Tide Pool Armor in the Port of San Diego

Fourth Monitoring Report | 26 Months Post Deployment | May 15-18, 2023

BACKGROUND

In March 2021, ECOncrete launched a three-year pilot project in The Port of San Diego to demonstrate an innovative new design of the COASTALOCK™ (CL), an interlocking precast concrete Armor unit. The pilot project is part of the Port's Blue Economy Incubator, a launching pad for sustainable aquaculture and Port-related blue technology ventures that support services focused on pilot project facilitation.

The pilot was installed in two sections at Harbor Island, where the current waterfront armor protection is a riprap rock mound, offering limited habitat value. This installation is the first CL installation in the world and includes 74 interlocking single-layer armor units, to provide environmentally sensitive edge protection. The unit's unique design allows it to generate multiple different habitats (Figure 1).

Requiring minimal maintenance, the CL units provide structural, ecological, and community engagement benefits, including the promotion of marine organisms and restoration of local ecosystems. ECOncrete is monitoring the installation to evaluate the ecological and structural performance of the CL units as an ecological armoring replacement to traditional riprap.

Figure 1. CL installation orientation options to create multiple habitats

MATERIAL AND METHODS

COASTALOCK Installation

Units were cast and installed by R.E. STAITE ENGINEERING INC. (RES). Casting was done at RES shoreside facility between 10/30/2020 to 12/09/2020, at a rate of four units per casting day, using four CL molds designed and manufactured by ECOncrete (Figure 2). Once casting was completed, and all units were cured, they were mobilized to the site on a barge for installation from the water side at two waterfront sites along Harbor Island, San Diego, CA (Figure 2).

CL units were installed between 02/11/2020 to 03/03/2021 using a crane and excavator placed on two barges (Figure 2). Installation was done in four rows, where the upper three rows were placed as water-retaining elements to mimic natural tidepools and the lower row was rotated sideways to generate cave habitats (Figure 3).

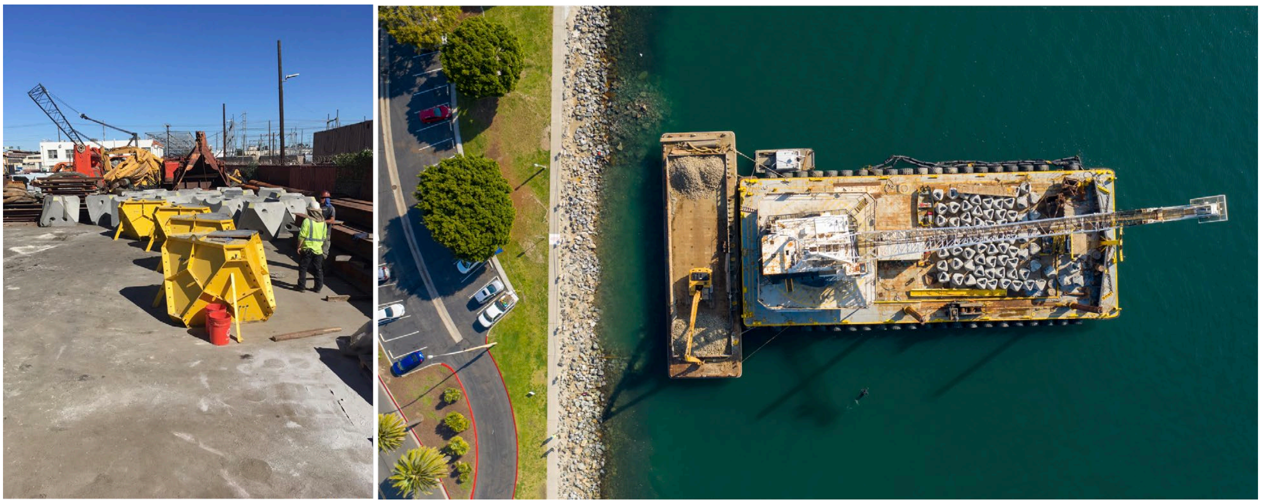


Figure 2. Left: CL casting; Right: CL installation at Harbor Island.

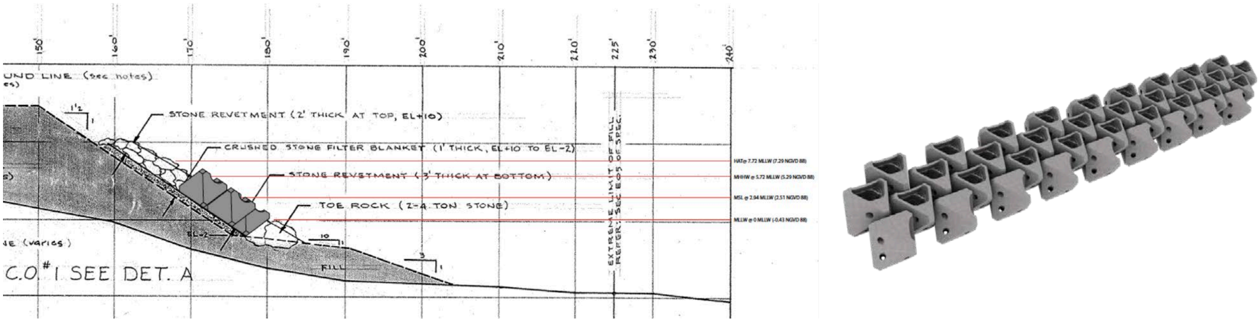


Figure 3. Left: Cross-section showing the CL installation relative to tidal level; Right: Schematic illustration of the CL units' installation in four rows.

BIOLOGICAL MONITORING

The plan aims to monitor the biological productivity and ecological value of the new sloped armor edge design at two waterfront sites along Harbor Island, San Diego, CA.

The monitoring plan is set to provide data with respect to:

1. Diversity indices – biodiversity, species richness, and species abundance – between the CL units and the adjacent riprap belt, located at the intertidal zone.
2. Differences in successional stages and biogenic buildup between CL units
3. Differences in water conditions between retained water (by the CL units) and nearby open water.

MONITORING ARRAY

The monitoring array includes 2 sites along the constructed riprap of Harbor Island, each with 37 CL units, and one control site located between site 1&2 (Figure 4).

The control site includes rocky areas from MHW to MLW representing the biological communities and physical conditions typical to the current riprap armor in the area.

The monitoring array will include a total of 27 CL/control patches as follows:

- Site 1 – a total of 9 CL, 3 at each tidal height (upper, middle, lower).
- Site 2 – a total of 9 CL, 3 at each tidal height (upper, middle, lower).
- Control – a total of 9 control patches, 3 at each height, similar to the pools.

Figure 4. Aerial view of the proposed locations for CL Tide Pool placement.

MONITORING PROTOCOL

Data collection

After installation, sampling was planned to occur every 6 months for 2 years. However due to travel restrictions during the COVID-19 pandemic, the first monitoring event took place in November 2021, at 8 MPD, the second monitoring event took place in May 2022, at 14 MPD, the third monitoring event took place in November 2022, at 20 MPD, and the fourth and last monitoring event took place in May 2023, at 26MPD. Each sampling event included pools sampling during low tide when the pools are separated from the open water and sampling the caves during high tide. During each monitoring event, the entire exposed surface area of the CL units was sampled.

Data were collected according to the protocol of Perkol-Finkel et al. (2008) [1] which includes:

- Percent of overall live cover
- Percent cover of encrusting species (sponges, tunicates, bryozoans, etc.)
- Count of solitary organisms (oysters, tunicates, massive species of Polychaeta tube worms, etc.)
- Quantitative evaluation of taxonomic groups which cannot be quantified by the above methods (turf algae cover, coralline algae, Serpullidae, and Sabellidae worms, etc.) following an index of:
    - 0 – absent

- 1 – sparsely scattered
- 2 – densely scattered
- 3 – densely uniform

Species were identified to the lowest taxonomic level possible in the field and, if necessary, samples were taken for laboratory identification. All samples were photographed using an underwater camera to assist in the identification process. Species were classified by status:

- Native species- a species or lower taxon living within its natural range (past or present), including the area it can reach and occupy using its natural dispersal systems.
- Invasive species- a species that causes ecological or economic harm in a new environment where it is not native.
- Cryptogenic species- a species whose origins are unknown.
- Mobile species- a species that moves across wide areas and is not settled on the substrate.
- Calcifying species- a species that deposit calcium carbonate skeleton in its subsurface.
- Water quality measurements, using a hand-held probe, to monitor:
    - Dissolved Oxygen
    - Turbidity
    - Temperature

Water quality will be monitored within the pools and in the shallow water control sites, 1 ft. below the water surface at low tide.

- Final monitoring, after 2 years, will include all the above as well as sampling for biogenic buildup (accumulation of $CaCO_3$) on the CL units, compared to control sites. This will be done by scraping a defined area within the water retaining part + on the outer part of the CL and of each control patch, removing all live cover. All scraped material will be collected into zipper bags for laboratory analysis according to biomass LOI (Loss on ignition) analysis protocol.

SAMPLING METHODS

- Rows – upper, middle, lower (as arrows in Figure 5).
- Randomly select three CL units at each row using an excel with a random function.
- Sample the outer and inner CL units using a sampling sheet (Appendix 1).
- To sample control, a rope was used to mark the outer parameter of on CL unit, then place the resulting circular rope on the control rocks and sample everything that falls inside the circle.
- Both control and treatment are sampled in the same corresponding tidal height (Figure 6).

Figure 5. CL layout and numbering of units.


Figure 6. Example of monitoring in the upper tidal area. Left: control rocks marked by a rope; Right: single CL unit.

Biomass Monitoring

Loss on ignition (LOI) is a common and widely used method to measure the organic and inorganic contents of a sample. This includes scraping a marked area using a 15*15 cm quadrate. Removal of all live cover from two quadrates within the water retaining part and three quadrates of the outer surface of the CL. From the control rocks, three quadrates were scrapped. The scraped mass was then dried in an oven (80 °C for 24 h), weighed (dry weight), burned in a furnace (650 °C for 6 h), and weighed again (ash-free dry weight). From the resulting weights, the organic and inorganic masses were calculated. Results were standardized to gr/cm^2 to account for the number of quadrates sampled.

Structural Monitoring

The structural performance of the CL units will be evaluated twice a year for up to two years post-installation. The monitoring protocol will be identical across the three locations.

Monitoring will include:

- The physical condition of individual CL units.
- The condition of the structure (i.e., sliding, sinking, or displacement)
- The surrounding project area (toe, left and right flank, and upland areas).

The results of the monitoring for the three sites will be summarized in a final report and presented to the Port of San Diego for their review and approval.

Data Analysis & Success Criteria

To detect spatial and temporal differences between the three sites over the two-year monitoring period, as well as differences between the CL units and the control sites, a statistical examination of the gathered data will be conducted to determine whether there is an observed "significant statistical difference". This will include similarity and diversity indices using R-studio statistical software and the 'vegan' package for the ANOVA and Tukey tests calculations.

Four main parameters will be evaluated:

1. Community assemblage
2. Species diversity
3. Species richness
4. Biogenic Build-Up

Success will be considered when at least 2 of the 4 parameters show positive significant differences between the CL units and control sites.

Failure will be considered if 1-4 parameters show positive significant differences between the control sites and CL units (Control will present higher values than CL).

Any result between failure and success will be considered a successional stage of the community which requires a prolonged monitoring period.

RESULTS

26 MONTHS POST DEPLOYMENT (MPD), MAY 2023

Community structure

Figure 7- The biological growth covering the CL over time. (A) The CL on the day of deployment, (B) three MPD, (C) 14 MPD, and (D) 26 MPD.

A total of 42 invertebrates, 25 algae species, and four fish species were documented during the first, second, third, and fourth monitoring events, 8-, 14-, 20-, and 26-Months Post Deployment (MPD) respectively, both on the ECOncrete COASTALOCK (CL) units and control rocks (Table 1). The sessile community was comprised of algae, bryozoans, sponges, tunicates, polychaetes, crustaceans, mollusks, and cnidarian, while the mobile invertebrate community was comprised of decapods, mollusks, and fish (Table 1).

Table 1. Taxa identified on COASTALOCKs and control rocks. †Mobile species; *Invasive species; ¥calcifying species.

Taxa	Species	ECOncrete CL 8 MPD	ECOncrete CL 14 MPD	ECOncrete CL 20 MPD	ECOncrete CL 26 MPD	Control rocks 8 MPD	Control rocks 14 MPD	Control rocks 20 MPD	Control rocks 26 MPD
Green algae	*Enteromorph sp.*	+	+	+	+		+	+	
	Ulva Californica	+	+	+	+	+	+	+	+
	Codium fragile	+	+				+		
	Ulva sp.	+	+	+	+	+	+	+	+
seagrass	*Phyllospadix spp.*		+		+				
Brown Algae	*Dictyota dichotoma*	+	+	+	+	+	+		
	Colpomenia peregrine	+	+	+	+	+	+	+	+
	Sargassum muticum	+	+	+	+	+	+	+	
	Fucus sp.	+	+	+	+		+	+	+
	Pelvetia fastigiata		+						
	Saccharina sessilis		+						
	Laminaria sp.		+						
	Undaria sp.				+				
	Unidentified brown encrusting algae 1		+	+					
	Unidentified brown encrusting algae 2		+				+		
Red algae	*Asparagopsis armata* *	+	+	+		+	+	+	
	Mastocarpus papillatus	+	+	+			+	+	+
	Hildenbrandia sp.		+						
	Unidentified red algae		+	+	+			+	
	Laurencia pacifica		+						
	Chondracanthus exasperatus				+				+
Coralline algae	*Corallina sp.* ¥	+	+	+	+	+	+	+	+
	Amphiroa sp. ¥	+	+		+	+			
	Lithothamnion sp. ¥	+	+	+	+	+			
	Plocamiumsp. ¥				+				
Bryozoan	Bryozoans encrusting	+	+	+	+	+	+		+
	Bugula neritina		+		+				+
Tunicate	*Botrylus sp.*	+	+				+		
	Botrylloides diegensis		+						
	solitary tunicata	+							
	Styela plicata	+	+	+	+	+	+	+	+
	Styela clava	+		+	+	+		+	
	Herdmania sp.		+		+		+		
	Unidentified solitary tunicate		+		+				+
Sponge	*Haliclona sp.*	+	+	+	+	+	+	+	+
	Halichondria sp. ¥	+	+	+	+	+	+	+	
	Unidentified encrusting orange sponge	+		+	+	+	+	+	+
	Unidentified encrusting sponge		+	+	+		+	+	
Polychaeta	*Spirorbis sp* ¥	+	+	+	+	+	+	+	+

Taxa	Species	ECOncrete CL				Control rocks			
		8 MPD	14 MPD	20 MPD	26 MPD	8 MPD	14 MPD	20 MPD	26 MPD
	Sabellidae sp. ¥	+	+	+	+	+	+	+	+
	Dasychone sp. †	+	+	+			+		
Barnacles	Barnacles ¥	+		+	+	+		+	+
	Megabalanus californicus ¥		+		+		+		+
	Chthamalus dalli ¥		+		+		+		+
Oyster	*Crassostrea gigas* ¥	+		+	+	+		+	+
	Ostrea lurida ¥	+		+	+	+		+	+
	Crassedoma gigantea		+	+				+	
Bivalve	*Unidentified bivalve / oyster*¥		+		+				
	Mytilus sp. ¥	+	+	+	+		+	+	+
Limpet	*Lottia gigantean* †¥	+	+	+	+	+	+	+	+
	Macklintockia scabra †¥	+	+	+	+	+	+	+	+
Gastropoda	*Littorina sp.* †¥	+	+	+	+	+		+	
	Tegula sp. †¥				+				+
	Aplysia californica †	+	+	+	+		+	+	
	Haminoea virescens†¥				+				
Cnidaria	*Anthopleura sp.*	+				+			
Decapoda	*Decapoda isopoda sp.* †¥	+		+					
	Ligia occidentalis†¥		+						
	Cirolana harfordi†¥		+						
	Pachygrapsus crassipes†¥		+		+		+	+	+
	Cancer magister †¥	+		+	+				
	Cancer productus †¥	+							
	Panulirus interruptus †¥	+		+					
	Penaeus monodon†¥			+	+				
Nudibranch	*Navanax inermis* †	+	+	+	+				
Chiton	*Stenoplax conspicua* †¥	+	+		+	+	+		+
Fish	*Hypsypops rubicundus* †	+	+	+				+	
	Clinocottus analis †	+	+						
	Heterosticbus sp. †	+	+	+					
	Unidentified fish†	+							

At eight MPD, a diverse community has developed on the CL units, including 13 algae species, 15 sessile invertebrates, 11 mobile invertebrates, and 4 fish species, whereas on the control rocks only 7 algae species, 12 sessile species, and 5 mobile invertebrate species were identified. Fish, Bivalves, Decapods, and nudibranchs were noticed to inhabit the CL units only (Table 1). In addition, a few adults, and dozens of juveniles *Aplysia californica* were found only within the CL cavities.

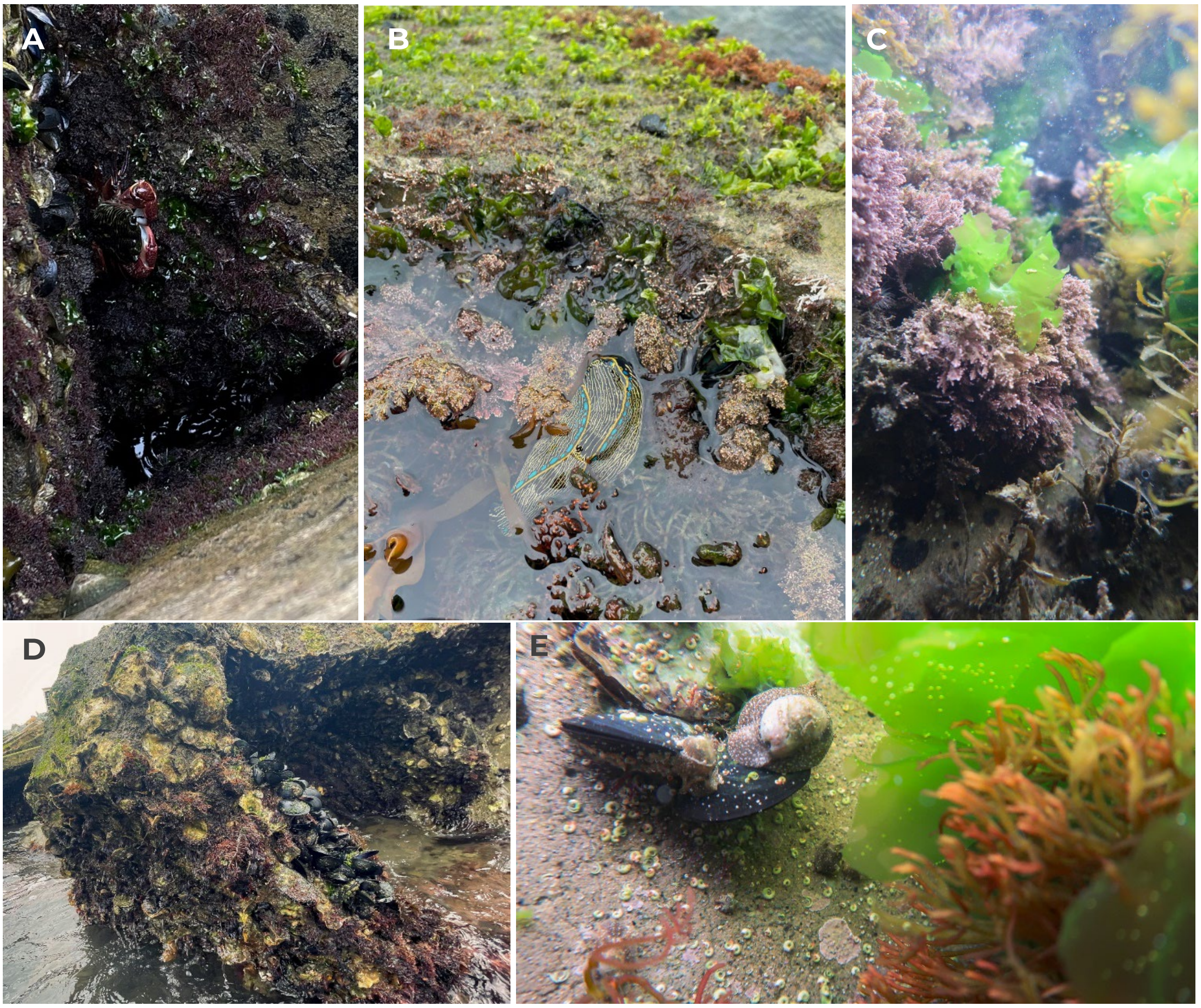


Figure 8. Biological development on the CL units 26 MPD; (A) Pachygrapsus crassipes crab between the CL units, surrounded by Mollusks (oysters, mussels, limpets, chitons) and Algae. (B) A Navanax inermis sea slug swimming in the CL cavity, inhabited by different algae species. (C) The brown algae Sargassum muticum, green algae Ulva sp., and coralline algae Corallina sp. within the CL cavity. (D) A CL unit covered by Bivalves (Mytilus sp., Crassostrea gigas, Ostrea lurida), different Algae species, and smaller-scaled species (barnacles and gastropods). (E) A CL cavity populated by green algae Ulva sp. and red algae Amphiroa sp. Mytilus sp. bivalves, Haminoea virescens, and Spirobis sp.

At 14 MPD a more diverse community developed on the CL units, including 22 algae species, 20 sessile invertebrates, 9 mobile invertebrates, and 3 fish species, while on the control rocks 12 algae species, 12 sessile invertebrates, and 6 mobile invertebrate species were observed. Fish were not detected on the control rocks (Table 1). In addition, high algal coverage was observed within the CL cavities, providing food to the grazing invertebrates (such as limpets, mollusks, and decapods) and shelter for the grazer decapod *Pachygrapsus crassipes* to molt or for sea slugs to lay their eggs.

At 20 MPD the CL units continued to present a more diverse community, including 13 algae species, 14 sessile invertebrates, 9 mobile invertebrates, and 2 fish species, while on the control rocks 10 algae species, 12 sessile invertebrates, 5 mobile invertebrates, and one fish species were observed (Table 1). The general decline in species number observed in this monitoring compared to the previous monitor is referred to as seasonal changes.

At 26 MPD, the species richness of CL units continued to demonstrate a diverse community, including 15 algae species, 19 sessile invertebrates, and 11 mobile invertebrates (Figure 8), whereas, on the control rocks, there were 7 algae species, 14 sessile invertebrates, and 5 mobile invertebrates, no fish species were documented in this monitoring event in both treatments (Table 1).

The difference between community assemblages developing on ECOncrete CL and the control rocks is described in the non-metric multidimensional scaling (nMDS) plot (Figure 9). The community assemblage on the CL units and control rocks shows a resembling pattern during monitoring events of 8 and 20 MPD (same season with a year gap), however, the communities found at 14 and 26 MPD show greater differences. The community assemblages on the CL significantly differ from those on the control rocks ($p < 0.05$). In addition, there is a significant separation between communities from each monitoring event within each site ($p < 0.0001$).

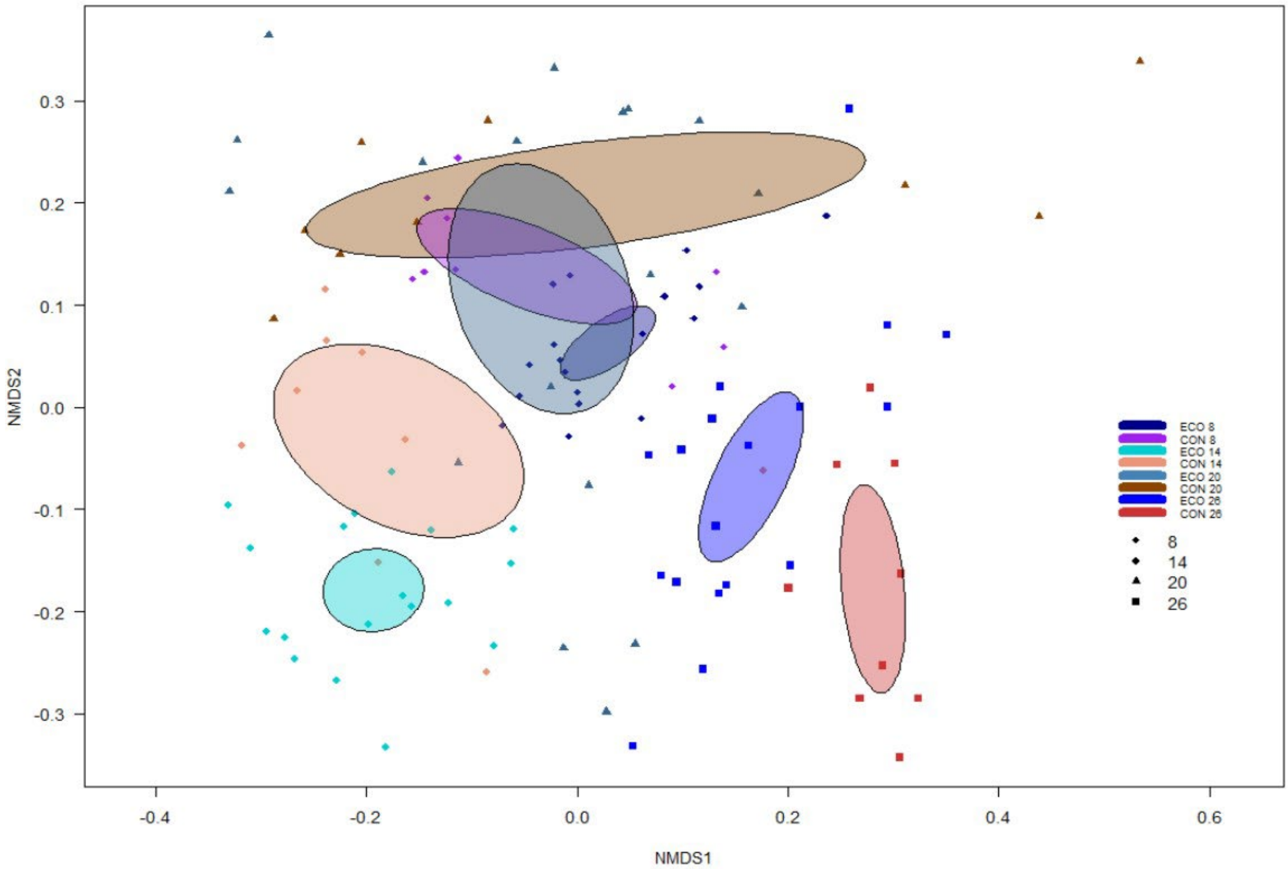


Figure 9. 2D nMDS of community-based clustering on the CL and Control Rocks 8, 14, 20, and 26 MPD.

At eight MPD, a significant elevation was observed in the averaged species richness in the CL units compared to the control rocks. This effect was enhanced by 14 MPD. The average species diversity represented a similar trend during the 8 MPD with a slight increase in the CL compared to the control rocks. This difference became more prominent during the 14 MPD, where CL presents a significant increase in diversity compared to the control rocks. At 20 MPD, there was no significant difference in richness between ECOncrete CL and the control rocks, while after six months, at 26 MPD the average richness in all tidal heights was higher on CL units compared to control rocks. A similar trend was observed in the average biodiversity showing an increase in counted species (Figure 11A), and an increase in covering species on the lower CL units.

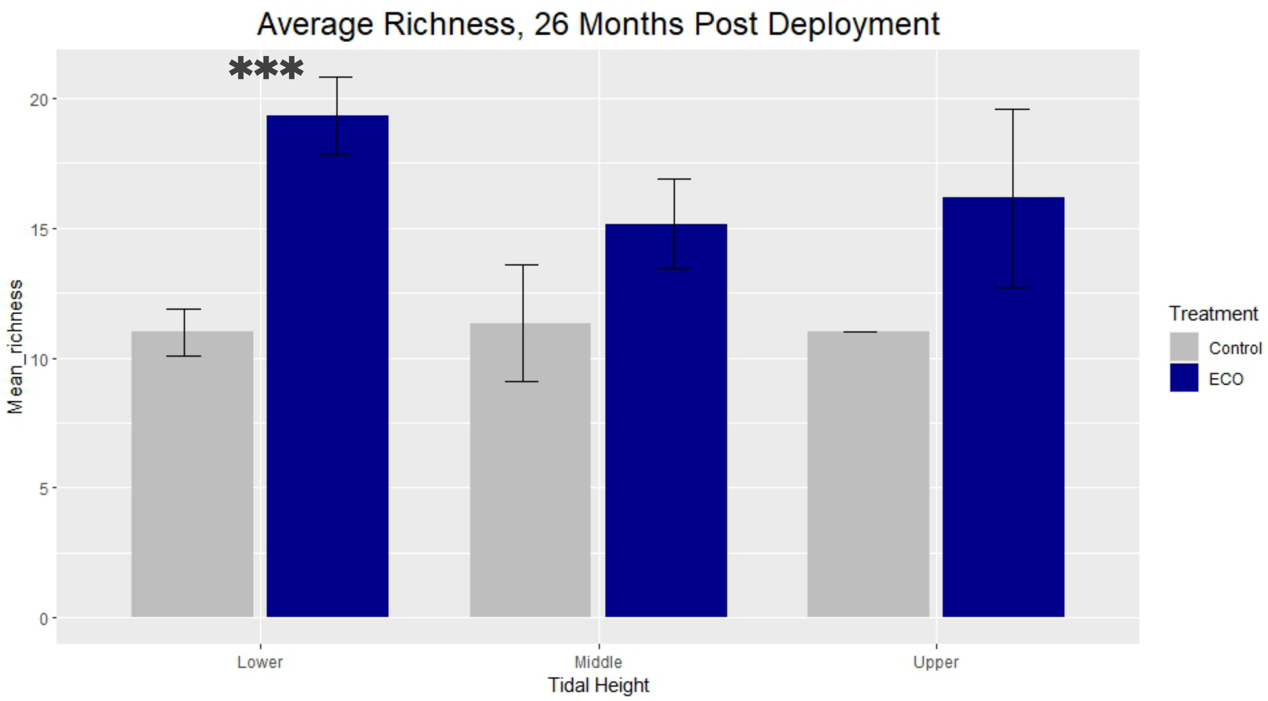
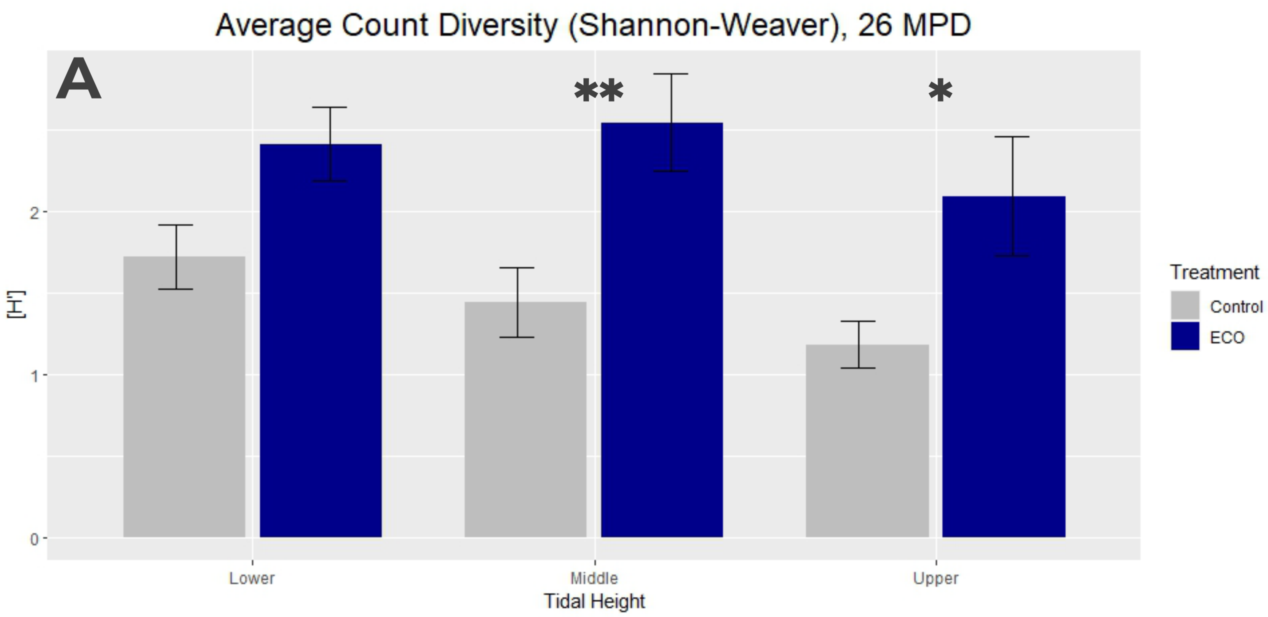


*Figure 10. Species richness between ECOncrete CL and the control rocks, at three different tidal heights, 26 months post-deployment. Error bars represent standard deviation. * = p<0.05, **= p<0.01, *** = p < 0.001, ****= p<0.0001.*



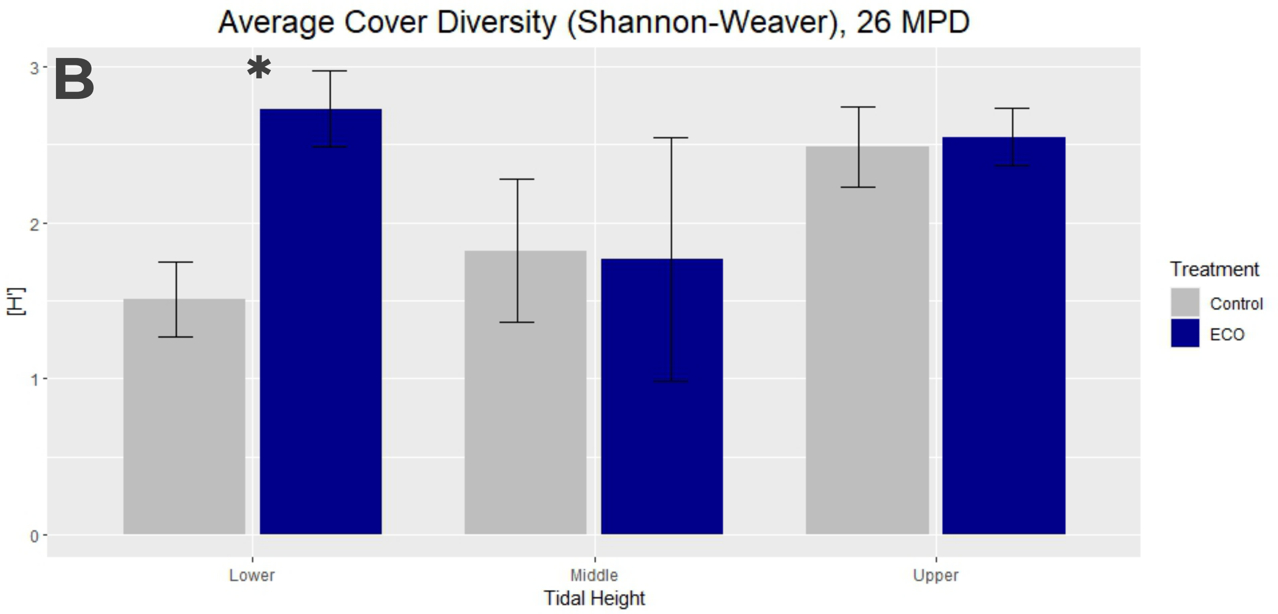


*Figure 11. The difference of COUNT (A) or COVER (B) -monitored species diversity between ECOncrete CL deployed and the control rocks, at three different tidal heights, 26 months post-deployment. Error bars represent standard deviation. * = p<0.05, **= p<0.01, *** = p < 0.001, ****= p<0.0001.*

When looking at the contribution of each phylum to the differences between the two treatments, the algae community covering the CL units was significantly more diverse in all three tidal heights compared to the control rocks (Figure 12A). The same trend was observed for algal species richness (Figure 12B).

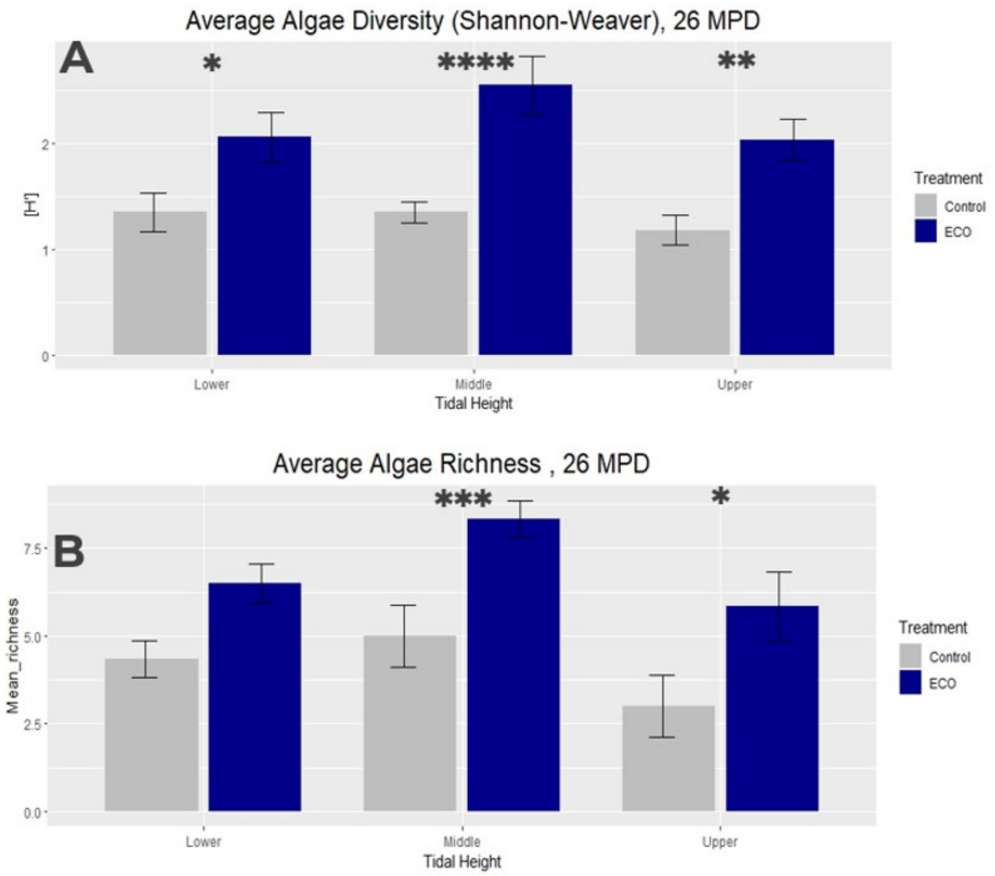


*Figure 12. The difference in Algae diversity (A), and richness (B) between ECOncrete CL and the control rocks, at three different tidal heights, 26 months post-deployment. Error bars represent standard deviation. * = p<0.05, **= p<0.01, *** = p < 0.001, ****= p<0.0001.*

Biomass analysis

The 26-month post-deployment monitoring event included sampling for biogenic buildup to assess the organic and inorganic matter in order to compare the accumulation of CaCO3 on the CL units and control rocks (Table 2).

Results show significantly higher biomass on ECOncrete CL units compared to the control rocks, both for organic and inorganic matter accumulation (average values in Table 2). Significant differences were found between CL and control for inorganic biomass accumulation (Figure 13-14).

Table 2. Differences in the accumulation of organic (OW) and inorganic (IOW) weight between CL (ECO) and control rocks (CON).

	Ave. IOW (gr/m²)		Ave. OW (gr/m²)	
	ECO	CON	ECO	CON
Upper	1464	844	440	124
Middle	4157	3062	827	430
Lower	8338	2672	971	486
Average	4653	2193	746	346

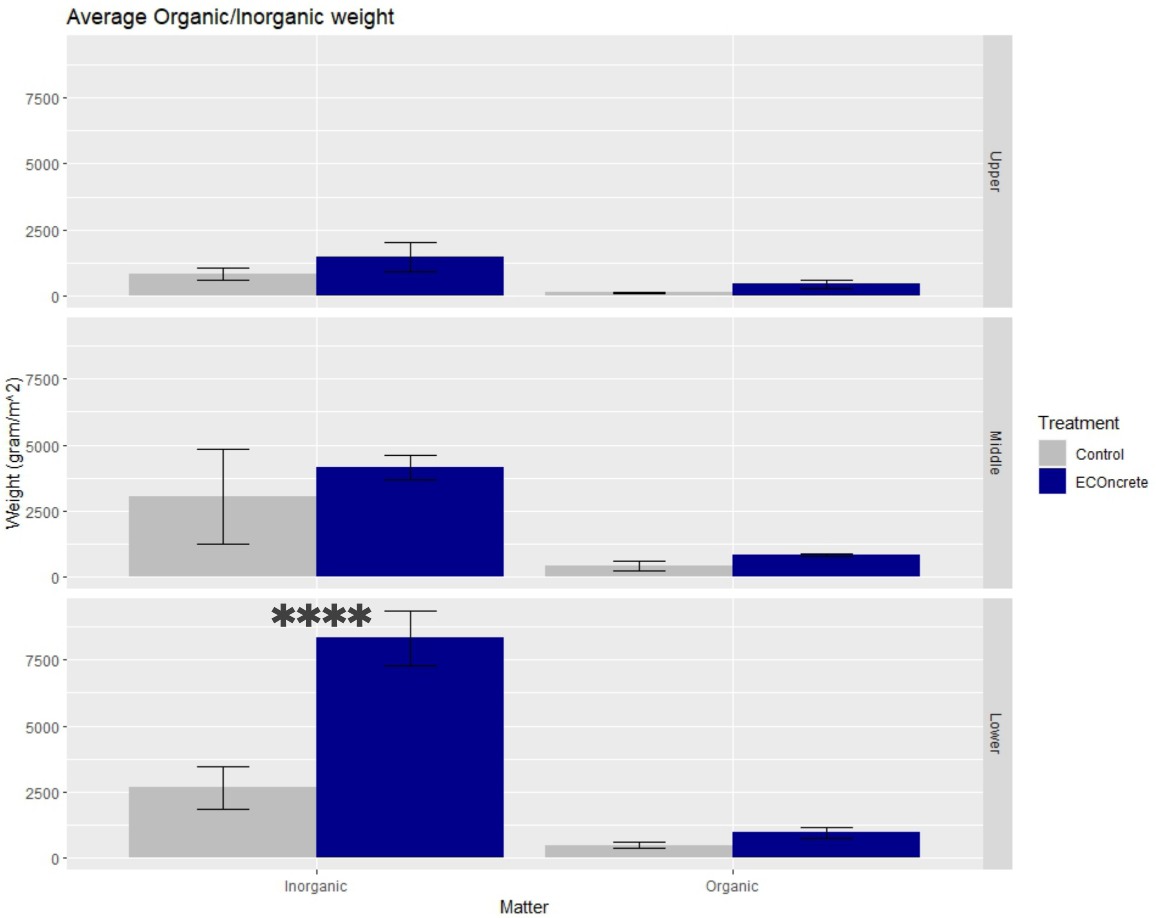


*Figure 13. The difference in the accumulation of organic/inorganic biomass on ECOncrete CL and the control rocks, at three different tidal heights, 26 months post-deployment. Error bars represent standard deviation. * = p<0.05, **= p<0.01, *** = p < 0.001, ****= p<0.0001.*

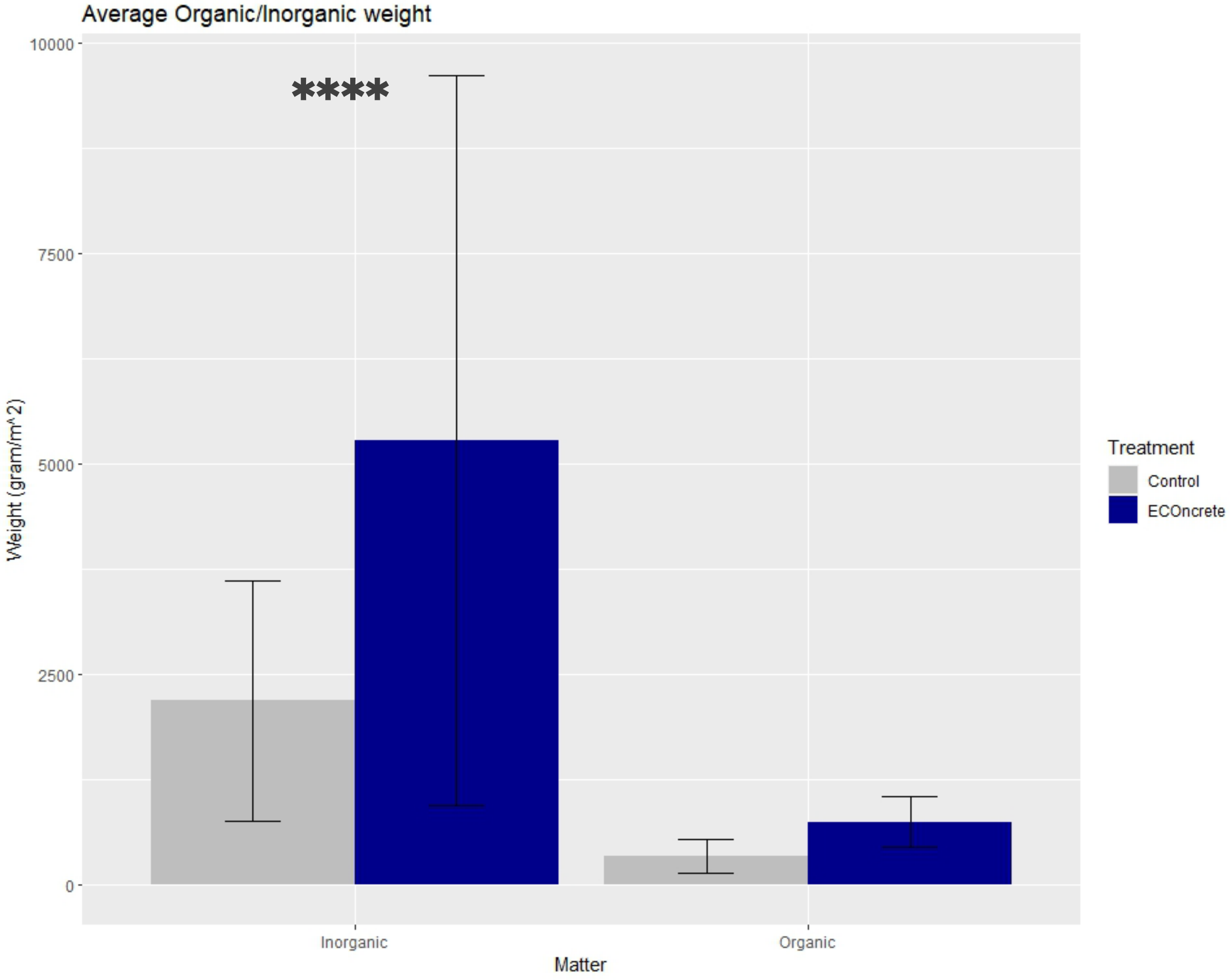


*Figure 14. The difference in the accumulation of organic/inorganic biomass on ECOncrete CL and the control rocks, at three tidal heights, 26 months post-deployment. Error bars represent standard deviation. * = p<0.05, **= p<0.01, *** = p < 0.001, ****= p<0.0001.*

Water quality

Higher temperatures were measured at the water-retaining CL units than in the open water nearby, with slightly increased temperatures at the upper units, which are separated from the open water during the measurement, at low tide. Control measurements were slightly lower at the lower tidal height, due to constant water exchange with the open water (Figure 15A).

Dissolved oxygen measurements at the CL units were also higher compared to the control, with higher values at the top row, (Figure 15B). These results are in correlation with the high algal cover observed at the CL units at the time of sampling when photosynthesis occurs, and no water exchange within cavities.

Turbidity measured at most sampling points showed low values in CL with an increase in the control site (Figure 15C).

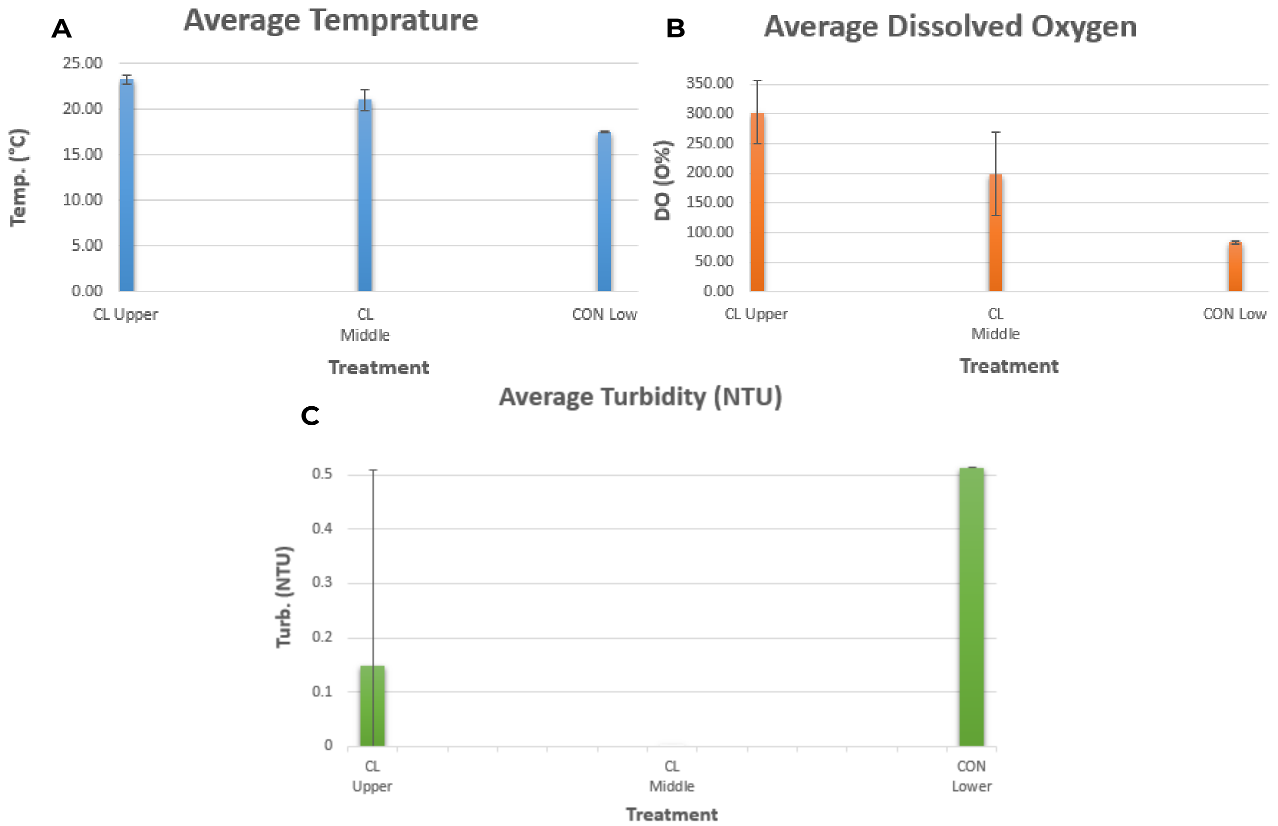


Figure 15. Abiotic parameters 26 MPD; (A) temperature, (B) dissolved oxygen, and (C) turbidity. Parameters were measured in ECOncrete CL's water retaining part at two tidal heights (Upper and Middle), and the control rocks at the Lower tidal. Error bars represent standard deviation.

Structural performance

Visual inspection of the CL unit's 26 MPD revealed no visible outer cracks or brakes on the surface of the units. Deployment configuration at both sites stayed fixed, without any notable movement of the infrastructure.

CONCLUSIONS AND RECOMMENDATIONS

The community structure of ECOncrete Coastalock has shown increasing trends of species richness throughout the monitoring events compared to the adjacent control rocks, which have been in place for decades.

The CL cavities constitute a newly introduced water-retaining habitat that was missing at the riprap rocks. This new habitat enables the recruitment of multiple species of algae and invertebrates, resulting in the establishment of a diverse marine community. This effect is amplified in the upper row, which acts as a separate pool during low tide. The water-retaining feature enables multiple species of marine organisms to thrive in this newly introduced habitat that could not inhabit riprap rocks of the same tidal height. The most prominent example is the high number of mobile mollusks, which can grow and feed only with the presence of *Ulva sp.* [2], which was highly abundant in the CL cavities (Figure 8B).

In addition, the observation of the decapods (Figure 8A) and sea hares (Figure 8B) on the CL might indicate that it serves as their main habitat. Previous studies have shown that food availability [3], physiological constraints or benefits [4], and predation pressure [5], influence the habitat selection of decapods. The CL units provide those conditions for the crab and sea hares, facilitating their recruitment within this habitat. Moreover, the CL cavities were filled with sea hares' eggs and juveniles, showing they use it as spawning ground providing warm water and food. The community assemblage on the outer surface of the CL was similar to the community of the control rocks, characterized by more tolerant species inhabiting the area. Species such as barnacles, oysters, and limpets developed different mechanisms of sealing themselves within their shell, coping with the dry period during low tide.

Not only the cavities but the entire CL's texture and design enhance the settlement of different individual species such as Mollusks, Crustaceans, and others. It was observed mostly through the count-monitored species biodiversity that was higher for ECOncrete's CL units in all three tidal heights than the control rocks (Figure 11A). The ecological design of the CL allows for a multi-directional placement, thus, addressing species-specific needs across the different tidal zones ranging from overhangs and tidepools at the splash and supratidal zone to caves at the intertidal and neritic zone. In the upper tidal zone on the coast of San Diego, it is of great importance to create shaded habitats to allow for a higher accumulation of hard-shell organisms on the shoreline. Based on monitoring observations, our recommendation for future shoreline development around the Port of San Diego will be to rotate the CL units in the splash zone to create overhangs and enhance local species recruitment.

In all tidal heights and during all monitoring events, a high assemblage of the algal community was observed (Table 1). Seasonal succession in the macro-algal population is well documented. Common algal dynamics are characterized by population establishment during springtime, due to nutrient elevation after winter water mixing, followed by a population decline during summertime, due to temperature elevation and grazing of herbivory species [6,7]. This effect is increased in the tidal zone, where a high range of temperature and salinity occurs throughout the day, due to the temporary separation of the pools from the open sea [8,9]. Throughout the monitoring sessions, the CL units showed a healthier, richer, and more diverse algal community compared to the control rocks (Figure 12).

The high algal coverage within the CL cavities correlates with the high measurements of dissolved oxygen taken (Figure 15B). The increased oxygen levels can support a larger community within the CL cavities which could lead to a richer and more diverse population in the area [10].

At 26 MPD, the calculated accumulation of organic/inorganic matter showed a twofold increase in the CL units than control rocks. The CL units accumulated an average of 4653 g/m^2 inorganic matter while the control rocks showed 2193 gr\m^2 accumulation. Organic material results on the CL units showed 746 gr/m^2 and 346 gr/m^2 on the control rocks (Table 2). Ecologically enhanced CMI such as the CL can potentially support much healthier and more productive communities that are better equipped to withstand periodic environmental and physical disturbances as engineering species have substantial ecological implications by forming a marine community with higher stability and matureness. In addition to habitat value, the chemical process of biocalcification (biogenic buildup) of calcitic skeletons utilizes the CO_2 molecules from the seawater to generate $CaCO_3$ skeletons, essentially removing atmospheric CO_2 [10].

Considering that for every 1000 g of $CaCO_3$ ~120 g of carbon is stored in $CaCO_3$ skeletons, these assimilation rates can be translated into significant volumes of carbon sequestration throughout the lifespan of the infrastructure. Published rates of carbon sequestration from a range of tidal saline wetlands vary from 21 to 1713 g C/m^2/y, with averages of 22–244 g C/m^2/y; thus, the rates determined here fall within the range of published values [11-14].

These initial results are in line with previous long-term monitoring studies of ECOncrete installations which showed a community transition towards a richer, more diverse, and more natural, as well as lowering the ratio of invasive to native species, exhibiting a greater similarity to natural assemblages occurring in the area on and around ECOncrete infrastructures compared to control sites [15-18].

The results of this study not only indicate the ability of infrastructures to support ecological services without compromising their structural prepossess and target use but also gain advantages such as structural durability and a longer service life as a result of bio-protection [19].
The integration of ecological enhancement measures in marine infrastructure can be an effective tool to maintain biological resources and their associated ecosystem values on site. Based on the results of this study, Coastalock design alterations have increased the richness, abundance, and diversity of sessile assemblages compared to control rocks and supported a higher abundance of algae species.
Nature Inclusive Design (NID) should be integrated into coastal and marine development as it promotes a more sustainable and adaptive approach by addressing both ecological and structural functioning to tackle many of the coastal climate - resilience problems faced today.

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Appendix 1- sampling sheet used during the monitoring fieldwork.

ECONCRETE	**Project Location:** Port of San Diego	**Survey Type:**	**Site #: 1 / 2 / Control**	**Rep #: 1 / 2 / 3**
	Date: **Time:**	**Tidal Height:** Upper / Middle / Lower	**Surveyor:**	

TAXA	Outer	Cavity	Lifting Holes	Notes
Green Algae [I]				
Brown Algae [I]				
Red Algae [I]				
Turf algae [I]				
Coralline algae [I]				
Sponges [I]				
Bryozoans – Enc [%]				
Bryozoans – Bran [I]				
Tunicates – Col [%]				
Tunicates – Sol [#]				
Spirorbid [I]				
Serpulidae [I]				
Dasychone [#]				
Sabellidae [#]				
Oysters [#]				
Bivalves [#]				
Barnacles [#]				
Hydrozoa [#]				
Anemone [#]				
Limpet [#]				
Gastropods [#]				
Fish [#]				
Decapoda [#]				

Additional Notes: