014

Summary

During June 2013, a total of 18 piles in Pier 6 were underwent concrete encasement using ECOncrete's ecological pile encasement technology. This report summarizes the findings of three biological surveys, 3, 10, and 14 months post deployment, that were done on site.

Species richness did not differ significantly between the first two monitoring events and presented an early stage succession community, composed mainly of barnacles, colonial and solitary tunicates, bryozoans, and sessile polychaetes. A significant change was noted in the third sampling, as species richness on the ECOncrete jackets went up by 50% reaching a total of 18 species, while the Control fiberglass jackets presented a 10% decrees with 9 species.

As early as 3 months post deployment ECOncrete jackets already had live cover of 70-100%, while Control jackets, presented a scattered colonization (20-50%) with lower diversity. In the third monitoring, live cover on ECOncrete jackets was 90-100%, while Control jackets had only 40-85%. In both ECOncrete and Control jackets the lower cover values were typical to the upper tidal area.

Community composition of the sampled tiles significantly differed between ECOncrete samples and Control Fiberglass tiles in both tiles sampling events (April and August 2014). Differences were also noted between the North and the South piles. Differences between the ECOncrete and Control tiles were clearly evident at a community structure level, where Control tiles had an overall lower cover, and less diverse community compared to that of ECOncrete tiles.

Biomass of the sampled tiles significantly differed between ECOncrete and Control tiles in both the spring and the summer biomass samplings, where ECOncrete tiles had a much higher biomass accumulation compared to Control tiles. This trend was stronger in scale during the

spring where ECOncrete tiles had 10 fold higher the biomass compared to control, while in the summer ECOncrete had 3.5 folds greater biomass.

The fundamental differences in the biological parameters evaluated between ECOncrete and Control jackets is likely to result from the combined effect to material, texture and design of the former, creating ample of niches for marine life to develop.

While biomass on Control jackets did not show a specific trend with respect to distance from pier edge (between pile rows 1 to 3), biomass on ECOncrete jackets tended to increase towards the third (inner) row. While the exact reason for this difference is not fully understood, we can suggest that it might be a result of less predation, or suspended materials fluxes that affect the food supply of filter feeding organisms on the piles. In any case, this indicates that the biological conditions in row 3 are clearly suitable for colonization by diverse marine fauna given the appropriate substrate, and that pile enhancement can potentially extend deeper under the pier.

We expect additional fluctuations in species richness in both the ECOncrete and the Control Jackets, up to a point in which the number of species will stabilize in future sampling events, as the community will get to a steady state. Nonetheless, as the habitat features offered by the two types of jackets are different, the trend of lower richness at the Control jackets is expected to remain.

Background

While coastal zones occupy less than 15% of Earth's land surface, they are inhabited by nearly two thirds of the human population[1], making coastal development and urbanized seascapes inevitable[2]. Coastal and marine infrastructure (CMI), such as coastal defense structures, marinas, and ports, are mainly composed of concrete, which is known as a poor substrate for biological recruitment of natural assemblages and a substrate that is often colonized by nuisance and invasive species. This is one of the main reasons why coastal development is considered the prime cause for habitat loss, reduced biodiversity, and damaged ecosystem services.

Concrete is one of the main construction materials globally, and in the marine environment it commonly accounts for over 50% of CMI. Nonetheless, concrete is known as a poor substrate for biological recruitment, and is considered toxic to many marine organisms, mainly due to unique surface chemistry which impairs the settlement of various marine larvae[3, 4]. ECOncrete is a sustainable solution for concrete based CMI, harnessing biological processes for creating environmentally and structurally improved infrastructures. ECOncrete technologies increase the ability of CMI such as seawalls or pier piles to supply enhanced ecosystem services, while improving their structural integrity and durability. This is achieved by slight modifications to the composition, surface texture, and macro-design of concrete elements[5].

The unique feature of ECOncrete encourage diverse biological recruitment of different species, including habitat forming species and engineering species[6] that are capable of modifying the substrate and add biological niches. Many of these species are also contributing to a process called biogenic buildup; where engineering species like oysters, serpulid worms, barnacles and corals deposit calcium carbonate ($CaCO_3$) skeletons onto hard surfaces thus creating valuable habitat to various organisms[6] while also contributing to the structures' strength, stability and durability[7].

Developing and applying innovative sustainable construction methods for CMI is of prime importance nowadays in light of global threats of sea level rise and increased storminess. This is especially relevant for densely populated coastal areas like the Manhattan metropolitan area that suffer from aging infrastructures undergoing severe deterioration. One of the main problems of aging infrastructure around Manhattan is deterioration of wood or steel piles due to boring marine organisms and oxidizations. Steel deterioration in the marine environment and especially in the intertidal zone is a well-known factor, and wood pile deterioration dates back to the early use wood in piers and other waterfront facilities. Even though wood deterioration has been prevented to some extent with the use of preservative treatments, marine borers and fungi are still the two main groups of organisms responsible for pile deterioration in the marine environment. As the water quality at the Lower Hudson River Estuary improved in recent years thanks to mitigation efforts, these organisms flourish and cause severe damages to CMI in the areas. As a result, many piles must undergo time consuming and high cost encasement procedures, most of which utilize disposable fiberglass forms, left to deteriorate in the water, with a concrete filling. As hundreds of thousands of piles are likely to undergo repair in the upcoming years, it's time to explore new ecologically sensitive and more sustainable yet cost-effect solutions.

Project Description

During June 2013, a pilot project examining a new pile encasement technology was deployed at the Brooklyn waterfront in collaboration with the Brooklyn Bridge Park Corporation. The project was executed by D'Onofrio General Contractors Corp. and Walker Diving - Underwater Construction.

This new pile encasement technology illustrated in Image 1, provides all the functional and structural support required from a standard concrete encasement, yet with an added biological and ecological value.

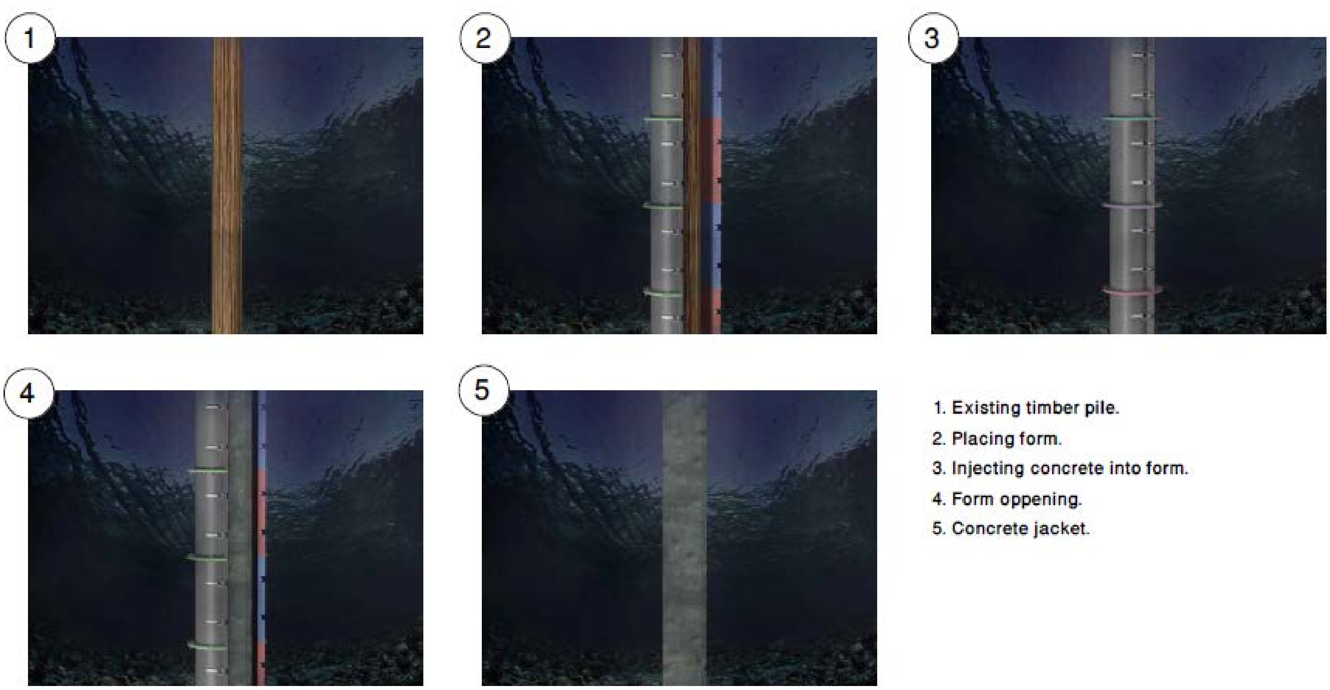

Image 1: Schematic illustration of ECOncrete pile encasement.

As opposed to standard pile encasement, utilizing regular Portland cement and left-in-place fiberglass forms (often left on-site susceptible to long-term deteriorate), ECOncrete's ecological pile encasement utilizes ECOncrete's ecologically active concrete mix cast on-site using reusable forms with a custom made textured surface (Image 2). This generates concrete jackets which encourage growth of a wide diversity of marine flora and fauna and provides both structural and environmental benefits. The use of reusable forms and ECOncrete mix design do not change the standard working procedure.

Forms and concrete admixture were sent to BBP from ECOncrete LTD, Israel. The concrete was batched at Eastern Concrete, Brooklyn, according to the ECOncrete mix design. Cement, aggregate, slag, sand, and water were batched in the plant central mixer (slump 2) and the admixture was added in the mixer truck resulting in a slump 7-9 mix. Concrete mix was pumped through one port in each forms (9f each). Forms were stripped (removed from the pile, exposing the ECOncrete casing) 60 - 18 hours after casting (see Table 1), depending on the day of casting. The concrete mix contained structural and micro fibers, and rebar was not used.

The pilot project includes two series of piles, one at the South Western and one at the North Eastern face of Pier 6 at Brooklyn Bridge Park (Image 3, Table 1). In each of the two areas, 9 piles underwent encasement using ECOncrete technologies, while other piles in the Pier underwent standard repair. This layout enables a direct comparison of the two repair techniques. The 9 piles in each of the two areas include 3 piles from the outer most row of the pier, 3 in the second, and 3 in the third row. This layout enables assessing the biological performance of ECOncrete's pile repair in growing distance from the pier edge.

Image 2: ECOncrete pile repair. Upper: ECOncrete reusable forms with textured surface. Lower: Jacket surface with increased surface roughness aimed at enhancing marine growth.

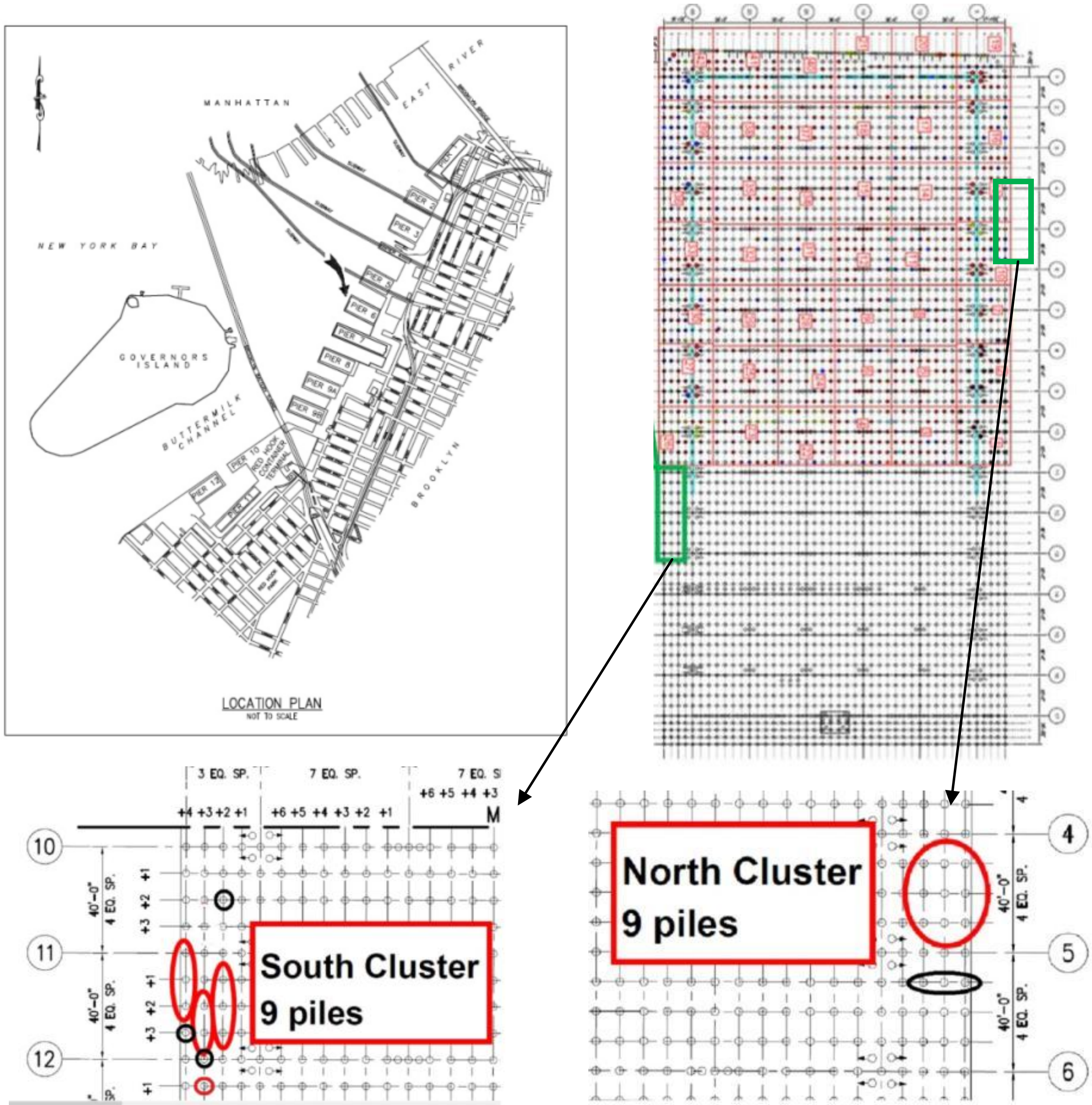

Image 3: Pilot project location at Pier 6, Brooklyn Bridge Park, Brooklyn, New York. ECOncrete jackets in red and Control in black.

Table 1: Piles # and installation Data. Note "stripped date" represent both date of stripping forms and installation of monitoring tiles.

South side	Pile #	Cast date	Stripped
ECOncrete	11+0 44	14.6.13	17.6.13
ECOncrete	11+1 44	14.6.14	17.6.14
ECOncrete	11+2 44	14.6.15	17.6.15
ECOncrete	11+2 43	14.6.16	17.6.16
ECOncrete	11+3 43	14.6.17	17.6.17
ECOncrete	11+1 42	14.6.18	17.6.18
ECOncrete	11+2 42	14.6.19	17.6.19
ECOncrete	11+3 42	14.6.20	17.6.20
ECOncrete	12+1 43	14.6.21	17.6.21
Control	11+3 44		17.6.22
Control	10+2 42		17.6.23
Control	12+0 43		17.6.24

North side	Pile #	Cast date	Stripped
ECOncrete	4+1 1	20.6.13	21.6.13
ECOncrete	4+2 1	20.6.14	21.6.14
ECOncrete	4+3 1	20.6.15	21.6.15
ECOncrete	4+1 2	20.6.16	21.6.16
ECOncrete	4+2 2	20.6.17	21.6.17
ECOncrete	4+3 2	20.6.18	21.6.18
ECOncrete	4+1 3	20.6.19	21.6.19
ECOncrete	4+2 3	20.6.20	21.6.20
ECOncrete	4+3 3	20.6.21	21.6.21
Control	5+1 1		21.6.22
Control	5+1 2		21.6.23
Control	5+1 3		21.6.24

Expected outcomes

The primary biological/ecological goal of the project (separate from the technical and structural goals related to this new technology that are beyond the scope of this document), is to assess the community structure that develops over time on ECOncrete jackets in comparison to standard ones, and to evaluate their enhancement capabilities, and thus, assess the ability of ECOncrete encasement to serve has a habitat while at the same time functioning as a protective layer against biological degradation of the piles.

Based on the data we have collected to date on recruitment of benthic flora and fauna onto ECOncrete matrices in the LHRE area, we expect to find enhanced biological productivity and ecological value that can be foreseen as:

- Increased recruitment rates of invertebrates such as oysters, mussels, tunicates and sponges
- Increased biodiversity
- High abundance and cover of habitat forming and engineering species
- Reduced dominance of nuisance and invasive species
- Enhanced food supply for motile species such as crabs and fish
- Rich filter feeding communities capable of enhancing water quality locally*
- In the future, once benthic communities develop, shelter for small fish and inverts**

* While we can quantify the amount of filter feeding organisms on the piles, chances are we will not be able to measure improvement in water quality in their vicinity, due to the low number of replicates and in light of the current regime in the area constantly mixing the water column.

** Pile design does not aim to provide fish nursing grounds or habitat as structural constrains (limited thickness of concrete encasement) do not allow integration of designated holes and crevices that are > 1 inch. Nonetheless, a more complex 3D design can be applied in the future if a wider concrete encasement will be allowed.

On a more broad scale, the results of the project will provide managers, policy makers, architects and engineers a unique tool for transforming industrialized and urbanized waterfronts to ecologically active marine nature zones. By designing construction elements that combine societal and environmental needs we can increase their ability to support more native flora and fauna that can compete with invasive and nuisance species. In addition, making infrastructures better suited for the development of natural assemblages will contribute to the connectivity between natural populations in the area. Development of innovative sustainable construction technologies will help bridge development and sustainability, by addressing the ever-growing conflict between coastal development and its effect on natural coastal habitats.

Monitoring Regime

In order to inspect the benthic community that was develop on the piles over time, both ECOncrete pile encasements and standard pile encasements were monitored from the same two areas (north and south sides of the pier). Due to the harsh 2013 winter which caused floating ice that prevented safe diving, the results in this report summarizing the findings of three sampling events, 3 (9.28.13) 10 (4.1.14) and 14 (19.8.14) months post deployment (PD).

Biological sampling included underwater photography, a careful on-site survey for generating a comprehensive species list, and sampling for biomass. The latter was performed using small detachable concrete tiles that were mounted upon the piles using a strap after opening the forms (4.5 feet below the top of the jacket) allowing the tiles to be detached for laboratory analyses. The tiles were weighed prior to deployment and were reweighed after submersion (dry weight after 48H in 60°C) so that the amount of accumulated organic and inorganic weight could be measured accurately. Similarly, detachable fiberglass tiles were mounted onto standard piles and all recruited cover was analyzed for organic and inorganic weight (Image 4). Both types of tiles were surveyed for a species list and live cover. In order to normalized the results, the sides and the back of tiles were scraped from flora and fauna after extracting from the water, leaving only the side of tiles that face the open water to be inspected and weighed (textured side of the concrete tiles and one of the smooth side of the fiberglass tiles).

Chlorophyll concentration measurements were initially a part of the monitoring program, but results from a two year experiment in the LHRE (Governors Island, Brooklyn Navy yard) and findings in other areas in the world[5] indicated that this facture provides insignificant data, and so it was excluded from the monitoring program.

The 3 months PD event included a full visual inspection of the pile and a comprehensive species list while the 10 months PD monitoring included sampling of tiles. Zero visibility at the 10 months PD event prevented visual inspection of the piles and all data was generated from the monitoring tiles. The 14 months PD monitoring (Aug 2014) included a full visual inspection of the pile, a comprehensive species list and sampling of tiles. The monitoring program will continue for additional 10 months in order to provide continues data for a period of 2 years post deployment. Inspection of pile encasements integrity was also a part of the planned monitoring, and was conducted by CH2MHILL (*Halcrow* engineers) July 2014 (report# 201997).

Image 4: Monitoring array installation. Left: ECOncrete tiles and fiberglass tiles (control). Right: Under water assembly.

Statistical Analyses

Community data was analyzed using PERMANOVA tests conducted on Bray Curtis Similarity matrix applied on raw data, while Biomass data were conducted on Euclidean Distance Similarity matrix applied on raw data. PERMANOVA Factors in both cases included Site (Random Factor: North vs. South), Treatment (Fixed Factor: ECOncrete vs. Control), Row (Fixed Factor: 1, 2, 3), and interaction terms. Season was added (Random factor) as of the 14 months PD monitoring analyses. In cases the number of unique permutations was low, statistical significance was determined using a Monte Carlo test (PMC). For community data, a non-parametric Multi Dimensional Scaling (MDS) was conducted in order to illustrate trends within the data. Vectors representing the relative contribution of taxa to the similarity between samples was superimposed on the plot. All analyses were performed using the PRIMER V6.1.13 & PERMANOVA + V1.0.3 program[8,9].

Results

Three months PD sampling

As early as 3 months post deployment ECOncrete jackets had live cover of 70-100%. On the other hand, Control jackets, that presented a smoother Fiberglass surface, exhibited scattered colonization (20-50%). The first phase of colonization on the ECOncrete jackets was composed mainly of barnacles, colonial and solitary tunicates (Image 5, 6), sessile polychaetes and the bivalve *Mytilus edulis*. During sampling, a number of blue crabs (*Callinectes sapidus)* were observed mating on the ECOncrete jackets (Image 7). The control jackets recruited mainly barnacles (often only the base disc unit with actual barnacle detached), the small sea anemone *Bunodactis stella,* as well as some colonial and solitary tunicate (Image 8). 14 species were noted in this survey altogether, 11 species were found on ECOncrete jackets and 10 on Control jackets. From these, 11 were filter feeders (tunicates, barnacles, sessile polychaetes, sponges, and bivalves) and 3 of were habitat formers (barnacles and sessile polychaetes- biogenic builders by calcium carbonate deposition). A complete species list is detailed in Table 2.

Image 5: Colonial and solitary tunicates on ECOncrete jackets 3 months PD.

Image 6: ECOncrete jackets 3 months PD: (bottom) *Balanus improvises* and *Hydroides dianthus*.

Image 7: Blue crab (*Callinectes sapidus)* mating on ECOncrete jackets.

Image 8: Control pile with Fiberglass form - 3 months PD.

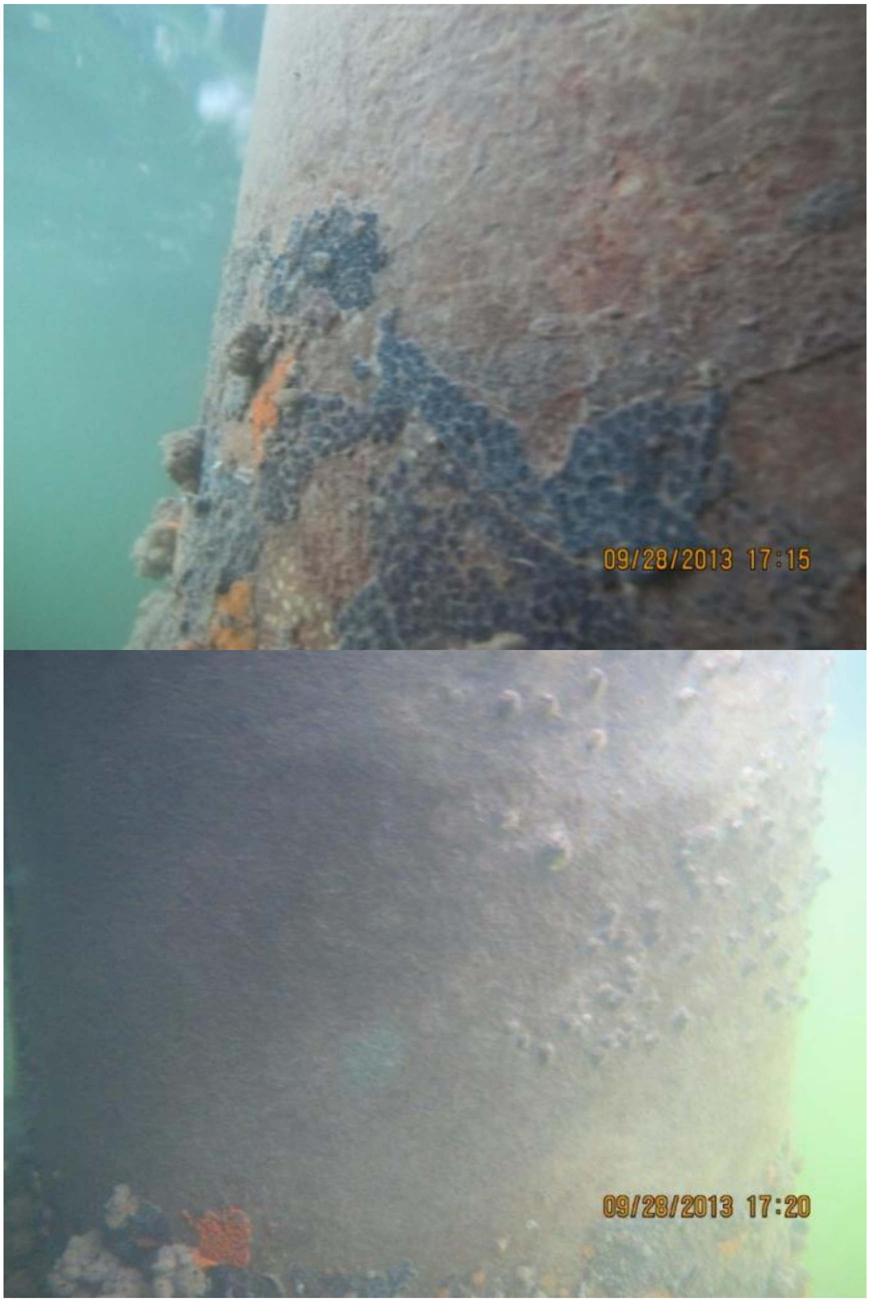

Image 8a: Control jackets with Fiberglass form - 3 months PD.

Ten months PD sampling:

As water during the survey (4.1.14) was extremely murky (Image 9) and visibility was almost zero, all data was collected from the monitoring tiles onshore (Images 10). Similar to the 3 month PD sampling, the 10 month tiles sampling presented an early stage succession community composed mainly of barnacles, colonial and solitary tunicates, bryozoans, and sessile polychaets (Image 10, 11). The control jackets presented a smoother surface with scattered colonization, which consisted mainly of barnacles (often only the base disc unit with actual barnacle detached), and colonial and solitary tunicate. 12 species were noted in this survey altogether, all were found on the ECOncrete monitoring tiles and 10 of them on the fiberglass control tiles. 11 species were filter feeders (tunicates, barnacles, sessile polychaetes, sponges, and bryozoans) and 6 of those were habitat formers (barnacles and sessile polychaetes - biogenic builders by calcium carbonate deposition). A complete species list is detailed in Table 2.

Image 9: Ten months PD sampling, poor visibility dictated onshore analyses.

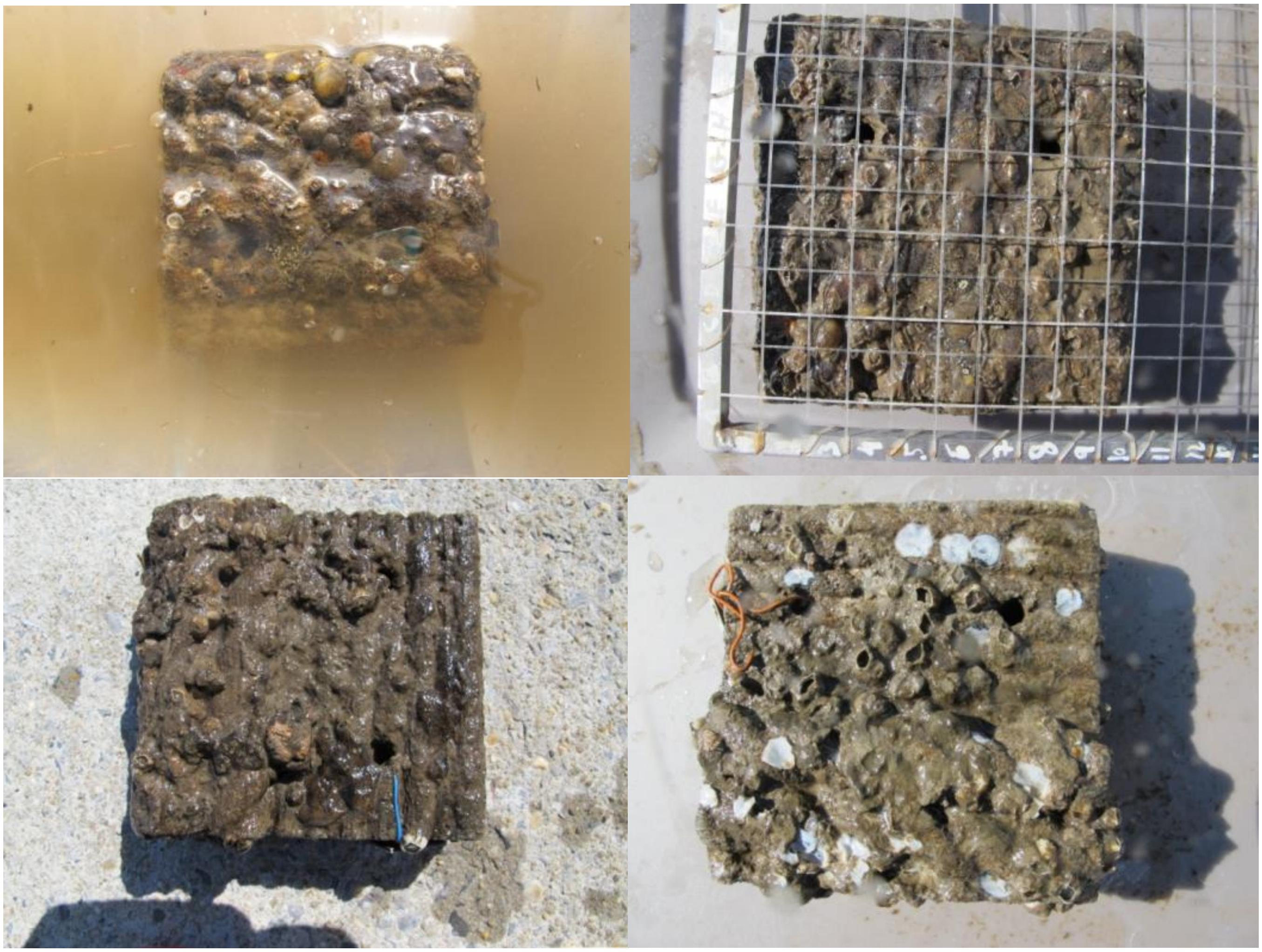

Image 10: ECOncrete monitoring tiles 10 months PD undergoing onshore analyses.

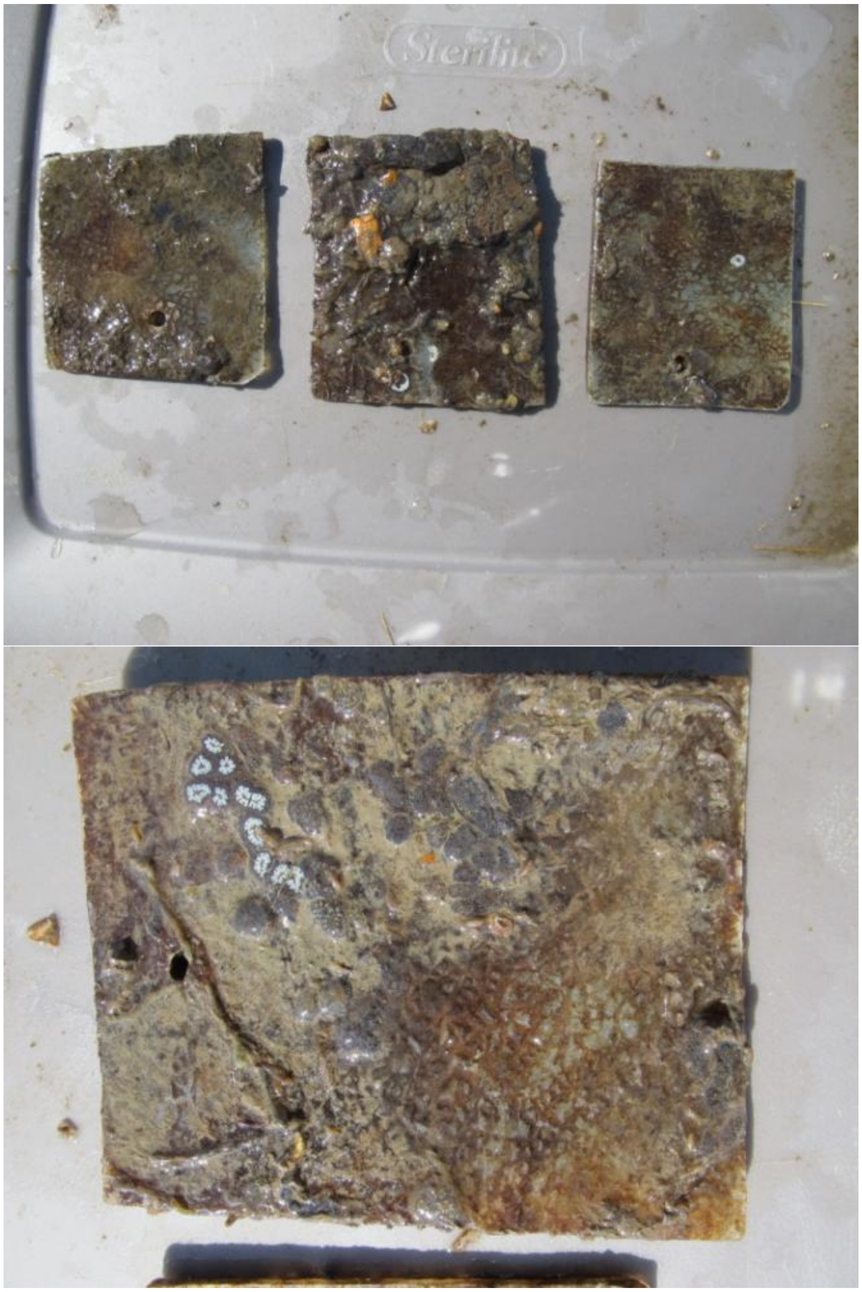

Image 11: Ten months PD - Control fiberglass tiles**.**

Table 2: Species list of taxa appearing on the jackets 3, 10 and 14 months PD. Note that different sampling efforts were conducted at the different time points (Visual census at 3 months PD vs. on-shore Tile analyses 10 months PD and both at 14 months PD).

PHYLUM	CLASS	SPECIES	3 months PD visual inspection of jackets		10 months PD tiles monitoring		14 months PD inspection & tiles monitoring	
			ECOncrete	*Control*	*ECOncrete*	*Control*	*ECOncrete*	*Control*
Porifera	Desmospongiae	*Microciona prolifera*	+		+		+	
		Halichondria bowerbanki					+	
		Haliclona loosanoffi					+	
Cnidaria	Anthozoa	*Bunodactis stella*		+				
		diadumene leucolena					+	+
Bryozoa	Gymnolaemata	*Schizoporella unicornis*			+	+	+	
		Membranipora membranacea					+	
Mollusca	Bivalvia	*Mytilus edulis*	+	+			+	+
	Gastropoda	*Urosalpinx Cinerea*					+	
Annelida	Polychaeta	*Spirorbis* sp.	+	+	+		+	
		Hydroides dianthus	+		+	+	+	+
		Family: Sabellidae	+	+	+	+	+	
Arthropoda	Decapoda	*Callinectes sapidus*	+					
	Maxillopoda	*Balanus improvisus*	+	+	+	+	+	+
	Infra: Cirripedia	*Balanus amphitrite ?*	+	+	+		+	+
	Isopoda				+	+		+
Chordata	Ascidiacea	*Botryllus schlosseri*	+	+	+	+	+	
		Molgula sp.			+		+	+
		Molgula citrina		+	+	+	+	+
		Molgula manhattensis	+	+	+	+	+	+
		Didemnum sp.	+	+			+	

Community Data:

Community composition of the sampled tiles significantly differed between ECOncrete samples and Control Fiberglass tiles (Table 3, P(MC)=0.005). In addition, a significant difference was found between the North and the South jackets (Table 3, P(MC)=0.015). These results are clearly illustrated in the MDS plot (Fig. 1) where ECOncrete tiles are clustered on the right, and Control ones are clustered on the left. Whereas, North jackets are clustered on the upper side of the plot, while South jackets are clustered on the bottom. The vectors represented on the plot are indicative of the relative contribution of various taxa to the similarity between the samples scattered in the plot. It appears that Control jackets had a more dominant appearance of Polychaete worms and Bryozoans, while ECOncrete tiles had a more diverse community structure dominated by Colonial and Solitary Tunicates, Barnacles, and hard bodied Tube worms (Serpullidae polychaets). No clear difference was detected between the three rows of jackets sampled (Table 3, P(MC)=0.337).

Figure 1: MDS of community data from tiles sampling conducted April 2014. Vectors are indicative of the relative contribution of the taxon to the similarity between the samples scattered in the plot. ECOncrete tiles (ECO) are marked blue, Control (C - fiberglass) tiles are marked black. N = North Jackets, S = South Jackets.

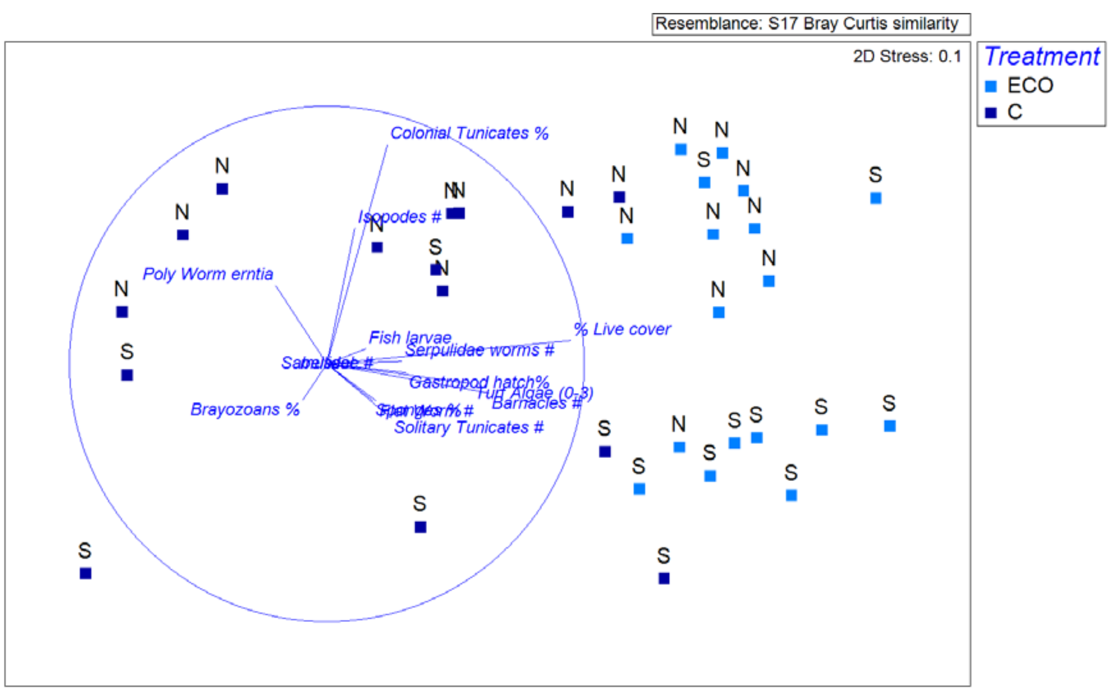

Table 3: Results of PERMANOVA analyses for tile Community data. Factors being Site (Random Factor: North vs. South), Treatment (Fixed Factor: ECOncrete vs. Control), Row (Fixed Factor: 1, 2, 3), and interaction terms. Bray Curtis Similarity matrix was applied on raw data. As in certain cases the number of unique permutations was low, statistical significance was determined using a Monte Carlo test (PMC).

PERMANOVA - Permutational MANOVA							
Resemblance: S17 Bray Curtis similarity							
Source	*df*	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Site	**1**	**3137**	**3137**	**5.5416**	**0.001**	**999**	**0.005**
Treatment	**1**	**8538.1**	**8538.1**	**21.124**	**0.001**	**6**	**0.0151**
Row	2	1060	530.02	1.3605	0.382	178	0.3373
Site x Treatment	1	404.18	404.18	0.714	0.538	999	0.537
Site x Row	2	779.16	389.58	0.6882	0.656	998	0.616
Treatment x Row	2	724.86	362.43	0.84874	0.596	996	0.6147
Site x Treat x Row**	1	427.02	427.02	0.75434	0.515	999	0.519
Res	22	12454	566.08				
Total	32	31419					

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Biomass:

Biomass of the sampled tiles significantly differed between ECOncrete samples and Control Fiberglass tiles (Table 4, P(MC)=0.043), as clearly illustrated in Figure 2. ECOncrete tiles had an overall average biomass accumulation of 0.083 gr/cm^2, more than a tenfold compared to Control tiles that had an average of 0.007 gr/cm^2 (Fig. 2).

No significant difference was found between the North and the South jackets (Table 4, P(MC)=0.084), nor between the three rows of jackets (Table 4, P(MC)=0.585). Nonetheless, a significant interaction term (Table 4, Site x Row Interaction Term P(MC)=0.002) suggested that these factors exhibited differential patterns in the different sites. Based upon the Pairwise comparison conducted, at the South jackets, the first row (the most external one) differed from the second and third rows, while in the North jackets, the second row differed from the others (Table 4, P<0.05 in call comparisons).

Moreover, when only ECOncrete jackets were analyzed, a significant difference between the three rows was evident (PERMANOVA, P = 0.036), where biomass accumulated on the tiles increased when going deeper under the pier, as can be seen in Figure 2.

Figure 2: Average Biomass (gr/cm^2±SE) of from tiles sampling conducted April 2014.

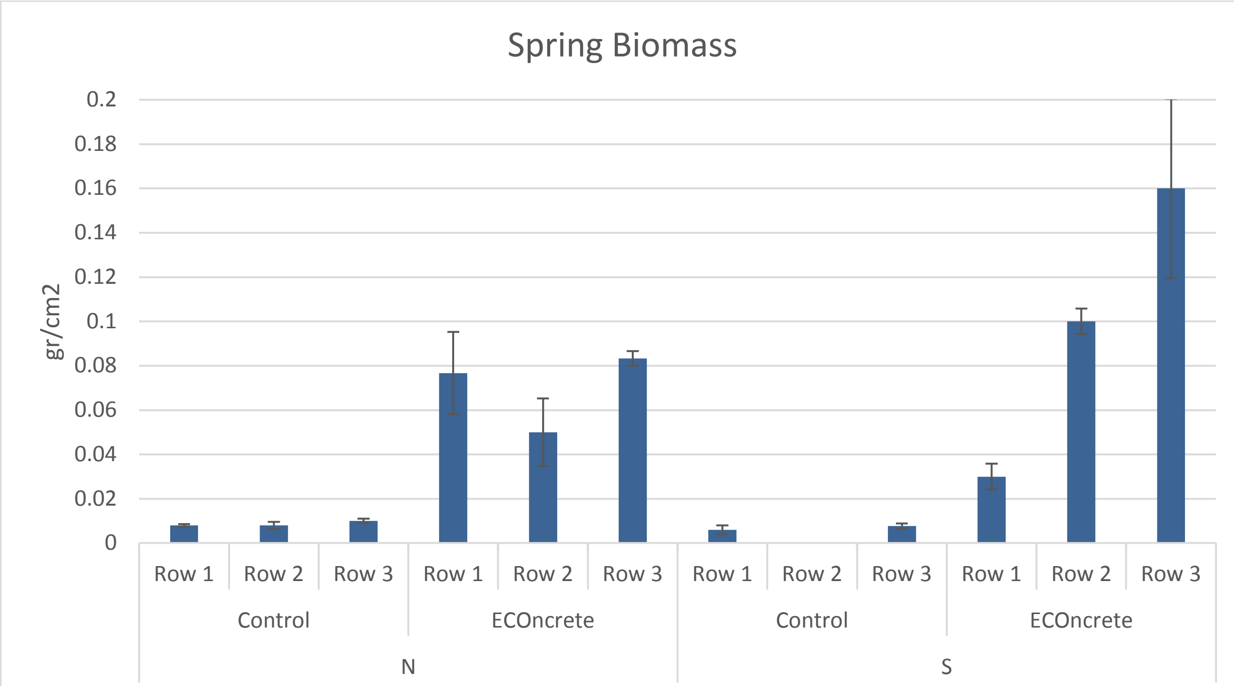

Table 4: Results of PERMANOVA analyses for tile Biomass data. Factors being Site (Random Factor: North vs. South), Treatment (Fixed Factor: ECOncrete vs. Control), Row (Fixed Factor: 1, 2, 3), and interaction terms. Euclidean Distance Similarity matrix was applied on raw data. As in certain cases the number of unique permutations was low, statistical significance was determined using a Monte Carlo test (PMC). In cases where interaction term was significant (Site x Row), Pair-Wise tests were conducted to establish significance among fixed factors (Row).

PERMANOVA - Permutational MANOVA							
Resemblance: D1 Euclidean distance							
Source	*df*	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Site	1	1.72E-03	1.72E-03	3.0685	0.085	997	0.084
Treatment	**1**	**3.35E-02**	**3.35E-02**	**396.25**	**0.001**	**6**	**0.043**
Row	2	5.87E-03	2.94E-03	0.68699	0.497	339	0.585
Site x Treatment	1	7.59E-05	7.59E-05	0.13562	0.712	997	0.727
Site x Row	**2**	**8.68E-03**	**4.34E-03**	**7.76**	**0.002**	**999**	**0.002**
Treatment x Row	2	7.34E-03	3.67E-03	0.49782	0.697	999	0.717
Site x Treat x Row**	1	7.03E-03	7.03E-03	12.569	0.003	997	0.004
Res	22	1.23E-02	5.59E-04				
Total	32	9.48E-02					

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PAIR-WISE TESTS			
Term 'Site x Row' for pairs of levels of factor 'Row'			
Within level **'South'** of factor 'Site'			
Groups	t	P(perm)	Unique perms
1, 3	**3.187**	**0.01**	**980**
1, 2	**9.0724**	**0.002**	**587**
3, 2	1.8447	0.145	581
Within level **'North'** of factor 'Site'			
Groups	t	P(perm)	Unique perms
1, 3	1.0117	0.304	982
1, 2	**2.904**	**0.019**	**993**
3, 2	**2.8428**	**0.019**	**992**

Fourteen months PD sampling:

The visibility during the survey (19.8.14) was descent (5-6 feet, Image 12) and both visual census and on-shore tile analyses were preformed. The 14 months PD sampling of the ECOncrete jackets presented a more diverse community than prior sampling events. Assemblages included coralline algae, sponges, gastropods, barnacles, colonial and solitary tunicates, bryozoans, and sessile polychaets (Images 13-17). Live cover on the jackets was app. 90-100% with the lower cover at the upper tidal area. The Control jackets presented scattered colonization, which consisted mainly of sessile polychaets, barnacles, as well as colonial and solitary tunicates, with live cover of app. 40-85% with the lower cover at the upper tidal area (Image 12).

Nineteen species were noted in this survey altogether, of which 18 were found on the ECOncrete jackets and 9 on the Control - fiberglass jackets. Sixteen species were filter feeders (tunicates, barnacles, sessile polychaets, sponges, and bryozoans) and 7 of those were habitat forming species (barnacles, bryozoans and sessile polychaets) that are contributing to the biogenic buildup on the jackets (by calcium carbonate deposition). A complete species list is detailed in Table 2. The 14 months PD sampling presented higher species number (19 species) then the previous monitoring (10 months PD - 12 species), this can be attributed to succession processes, but also to the different sampling effort, as the 10 months PD sampling did not included a visual survey due to poor visibility. When comparing only the data from the tile analyses in both sampling (10 and 14 months PD) there is an increase of 6 species in the later. These findings point to a general trend of maturing community with higher number of species with time, especially on the ECOncrete jackets.

Image 12: 14 month PD survey: Control jackets with Fiberglass form.

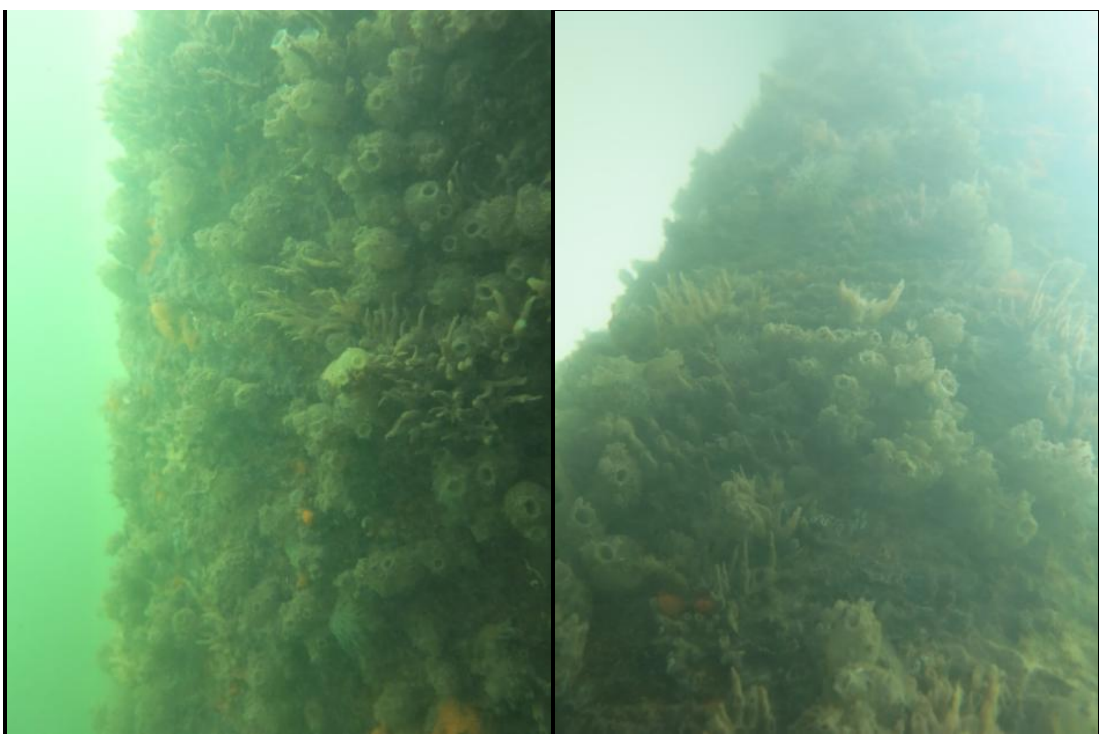

Image 13: 14 month PD survey: ECOncrete jackets.

Image 14: 14 month PD survey. Center of image: *Urosalpinx Cinerea* - oyster drill snail. Note the sessile community on the concrete composed of coralline algae (order Corallinales), barnacles, sponges, and sessile polychaets.

Image 15: 14 month PD survey (ECOncrete Jacket). *Halichondria bowerbanki*

Image 16: 14 month PD survey. *Haliclona loosanoffi (*Loosanoff's Haliclona*)* on ECOncrete jacket and sampling tile.

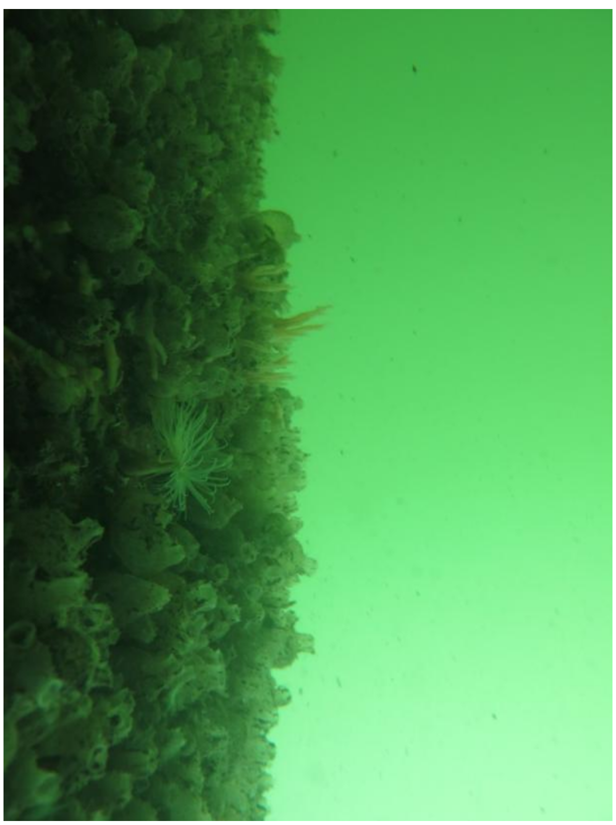

Image 17: 14 month PD survey (ECOncrete Jacket). The Sea anemone *diadumene leucolena* surrounded by the tunicate *Molgula spp.*

Community Data:

Community composition of the sampled tiles did not yield a significant difference between ECOncrete samples and Control Fiberglass tiles as a main effect (Table 5, P(MC)=0.419), however the Site x Treatment interaction term was significant (Table 5, P(MS)=0.002). Pair-wise comparison of the latter indicated that there were significant differences between ECOncrete and Control tiles, yet this difference was slightly stronger at the South site (Table 5, Pair-wise: P=0.002 for the South site and P=0.007 for the North site). Differences in community structure were also noted between the sites when examining the different treatments, i.e., control tiles differed between North and South, as did ECOncrete tiles (Table 5, Pair-wise: P=0.001 and 0.018 respectively). Similarly to the results of the 10 months PD sampling, here too ECOncrete tiles are clustered on the right, and Control ones are clustered on the left, yet this time with some overlapping samples in the center of the plot, while North jackets are clustered on the upper side of the plot, and South jackets are clustered on the bottom (Fig. 3). Vectors representing the relative contribution of various taxa to the similarity between the samples illustrate that Control jackets had a more dominant appearance of soft bodied Tube worms (Sabellidae Polychaets) and colonial tunicates, while ECOncrete tiles had a more diverse community structure dominated by Solitary Tunicates, bryozoans, isopodes, Barnacles, and hard bodied Tube worms (Serpullidae polychaets). No clear difference was detected between the three rows of jackets sampled (Table 3, P(MC)=0.302).

Figure 3: MDS of community data from tiles sampling conducted August 2014. Vectors are indicative of the relative contribution of the taxon to the similarity between the samples scattered in the plot. ECOncrete tiles (ECO) are marked blue, Control (C - fiberglass) tiles are marked black. N = North Jackets, S = South Jackets.

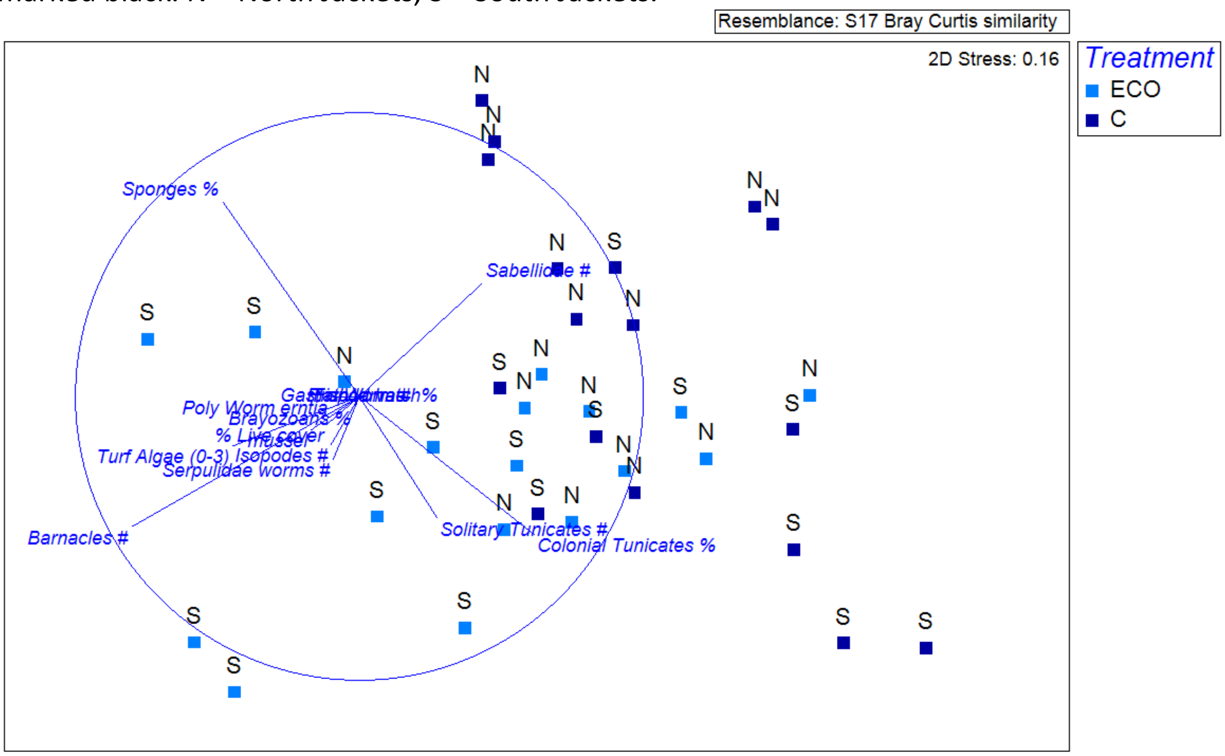

Table 5: Results of PERMANOVA analyses for tile Community data. Factors being Site (Random Factor: North vs. South), Treatment (Fixed Factor: ECOncrete vs. Control), Row (Fixed Factor: 1, 2, 3), and interaction terms. Bray Curtis Similarity matrix was applied on raw data. As in certain cases the number of unique permutations was low, statistical significance was determined using a Monte Carlo test (PMC). In cases where interaction term was significant (Site x Treatment), Pair-Wise tests were conducted.

PERMANOVA - Permutational MANOVA							
Resemblance: S17 Bray Curtis similarity							
Source	*df*	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Site	**1**	**1444**	**1444**	**5.6266**	**0.001**	**999**	**0.001**
Treatment	1	2157	2157	1.2544	0.349	6	0.4194
Row	2	1005.4	502.69	1.5856	0.288	180	0.302
Site x Treatment	**1**	**1719.5**	**1719.5**	**6.7001**	**0.001**	**997**	**0.002**
Site x Row	2	634.08	317.04	1.2354	0.295	997	0.261
Treatment x Row	2	739.16	369.58	0.8687	0.593	999	0.5756
Site x Treat x Row	2	850.88	425.44	1.6577	0.131	999	0.135
Res	23	5902.7	256.64				
Total	34	13939					

PAIR-WISE TESTS			
Term 'Site x Treatment' for pairs of levels of factor 'Treatment'			
Within level **'South'** of factor 'Site'			
Groups	t	P(perm)	Unique perms
ECO, C	**3.0061**	**0.001**	**999**
Within level 'North' of factor 'Site'			
Groups	t	P(perm)	Unique perms
ECO, C	**2.1896**	**0.007**	**998**

Term 'Site x Treatment' for pairs of levels of factor 'Site'			
Within level **'ECOncrete'** of factor 'Site'			
Groups	t	P(perm)	Unique perms
S, N	**2.0883**	**0.018**	**999**
Within level **'Control'** of factor 'Site'			
Groups	t	P(perm)	Unique perms
S, N	**2.9156**	**0.001**	**998**

Biomass:

Biomass on ECOncrete tiles was 3.5 higher than that on Control jackets 14 months PD. This trend did not differ between sites and site was not found to be a significant factor in the analyses (P(MC)=0.4194). While Treatment (ECOncrete vs Control) was not significant as a main effect (P(MC)=0.302), when analyzing results of both sites pooled together, a significant difference appears both between the treatments and between the rows (Table 6, P=0.001 and 0.037 respectively). Pair wise comparisons between rows indicate that row 3 differs from rows 1 and 2. This is evident in Fig. 4.

Similarly to the trend in April 14, ECOncrete tiles has much greater biomass compared to Control tiles (Fig. 4), where ECOncrete tiles had an overall average biomass accumulation of 0.072 gr/cm^2, compared to Control tiles that had an average of 0.021 gr/cm^2. This difference is less then was noted in April 2014 sampling (10 folds).

Figure 4: Average Biomass (gr/cm^2±SE) data from tiles sampling conducted August 2014.

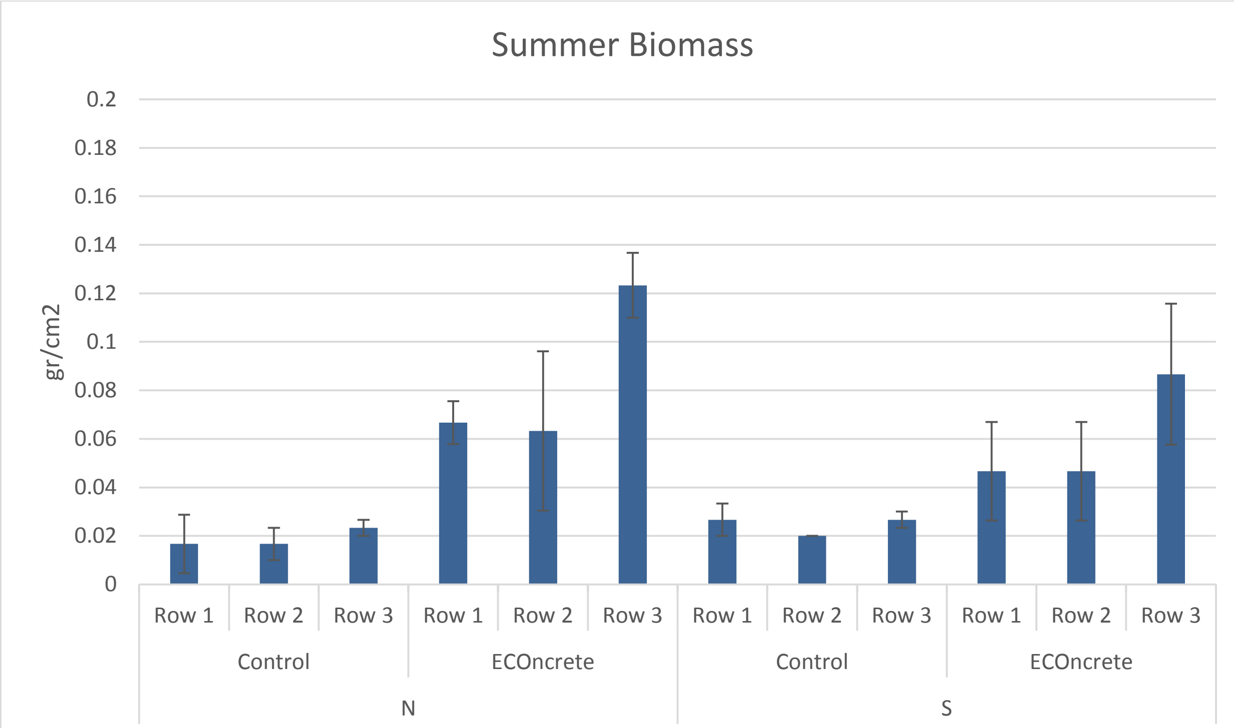

Table 6: Results of PERMANOVA analyses for tile Biomass data (Sites pooled). Factors being Treatment (Fixed Factor: ECOncrete vs. Control), Row (Fixed Factor: 1, 2, 3), and interaction terms. Euclidean Distance Similarity matrix was applied on raw data. Pair-Wise test was conducted to establish significant differences within the Row factor.

PERMANOVA - Permutational MANOVA							
Resemblance: D1 Euclidean distance							
Source	*df*	SS	MS	Pseudo-F	P(perm)	Unique perms	
Treatment	**1**	**2.24E-02**	**2.24E-02**	**28.505**	**0.001**	**984**	
Row	**2**	**5.83E-03**	**2.91E-03**	**3.7135**	**0.037**	**999**	
Treatment x Row	2	3.83E-03	1.91E-03	2.4386	0.112	998	
Res	29	2.27E-02	7.84E-04				
Total	34	5.48E-02					

PAIR-WISE TESTS			
Term 'Row'			
Groups	t	P(perm)	Unique perms
1, 3	**2.4709**	**0.021**	**831**
1, 2	0.23118	0.813	870
3, 2	**2.2177**	**0.045**	**957**

Discussion

Species richness did not differ significantly between the first two monitoring events and presented an early stage succession community, composed mainly of barnacles, colonial and solitary tunicates, bryozoans, and sessile polychaets. This might be due to the harsh 2013 winter, and the drop in water temperature that was noted earlier than usual and most likely affected recruiting rates. A significant change was noted in the third - summer sampling, as species richness on the ECOncrete jackets went up by 50% (from 12 in April to 18 in August) and the fiberglass jackets presented a 10% decrees (from 10 in April to 9 in August). The fact that ECOncrete jackets had two times the species richness that of the control fiberglass jackets might be attribute the combined effect of material, texture and design of the former, that creates extended number of ecological niches that can be utilized by different marine life.

Live cover on the jackets was app. 90-100% with the lower cover at the upper tidal area. The control jackets presented scattered colonization, which consisted mainly of sessile polychaets, barnacles, as well as colonial and solitary tunicates, with live cover of app. 40-85% with the lower cover at the upper tidal area

We expect additional fluctuations in species richness and cover on both the ECOncrete and the Control Jackets, up to a point in which the number of species will stabilize in future sampling events, as the community will get to a steady state. Nonetheless, as the habitat features offered by the two types of jackets are different, the trend of lower richness at the Control jackets is expected to remain.

Community Data:

Community composition of the sampled tiles significantly differed between ECOncrete samples and Control Fiberglass tiles in both tiles sampling events (April and August 2014). Differences were also noted between the North and the South jackets. These results were supported by the PERMANOVA test as a main effect in the spring, and under the interaction term during the summer (Tables 3 and 5 respectively). While in the spring the separation between ECOncrete and Control tiles was nearly complete as illustrated by the MDS plot (Fig. 1), during the summer there was some overlap between ECOncrete and Control tiles, mainly in the North site (Fig. 3). While during the spring sample cover and richness on the sample tiles was not as impressive as that documented by photography in the visual census conducted in October 2013, differences between the ECOncrete and Control tiles were clearly evident at a community structure level, where Control tiles had an overall lower cover, and less diverse community compared to that of ECOncrete tiles. This trend was supported by the vector representation of key taxa superimposed to the MDS plot (Fig. 1). It is likely that the sampling conducted in April 2014, during which water temperatures were still extremely low, following a very harsh winter, represents a somewhat dormant community state. This is supported by the summer findings that exhibited an increase in richness (Table 2) and cover, and it seems that filter feeders and other communities flourished and developed as water temperatures rose.

No clear difference was noted with respect to community structure between the three rows of jackets sampled appeared in neither of the samplings (Tables 3 and 5), although such a difference did appear in the biomass results from the summer sampling (see below).

Biomass:

Biomass of the sampled tiles significantly differed between ECOncrete samples and Control Fiberglass tiles in both the spring and the summer biomass samplings (Table 4, Fig. 2 and Table 6, Fig. 4 respectively), where ECOncrete tiles had a much higher biomass accumulation compared to Control tiles. This trend was stronger in scale during the spring where ECOncrete tiles had 10 fold higher the biomass compared to control, while in the summer ECOncrete had 3.5 folds greater biomass. This effect is likely to result from the combined effect to material, texture and design of the ECOncrete jackets, creating ample of niches for marine life to develop. Additionally, while this was not tested on site, it is most likely that the rough texture and 3D design of the jackets increase the boundary layer surrounding the jackets, thus facilitating attachment onto the newly formed habitat.

The trends in biomass were similar at both the spring and the summer samplings (Fig 2 and Fig 4 where ECOncrete accumulated significantly more biomass than control tiles. Nevertheless, biomass on the Control tiles increased much between spring and summer (from 0.007 gr/cm^2 in April to 0.021 gr/cm^2 in August), which might be attribute to filter feeders community such as colonial tunicates that flourish during summer and then reduce size and distribution during winter. This assumption can be supported by the low number of species found on the control jackets compeered to the ECOncrete jackets (9 to 18) which indicate that the change in biomass might be influenced by small number species. The spring 2015 sampling will provide a clearer view of this subject. Note, that although biomass on the Control Fiberglass tiles was clearly lower than that accumulated on the ECOncrete tiles, this can still be somewhat of an over estimation of biomass on the Control tiles. This is due to the added “edge effect” on the small sampling tiles (compared to the homogeneous surface of the actual Fiberglass jackets) and potentially due to the ability of the small control tiles to move with currents, a movement that potentially increased recruitment of filter feeding organisms such as tunicates[10]. This overestimation is not expected to be significant for the ECOncrete tiles as these do not shift lightly due to their weight, and as the tiles (and ECOncrete jackets) exhibit high complexity as a part of their design.

While during the spring sampling, there was an indication of differences between sites (via interaction term, Table 4), no significant difference was found between the North and the South jackets during the summer sampling. Nonetheless, during the summer the effect of Row was significant as a main effect, where Row 3 differed from the other (Table 6). When examining Figure 4, it seems that the 3rd row has a greater biomass compared to the others. This trend also appeared for ECOncrete jackets during the spring sampling (Fig. 2). While the exact reason for this difference is not fully understood, we can suggest that it might be a result of less predation, or suspended materials fluxes that affect the food supply of filter feeding organisms on the jackets. In any case, this indicates that the biological conditions in row 3 are clearly suitable for colonization by diverse marine fauna given the appropriate substrate, and that pile enhancement can potentially extend deeper under the pier. It is possible that conditions under the pier going into row three are still similar enough to those in the external rows, allowing communities to develop. If this trend persists in future samplings, we could potentially suggest implementing ECOncrete encasement even further down the pier (that is, in inner rows, beyond the first three rows tested to date).

Oysters:

Oysters were not noted at the 3 month PD visual survey nor on the monitoring tiles 10 month PD sampling. This might be due to lack of natural recruitment in the NY harbor during 2013 (personal communication Jim Lodge-Hudson River Foundation) as opposed to 2012 that presented a peak year in natural recruitment (associated with the mild 2012 winter). In addition, the lack of a visual survey at the 10 months PD monitoring, might have under estimated the community as the area that was surveyed was significantly smaller (surface of monitoring tiles vs. surface of jacket). Another factor that might influence this finding is the initial deployment of the pilot study (6/14-20/13) that was towards the end of the known oyster reproduction season (late June). During the 14 month PD sampling no oysters were noted the pilot study array. One mature (5 cm long) oyster was noted in vicinity to the study area, on a metal bar at the south cluster site. While the sampling tiles did not have any oyster recruitment, it is possible that newly recruited oysters were missed by the divers during the underwater visual inspection of the jackets. This can be verified in the next visual sampling (expected spring 2015) as size of 2014 recruits will increase.

Conclusions:

Results support the notion that ECOncrete encasement made of ecologically active concrete and with a rough surface texture and complex design indeed enhanced the recruitment of marine organisms onto the jackets, creating a richer and more diverse habitat compared to Control Fiberglass jackets that offer very limited habitat value. From the 19 species noted in the summer sampling Sixteen were filter feeders (tunicates, barnacles, sessile polychaets, sponges, and bryozoans) seven of which were habitat forming species (barnacles, bryozoans and sessile polychaets) showing an increase in ecosystem services. With time, the sessile community on the jackets is expected reach a steady-state, which will keep the biomass levels stable as biogenic buildup and bio-erosion process will reach equilibrium.

The biogenic crust on the ECOncrete encasement provides both bio-protection to the concrete encasement, and, at the same time, contributes valuable ecosystem services such as nursing grounds, contribution to water quality, and habitat to various motile and sessile organisms. We expect this trend to become even more significant with time, as community develops further and progresses into more advanced successional stages.

It is important to note, the above mentioned biological assemblages that developed on ECOncrete jackets did not interfere with the concrete encasement performance, and did not disrupt standard survey procedures. A year post deployment, CH2M HILL conducted an encasement inspection including a 100% visual inspection (Level I) on all accessible portions of the concrete encasements, and a hands-on (Level II) inspection on 100% of the concrete encasements. The inspection found that the ECOncrete encasements had hard and sound concrete, in overall Good condition, with generally no notable defects (Report # 201997, July 2014).

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