ENGINEERING WITH NATURE

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Epifaunal Community Development on Great Lakes Breakwaters: An Engineering With Nature Demonstration Project

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PURPOSE: This technical note describes an Engineering With Nature (EWN) project being conducted on the east arrowhead breakwater on Lake Erie in Cleveland Harbor, OH. Background information, project objectives, approaches, and preliminary monitoring results are included with this description. The U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) has partnered with the USACE Buffalo District (LRB) to design and implement modifications to LRB's normal maintenance procedures for breakwater repairs at this site. The structural design modifications are intended to produce greater environmental benefits to invertebrate and fish communities than would be present otherwise using standard practices. This work was funded through the U.S. Environmental Protection Agency's Great Lakes Restoration Initiative managed by the Great Lakes National Program Office.

BACKGROUND

Engineering With Nature Approach. Engineering With Nature (EWN) is a USACE initiative to enable more sustainable delivery of economic, social, and environmental benefits associated with water resources infrastructure. EWN directly supports USACE's "Sustainable Solutions to America's Water Resources Needs: Civil Works Strategic Plan 2011 – 2015" and contributes to the achievement of its Civil Works Mission and Goals (USACE 2013a, Text Box). In addition, the USACE Environmental Operating Principles (EOPs) — originally established in 2002 — were "reinvigorated" in August 2012 (USACE 2013b). The EOPs encourage USACE employees to consider the environment by creating synergy between sustainability and the execution of its projects and programs. Two EOPs that directly relate to EWN are: 1) to create mutually supporting economic and environmentally sustainable solutions; and 2) to collaboratively leverage scientific, economic, and social knowledge in order to understand the environmental context and effects of USACE actions.

> ***"Deliver enduring and essential water resource solutions, utilizing effective transformation strategies."***
>
> ***Goal 2. USACE Campaign Plan FY13-18.***

Engineering With Nature is defined as the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits associated with water resources projects through collaborative processes (Figure 1).

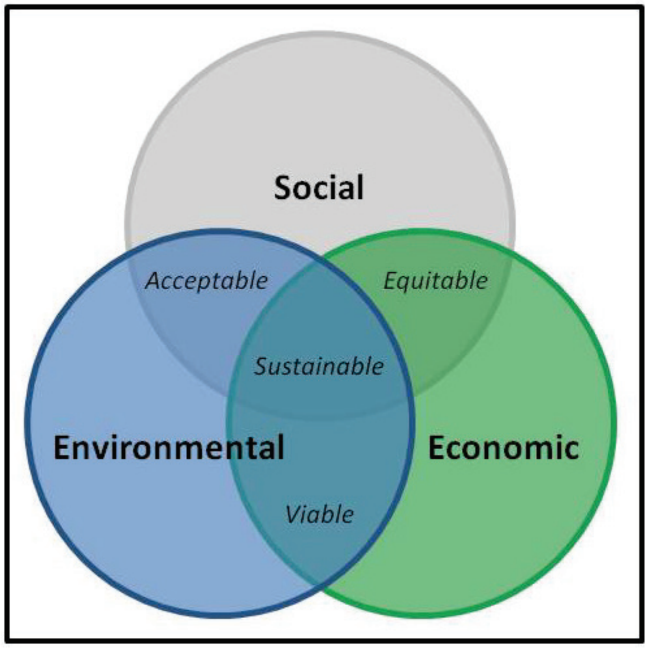

Figure 1. Triple-win outcomes can be achieved through EWN by systematically integrating social, environmental, and economic considerations into decision making and actions at every phase of a project. The result will be innovative and resilient solutions that are more socially acceptable, viable, and equitable; the solutions will also ultimately be more sustainable.

The EWN initiative is focused on demonstrating and documenting novel approaches that meet the EWN objective of providing sustainable approaches and benefits that support environmental and social objectives in addition to the traditional economic benefits for which most projects are primarily designed. Demonstrating this approach, and fostering its integration into USACE normal business practices of project design, is intended both to increase project value and to enable greater support from and collaboration with our partners and stakeholders.

The essential ingredients of the EWN approach to mission execution are:

- using science and engineering to produce operational efficiencies supporting sustainable delivery of project benefits;
- using natural processes to maximum benefit, thereby reducing demands on limited resources, minimizing the environmental footprint of projects and enhancing the quality of project benefits;
- broadening and extending the base of benefits provided by projects to include substantiated economic, social, and environmental benefits; and
- applying science-based collaborative processes to organize and focus interests, stakeholders, and partners to reduce social friction, resistance and project delays while producing more broadly acceptable projects.

Great Lakes Coastal Structures. Engineered structures feature prominently throughout the nation's waterways and coasts. In the Great Lakes alone, there are over 100 miles of engineered coastal structures. Structures like breakwaters and jetties were usually designed to manage some aspect of the natural environment; for example, to improve navigation safety through inlets or to protect harbor areas from waves (Figure 2). A key regulatory consideration of planners was to minimize any unintended consequences to the environment by a new structure, in accordance with environmental laws such as the National Environmental Policy Act (NEPA). However, once the basic regulatory compliance needs were met, few of the hundreds of jetties, breakwaters, bulkheads, and revetments under USACE purview were designed with features specifically intended to provide environmental or social benefits. Many Great Lakes structures have exceeded their design life; they are aging and are in need of significant repair. Consequently, structure repair and maintenance represent a major mission of USACE in the region. As plans for the new structures or maintenance of the existing ones are developed, planners, engineers, designers, scientists, and stakeholders may be able to identify project design features that will better support environmental or social services and those features that can be incorporated with little to no cost increase.

A breakwater is an engineered structure protecting a shoreline, navigation channel, or basin from waves; it is usually constructed parallel to the shoreline. Since the mid-1800s, breakwaters on the Great Lakes have typically been constructed using timber cribs, sheet piling, rubble mound stone, stacked stone, or concrete.

Figure 2. Example of harbor breakwaters and other coastal infrastructure development at Lorain, Ohio (photo: USACE Digital Library).

The Cleveland project (Figure 3) involves modifying the design of the standard concrete toe blocks used by the Buffalo District for breakwater maintenance repair to provide features that will create habitat opportunities for Great Lakes fish and invertebrates; these habitat opportunities would not otherwise be present. Toe blocks are installed at the lower limit of the repair and are typically submerged.

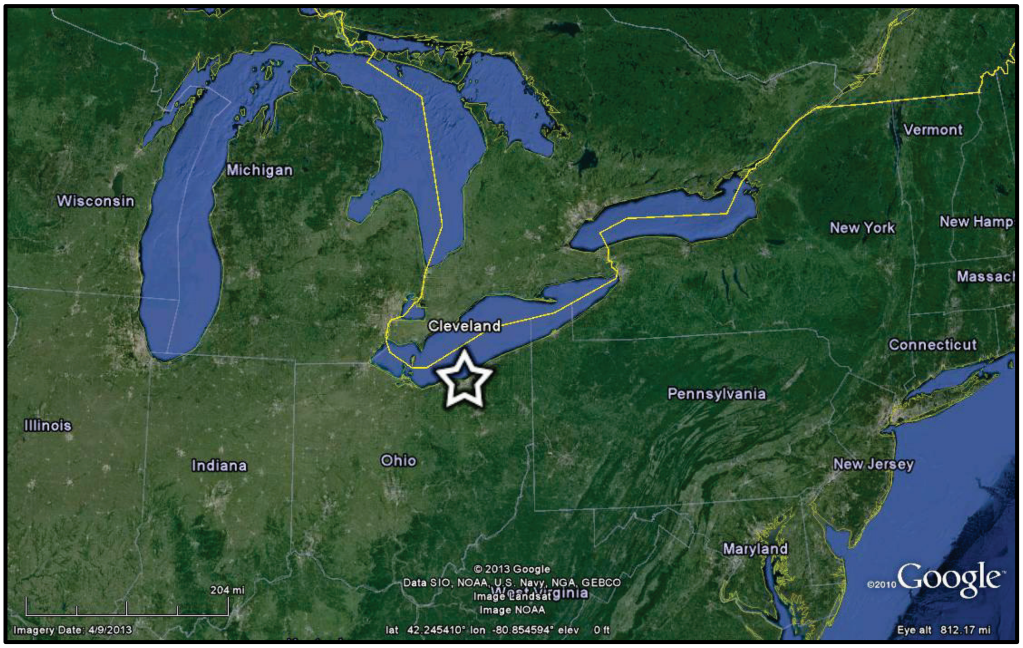

Figure 3. General location of the Cleveland, OH breakwater project (base map image: Google).

Existing breakwaters constructed in the Great Lakes do provide some habitat for fish and invertebrates, but that result is most often purely an indirect and unplanned consequence. The habitat that usually exists consists of refuge provided by spaces between armor units, but the rest of the structure is often relatively inhospitable for most organisms due to the featureless nature of the armor. This is particularly relevant when precast, smooth-surfaced concrete armor units are used.

This study is examining opportunities for creating substantially more habitat surface on the breakwater by modifying the shape and surface texture of the standard concrete blocks using textured liners or modified walls in the concrete block forms. Such approaches have been evaluated elsewhere (Way et al. 1995; Chapman and Blockley 2009; Browne and Chapman 2011; Chapman and Underwood 2011; Borsje et al. 2011), but to the authors' knowledge, none have been implemented in the Great Lakes region.

Approach. The EWN demonstration project in Cleveland, OH was constructed as part of scheduled breakwater repairs being conducted by LRB. Since Cleveland Harbor has over 28,000 feet (8,530 m) of breakwaters, LRB typically repairs harbor breakwaters in sections a few hundred feet long as available budget allows. The harbor breakwater is being repaired on a segment-by-segment basis over several years using large precast concrete blocks on the harbor side of the breakwater and quarry stone on the outside of the breakwater. The harbor side concrete block repairs involve placing a line of rectangular toe blocks (about 8' x 5' x 4' [2.4 x 1.5 x 1.2 m]) to form the base of the structure and several courses of sloped blocks leading to the crest of the structure (Figure 4). The first phase of the EWN toe block installation took place in April 2012.

Figure 4. Cleveland Harbor breakwater constructed of concrete toe blocks (partially submerged and algae covered) and slope blocks (photo: T.J. Fredette).

Because the toe blocks are normally completely or partially submerged, the team focused on these blocks as potential opportunities for applying EWN to produce greater habitat for invertebrates and fish. Earlier research was conducted on modifying the surface of infrastructure materials (Way et al. 1995, Chapman and Blockley 2009, Browne and Chapman 2011, Chapman and Underwood 2011), which suggested such an approach might have merit. Way et al. (1995) demonstrated invertebrate colonization could be increased on concrete revetment mats in the lower Mississippi River by roughening the concrete with a broom or creating grooves with a mold prior to the cement fully setting. Similarly, the work of Chapman and associates showed a number of different techniques that have been used to increase habitat on relatively featureless seawalls and revetments. Based on these earlier studies, it was determined that the featureless concrete of the blocks used by LRB could offer a similar opportunity and, if successful, this approach would be easy to incorporate into routine repair practices.

The basic scientific premise is that the existing smooth blocks offer limited opportunity for epifaunal organisms to attach and to have protection from currents and waves in order to become established. Adding crevices and grooves to the surface provides angular and protected areas where better attachment surfaces and some level of protection from hydrodynamic forces is provided, affording organisms an opportunity to become established. Once primary and secondary production is enhanced via colonization of periphyton and macroinvertebrates, these species serve as a source of food for fishes (Way et al. 1995).

Three separate surface texture/roughness treatments, in addition to unmodified control blocks, were applied to the block surfaces that face out from the structure: grooved, dimpled, and grooved shelf (Figure 5). The grooved surfaces were created using a commercially available form liner (Spec Formliners, Inc. Pattern 1705, 305 Standard Spec Flute) and the dimpled surface used a custom built form liner using plywood and round headed carriage bolts (Figure 6). The width and depth of the textures (Figure 7) were selected with the intent of providing habitat diversity; they were also selected to be open enough to discourage invasive goby species from using them as refuges. Dimples were about 250 mm wide and 7 mm deep. Grooves were 1.5 inches apart on center and 0.5 inches deep (38 mm on center and 13 mm deep). The grooved shelves were 18 inches (0.46 m) deep and began 18 inches (0.46 m) above the bottom of the block.

Thirteen toe blocks were installed in Cleveland between 16 April and 15 May, 2012. Plans to complete the Cleveland installation in April 2013 were deferred due to a need to make extensive repairs to the damaged breakwater caused by Hurricane Sandy in late October 2012. The toe block locations were randomly assigned to locations along the breakwater (Figure 8) using a random number table. Not allowed were 1) a side-by-side alignment of any block treatment and 2) shelf blocks on the ends. However, since the original plan specified that seventeen blocks would be installed in a single phase, but the work crew only had time to place thirteen, a shelf block was the last placed and that placement violated the original intention of the rule.

Figure 5. Control and modified toe blocks used in the Cleveland breakwater repair (photos: T.J. Fredette).

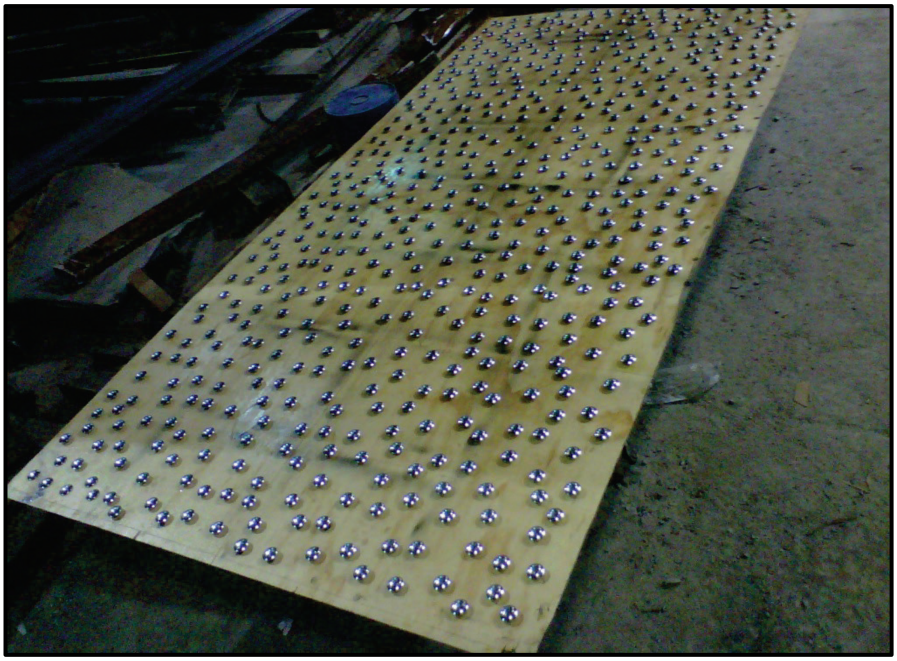

Figure 6. Form liner used to create the dimpled surface using round-headed carriage bolts mounted on plywood (photo: Courtesy USACE Buffalo District).

Figure 7. Close-up of grooved (top) and dimpled (bottom) concrete block surfaces (photos: T.J. Fredette).

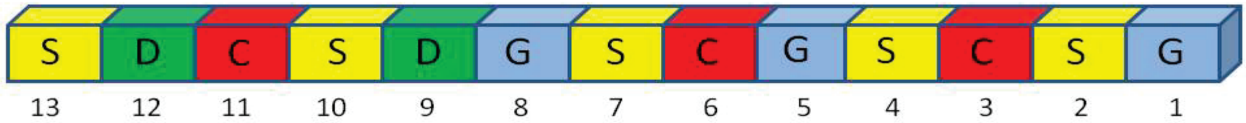

Figure 8. Block position diagram used for placement of the toe blocks at the Cleveland breakwater in April 2012. S = Shelf, D = Dimpled, G = Grooved, C = Control.

Sampling was conducted at the Cleveland site in October 2012, June 2013, and October 2013. A fourth event in late 2014 will complete the scheduled sampling. Sampling of the toe blocks was performed using a specially designed Plexiglas block sampler (Figures 9 and 10). The sampler was about 20 cm in diameter and had a top gasket with a slit to allow access for scraping the block surface using a Plexiglas scraper. Blocks were randomly sampled within treatment (block) type using a quadrat grid to guide the sample's location (Figure 11). Once the block surface was scraped, a suction hose attached to a wet/dry vacuum cleaner powered by a portable generator was inserted through the slit and the contents of the sampler were collected. The vacuum cleaner canister contents were then poured through a 500 µm sieve and the contents washed into sample jars for preservation with a 70% denatured ethanol solution. In the laboratory, the invertebrates present in each sample were sorted by major taxonomic group and counted. The algae from each sample was captured on a preweighed paper filter and dried in an oven at 60-65° C for 24-48 hours to determine dry weight.

Preliminary Sample Results. Only the sample results from Cleveland Harbor in October 2012, about five months following construction, were available for analysis at the time this report was written. These early results demonstrated that all the block types had algae (*Cladophora* spp.), and a variety of invertebrates colonized on them (Figure 12). The abundance of several organism groups was sufficient to conduct preliminary statistical comparisons (Table 1). These analyses indicated that some differences among the block types were evident at this early stage, with the grooved and grooved shelf often exhibiting the greatest abundances. These early results may not be indicative of species assemblages occurring on the blocks over longer time periods; thus, a longer period of observation is needed before any clear conclusions can be reached regarding the ability of the textured surfaces to provide greater habitat value than the non-textured blocks.

DISCUSSION

Ecosystem Benefits. While it is too soon to reach any conclusions about the success of the specific modifications made to the toe blocks in Cleveland, it is not too early to use this project as an example of the type of creative thinking that potentially could be applied to other breakwaters. It is also not too early to consider the potential systemwide implications if such efforts are to be put into common practice. If Cleveland is successful and the approach is implemented on a much larger scale as the maintenance program continues, there is considerable systemwide potential to increase the production of invertebrates that serve as food for fish. Additionally, these modifications have potential to provide refuge from predation for juvenile fish, either within the greater epiphytic growth or in the physical recesses of the grooves or dimples. Both the increase in invertebrate food production and enhanced juvenile survival could then contribute to improved adult fish stocks within the Great Lakes.

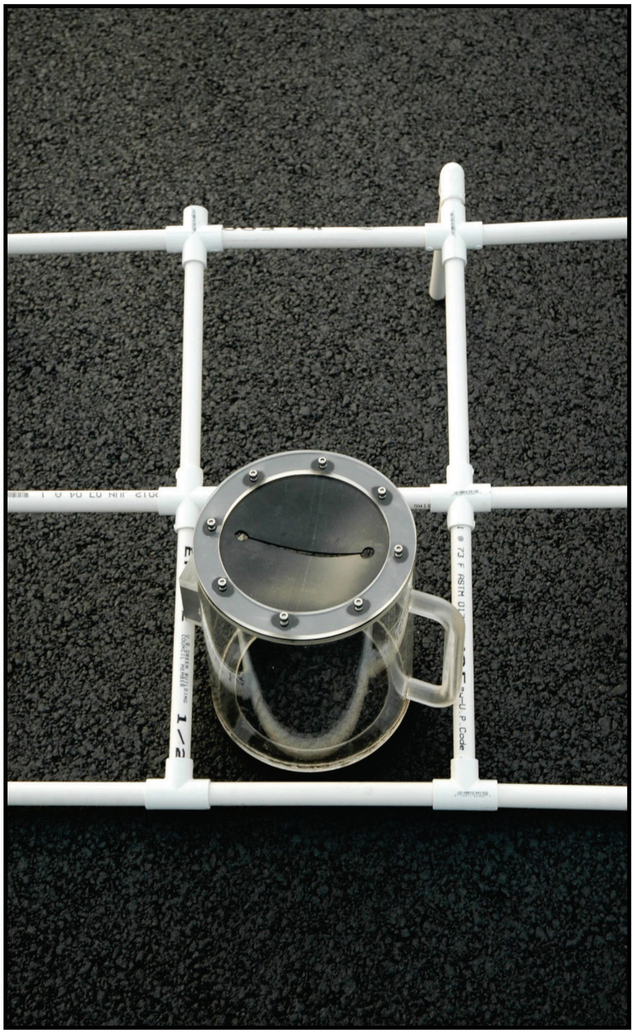

Figure 9. Plexiglas sampler used to obtain colonized organisms from the test blocks. Also shown is a portion of the PVC pipe sampling grid used to guide the sample's location (photo: T.J. Fredette).

Figure 10. Sampling a toe block using the Plexiglas sampler, scraper, vacuum, and the PVC pipe sampling grid (photo T.J. Fredette).

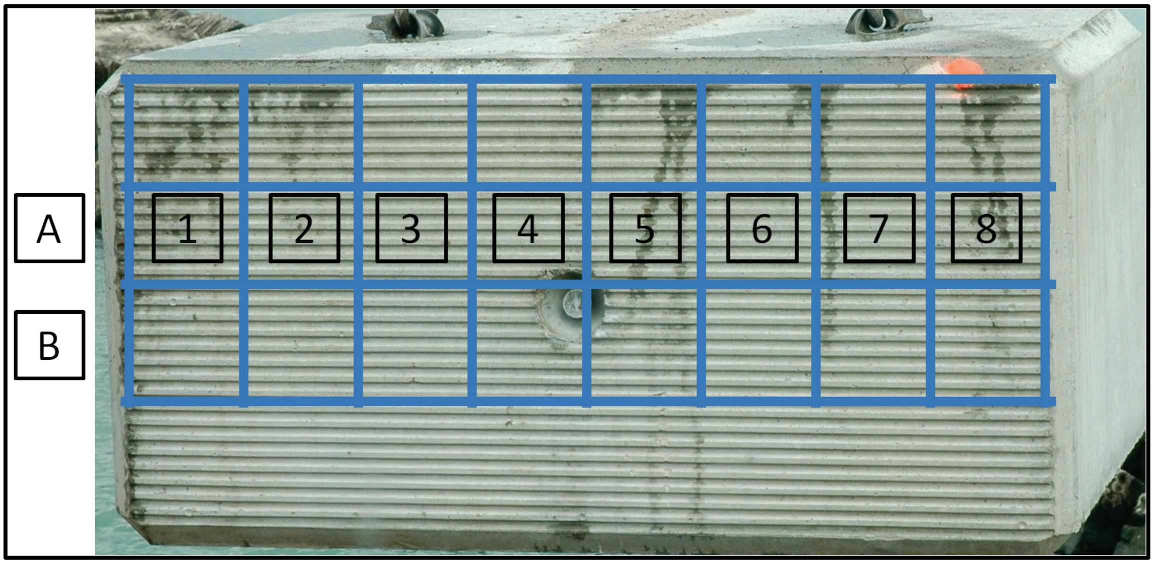

Figure 11. Sampling grid designations A and B superimposed on a grooved toe block. The top row of the block was not submerged in October 2012 due to the low water level in the lake. The bottoms of the blocks are generally inaccessible due to back-filled rock (photo: T.J. Fredette).

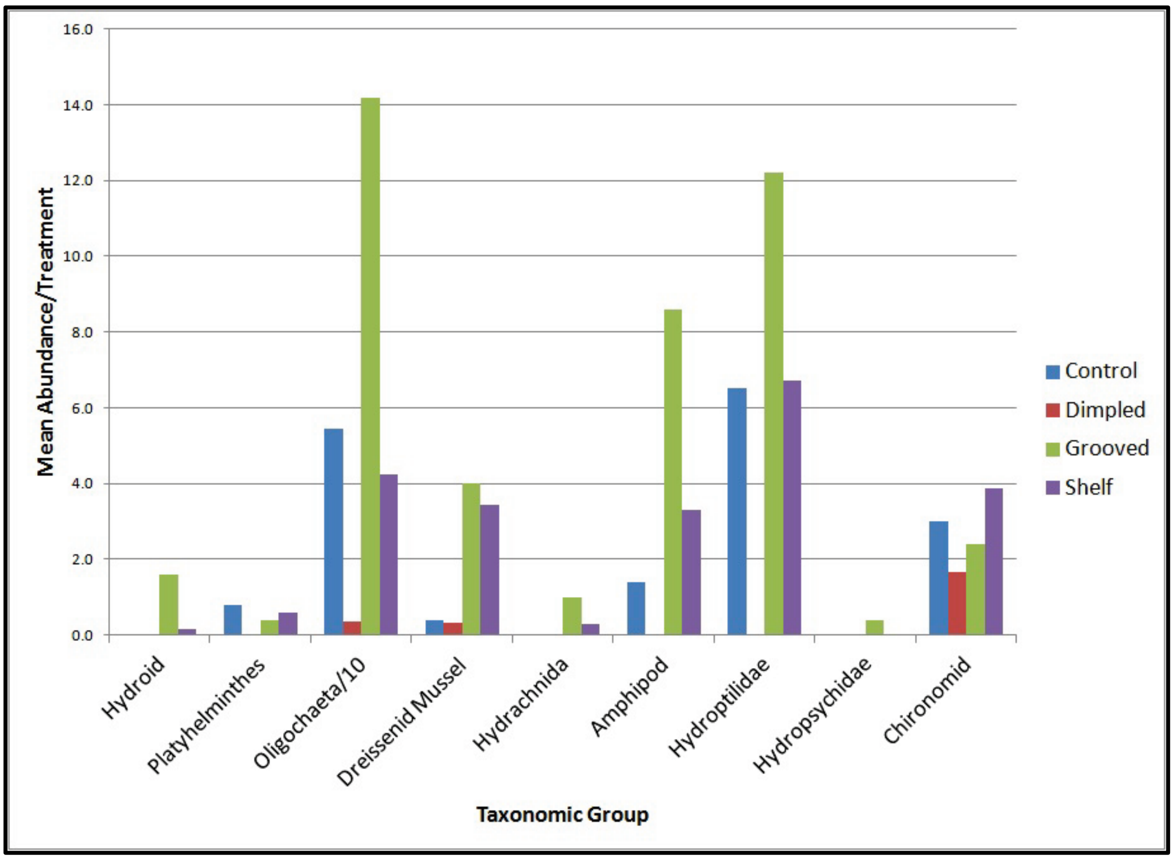

Figure 12. The mean sample abundance on the breakwater toe blocks in October 2012 at Cleveland Harbor by major taxonomic group. Oligochaete values are shown at 1/10th actual average.

Table 1. Statistical test results identifying differences in taxa abundance between pairs of surface treatments for taxa where a significant (P<0.10) or near significant difference between two or more treatments was indicated in the overall F test. Each pairwise test was significant at alpha = 0.05, with an experiment-wide error rate for the 6 possible pairwise tests for a taxa of alpha =0.26.

Taxon	Prob > F [a]	Treatment	Mean No. Per Quadrat	Multiple Comparisons[b] Taxa pairs with the same letter are not different at α=0.05	
Cladophora_DryWt	0.008 ***	Shelf	1.26	A	
Cladophora_DryWt		Grooved	0.49	A	B
Cladophora_DryWt		Plain	0.24		B
Cladophora_DryWt		Dimpled	0.06		C
Dreissenid Mussel	0.0574 *	Grooved	5.33	A	
Dreissenid Mussel		Shelf	4.00	A	B
Dreissenid Mussel		Plain	0.44		B
Dreissenid Mussel		Dimpled	0.33		B
Hydroptilidae	0.0145 **	Grooved	12.78	A	
Hydroptilidae		Shelf	7.00	A	
Hydroptilidae		Plain	6.22	A	
Hydroptilidae		Dimpled	0.00	B	
Oligochaeta	0.128	Grooved	161.44		B
Oligochaeta		Plain	62.22	A	B
Oligochaeta		Shelf	30.53	A	B
Oligochaeta		Dimpled	3.67	A	
Total	0.014 **	Grooved	191.56	A	
Total		Plain	73.78	A	
Total		Shelf	48.93	A	
Total		Dimpled	5.67	B	

[a] P values associated with ANOVA F-test of whether the evidence supports a difference in taxa abundance between any of the 4 surface types. Degrees of freedom associated with all F tests was dfn=3 and dfe=8. Increasingly stronger evidence of significance are indicated by * P<0.10, ** P<0.05, and *** P<0.01.
[b] Results of multiple comparison t-tests for taxa for which the overall ANOVA was significant or nearly significant at α=0.10. Pairs of treatments with the same letter are not different. The familywise Type I error rate for the 6 possible pairwise comparisons, each one significant at α=0.05, is approximately 0.26.

Incremental Project Cost. If implemented on a routine basis, the use of modified toe blocks is estimated to add less than 0.5% to the overall cost of a repaired segment of breakwater. This estimate derives from a $48/block increase in production costs, the installation of 34 toe blocks within a segment, and an overall typical project cost of $950,000.

$$[(\# \text{ of blocks} * \text{cost change per block})/\text{project cost}] * 100 = \% \text{ change}$$

or

$$[(34 * \$48)/\$950{,}000] * 100 = 0.2\%$$

The Cleveland demonstration project also incurred an $11,400 cost to have a new block mold constructed. If this one-time cost is amortized over a 10-year period and factored into the above, the calculated total cost increase for the habitat improvements would still be only 0.3%. This level of cost increase is effectively negligible from a project planning standpoint and could easily be covered as part of normal project contingencies.

EWN Implementation. The Cleveland EWN demonstration project is just one of many possibilities that the existing Engineering With Nature initiative has identified (USACE 2013c). Other possibilities include modifications that provide nesting habitat for birds, including endangered terns and osprey (tern habitat is currently being developed in Ashtabula, OH, but is not discussed here), or wetland and shallow water emergent vegetated habitat created in protected areas around structures. Social benefits such as improved aesthetics and recreational bird watching are other aspects of these projects. Such modifications have the potential to address critical limiting factors in species sustainability, such as the quantity of spawning habitat, the abundance of food resources, or the availability of refugia for out-migrating juveniles. There are many miles of coastal engineering structures (breakwaters, piers/jetties, seawalls, and revetments) in the Great Lakes alone and hundreds of miles throughout the United States. Creative yet simple design modifications, such as those currently being investigated, offer tremendous opportunities to augment the long-term sustainability and habitat value of engineered structures. The current project will help USACE and stakeholders evaluate opportunities for enhancing aquatic habitat in and around these structures through low-cost measures that can be implemented as part of routine maintenance or scheduled repairs or modifications. Overall success will be achieved when the inclusion of EWN becomes fully integrated into the normal business practices of project planning and throughout the life cycle of projects.

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