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Use of Alternative Materials for Oyster Reef Construction

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BACKGROUND: Oysters are filter-feeding bivalve molluscs that form cohesive reefs in estuarine and near-coastal waters. In addition to their economic value, oysters can exert a powerful influence on water quality, phytoplankton productivity, and nutrient cycling (Dame 1996; Ulanowicz and Tuttle 1992); they also affect current patterns, flow, and sedimentation rates (Lenihan 1999). Oyster reefs often provide the only hard structure in areas usually dominated by softer sandy and muddy bottoms (McCormick-Ray 1998; Hobbs 1988). In estuaries such as the Chesapeake Bay, reef structure supports many species of fish, such as tautog (*Tautoga onitis*), black sea bass (*Centropristes striata*), oyster toadfish (*Opsanus tau*), naked goby (*Gobiosoma boscii*), and others. Many other mobile fish and shellfish species, from striped bass (*Morone saxatilis*) to blue crabs (*Callinectes sapidus*), use oyster reefs as foraging areas or as a refuge from predation (Posey et al. 1999; Glancy et al. 2003). Oyster reefs have been estimated to be more productive than salt marshes in terms of fish and shellfish biomass produced per acre (Peterson et al. 2003), making them a highly productive habitat of great ecological and commercial value.

Because oysters require a hard substrate for larval settlement (usually the shells of dead or living oysters), the increasing scarcity of shell in many areas has seriously limited or increased the costs of oyster habitat restoration. Dredging of "fossil" oyster shells (formerly productive oyster reefs that have since been covered by sediment) has been used in the past to obtain the necessary materials but is now considered undesirable due to the non-renewable nature of the resource and potential environmental impacts of dredging. As a result, use of alternative materials (Figure 1) for creation or restoration of oyster reefs has become of increasing interest to resource managers and scientists nationwide.

Figure 1. Subtidal Modular Concrete Oyster Reef, lower Rappahannock River, Virginia, heavily colonized by oysters and hooked mussels.

PURPOSE: Oyster reef restoration has become an important project component at many coastal U.S. Army Corps of Engineers (USACE) Districts. The Corps may be involved in oyster reef restoration and construction projects for a variety of purposes. Some are constructed as mitigation for dredging and navigation impacts; others may be related to the enhancement or creation of coastal habitats authorized by Section 1135 of the Water Resources Development Act (WRDA) of 1986, or Section 206 of the WRDA of 1996 (as amended). In the Chesapeake Bay, a large native oyster restoration program (authorized by WRDA section 704(b), as amended) is currently underway. Due to the increasing scarcity of natural shell, project planners are considering the use of alternative substrate in many of these oyster reef restoration projects. There is a critical need for cost-effective technologies and research synthesis to support the Corps of Engineers project needs in functional assessment, restoration, and stewardship of high priority ecosystems.

This technical note describes the use of artificial materials or shells of species other than oysters (e.g., surf clams or whelks) to construct oyster reefs. Alternative materials, whether used as a reef base with a veneer of shells, or to construct entire reefs, offer a viable option in oyster restoration efforts. This report provides information on the potential use of such materials to restore both intertidal and subtidal oyster reefs.

OYSTER ECOLOGY: Oysters are ecosystem engineers, in that they are capable of causing physical changes in both the biotic and abiotic environment as they create their own habitat (Jones et al. 1994), commonly known as oyster bars, rocks, or reefs. Oyster reefs stabilize benthic or intertidal habitats due to their structure (Nestlerode et al. 2007), which can act as a natural breakwater. Unlike motile gastropod mollusks, juvenile and adult oysters are sessile and highly dependent on hard structure for settlement and survival. Their gregarious settlement behavior and production of their own hard habitat substrate are keys to the long-term persistence of oyster reefs. An undisturbed, natural oyster reef typically thrusts up from the surrounding bottom by 1 m or higher and can be many hectares in area. The living veneer of oysters and recently dead shells forms a cohesive structure that provides significant protection and refuge from predation for the oyster. The core and base of the reef, below the sediment/water interface, consists of older dead shells and shell fragments (Hargis 1999, Kennedy and Sanford 1999).

Oysters are filter feeders, and an adult (> 75 mm shell height) Eastern oyster (*Crassostrea virginica)* is capable of filtering up to 60 gal of water per day when it is metabolically active (Christmas and Jordan 1987). Therefore, restored oyster populations could potentially improve water quality and clarity by reducing phytoplankton blooms caused by eutrophication, and reducing total suspended solids (TSS) (Newell et al. 2007, Cerco and Noel 2007). Oysters are also prey for a diverse suite of predators, including larval fish during the oyster planktonic larval phase, and mud and blue crabs as adults.

Oyster populations along both coasts of the United States have been decimated due to overfishing, habitat destruction, pollution, and disease. Oyster stocks in most areas represent only a small fraction of their historic levels (Kirby 2004). The decline of the east coast native oyster, (*Crassostrea virginica*) has been well documented in the Chesapeake Bay (Rothschild et al. 1994). On the Pacific coast, native Olympia oyster (*Ostreola conchaphila*) populations have also declined (Kirby 2004). Few undisturbed oyster reefs remain in U.S. coastal waters and many are flattened with little cohesiveness or significant relief from the surrounding bottom. Such reefs are more prone to sedimentation, hypoxia, and further damage by oyster harvesting (Powers et al. 2005; Lenihan and Peterson 1998; Rothschild et al. 1994). Loss of the great majority of oyster reefs (> 90 percent in many coastal areas) has significantly reduced the habitat diversity as well as ecosystem services provided by these reefs. Unlike wetlands, coral reefs, and beds of submerged aquatic vegetation, which are recognized as valuable habitat of great ecological importance and protected by state and Federal government agencies, oyster reefs are permitted by state fishery management agencies to be fished, thereby creating a cycle of disturbance that results in further degradation (Powers et al., in press; Lenihan and Peterson 1998). In recent years, some restored oyster reefs have been set aside as sanctuaries free from oyster fishing pressure in several states, including Maryland, North Carolina, and Virginia.

"Typical" Oyster Reef Construction Using Shell. Oyster larvae will settle on most hard materials in the aquatic environment, as long as the material is not covered with sediment or colonized by other organisms, excluding conspecifics. Shells used in restoration efforts (Figure 2) are often derived by dredging formerly productive oyster reefs that have had their surface shell removed by commercial fishing activities and since been completely covered by sediment. Such "fossil shell" beds have been the primary source of shell material used in fishery restoration programs in the Chesapeake Bay as well as more recent ecological restoration attempts.

Construction methods using these shells typically involve placing a small amount of the dredged "fossil" shell on the bottom, most often just several inches thick. Such sites seldom last more than 10 years due to harvesting methods (Smith et al. 2005; Powell et al. 2006). Continuous input of fresh shell material is needed to maintain these areas, resulting in annual maintenance costs that are expensive and unlikely to be part of a sustainable long-term ecosystem restoration plan. Fresh or "shucking house" shell is also used for these purposes in the Chesapeake Bay, Florida, and elsewhere. Other sources of shells include clam shells from commercial aquaculture operations or offshore fisheries, including *Rangia cuneata* clam shells in the Gulf Coast states. Due to environmental concerns, *Rangia* shell dredging has largely ceased in the Lake Pontchartrain (Louisiana) region, making these shell resources scarce. Along the Atlantic coast, shells of the surf clam (*Spisula solidissima*) have also been used as cultch (i.e. oyster setting substrate).

The use of "fossil" shells for oyster reef restoration should be approached with caution and careful planning. It is a limited and largely non-renewable resource, due to the collapse of most oyster populations that produce shell, and should only be used where the constructed reef has a good chance of long-term (> 10 years) persistence. Limited shell resources can be maximized by incorporating dredged materials into the reef construction process. For example, in 1988, USACE Baltimore District constructed oyster reefs in Chesapeake Bay by placing 14,000 yd^3 of dredged fine sands on a 0.85-ha plot near Slaughter Creek, Maryland (Earhart et al. 1988). The site was then covered with a 20-cm layer of oyster shell. Subsequent monitoring indicated that spat settlement and development were comparable to that on natural reefs (Clarke et al. 1999). The

Figure 2. Dredged shell placement, Lynnhaven River, Virginia. Placement techniques often further fragment the shells.

Wilmington District is investigating the feasibility of the construction of large-scale (>10 acres), high-relief oyster reefs, incorporating dredged material under Section 204 WRDA 1996. It is proposed that submerged enclosures will be filled with sand and topped with cultch. Alternative construction materials for the enclosure and various cultch types will be considered.

Natural oyster reefs have persisted for thousands of years in some locations, based on the depth of the reef footprint (Hargis 1999; DeAlteris 1988; Hobbs 1988). Constructed shell reefs can persist if heavily colonized by oysters, and oyster growth and recruitment rates exceed mortality and shell degradation. However, constructed shell reefs rapidly degrade if not heavily colonized by oysters (Figure 3). Half lives for oyster shells deployed on restoration projects vary; estimates range from 2 to 12 years in Delaware Bay (Powell et al. 2006), and 5.5 years on average in the Maryland portion of the Chesapeake Bay (Smith et al. 2005). Such limited life spans may be unacceptable for ecosystem restoration projects.

Figure 3. Time sequence photos of loose shell reef with low recruitment and few live oysters in Maryland. Note lack of vertical growth of live oysters, and covering of loose, uncolonized dead shell by sediment over time (photos by K. Paynter).

Alternative Materials as Restored Oyster Reef Substrate. Due to the increasing scarcity of shells in many areas, alternative materials provide an attractive option. Reefs made from alternative materials, mainly different types of stone or manufactured stone products, such as concrete, have a long history of use. In Europe, such reefs have been constructed for over 30 years, with a positive track record of attracting high densities of marine life, both pelagic and sessile (mainly bivalves) (Jensen 2002; Boaventura et al. 2006). One of the primary advantages of alternative materials is their long-term persistence in estuarine and marine environments. Although this property is not seen as advantageous by some (Mann and Powell 2007), it is desirable to construct a reef with an expected productive lifespan of at least several decades. A carefully planned and executed oyster reef restoration project should be expected to persist for at least 50 years, the typical expected lifespan for USACE projects.

Alternative materials appear to attract high numbers of oyster recruits, although this may be more related to the higher survival of recruits on the alternative materials compared to oyster or other types of shells. A study in New Hampshire (Mikulak et al. 2005) found significantly fewer mud and rock crabs in the alternative materials (limestone or concrete) compared to oyster shells. These two crabs are major predators on young oysters, and inflict significant mortality on oyster spat. If alternative materials are used, some consideration should be given to the size of the interstitial spaces, as space sufficient to allow blue crab predation on the smaller mud and rock crabs may enhance oyster survival.

Concrete. Recently, two large-scale oyster restoration projects initiated in the lower Rappahannock River, Virginia provided an opportunity to compare the effectiveness of concrete versus shells for oyster reef construction. This region once contained thousands of hectares of oyster reefs, and was one of the main commercial oyster fishing areas. The oyster population in this sub-estuary now represents only about 1 percent of its pre-exploitation level, and the remaining oyster habitat is in poor condition. The restored reefs represented the best available sub-tidal habitat for oyster settlement and growth. Annual recruitment is low; a typical year sees spat sets (Young of the Year or YOY oysters) at less than 10 per m^2 on the sanctuary reefs, though spat sets in the 100s per m^2 have occurred sporadically (Southworth et al. 2007).

The first project placed shells on former reef footprints in an effort to augment the commercial fishery and provide a small sanctuary component; the second project constructed a large concrete reef network using both materials of opportunity (a deconstructed bridge) as well as formed concrete modular reefs. The shell sanctuary reefs consisted of a series of shell mounds, up to 2 m high. The concrete reefs varied in height from 2-3 m above the bottom. Both the sanctuary shell reefs and the concrete reefs were constructed in time to receive the 2001 oyster recruits. Although both were subtidal and in close proximity to each other, significant differences in performance were observed between the shell and concrete reefs when both types were surveyed in 2005 (Lipcius and Burke 2006).

On the shell sanctuary reefs, an average of only 9 oysters/m^2 was observed. Most were classed as “small” oysters (reproductive oysters from 35-75 mm in total length) and were smaller than the legal market size (76 mm). Very few spat (average 1 spat/m^2) were observed on the shell reefs. The shells were also degrading, due to the action of the boring sponge (*Cliona truitti*), waves and currents, and general decomposition due to a lack of colonization by live oysters to provide the necessary living veneer to produce new shell material (Smith et al. 2005; Kennedy and Sanford 1999).

The concrete reefs supported a much higher population of oysters of various size classes (Figure 4), including some of the largest native oysters documented in the lower Chesapeake Bay since the disease Dermo increased in lethality in the early 1980s (Burreson and Andrews 1988). The modular surface area of the concrete reefs allows very high oyster densities (> 1,000 oysters per m^2 of bottom) to be achieved. The oyster population on the concrete reefs averaged 73 per m^2 of concrete surface (Lipcius and Burke 2006).

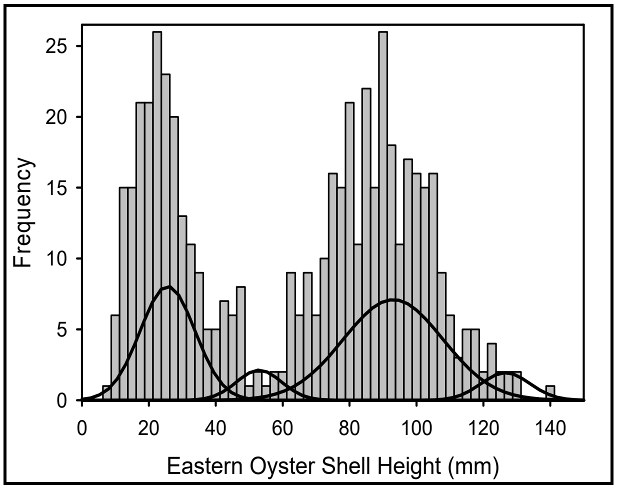

Figure 4. Size frequency distribution on concrete reefs in the lower Rappahannock. Peaks denote different age classes of oysters. Survival of large adults (> 75 mm) indicates disease resistance is developing in this population (Encomio et al. 2005; Lipcius and Burke 2006).

The presence of much larger oysters than on the nearby constructed shell reefs indicated higher survival over time, and healthier, more disease-resistant oysters. These results indicate that alternative materials cannot only work in subtidal environments, but could potentially perform better than shell reefs in low recruitment situations. The effectiveness of concrete as a substrate for oyster attachment may also be increased if calcium carbonate is added to the mixture, either as gypsum or shell fragments (Louisiana Department of Wildlife and Fisheries (LDWF) 2004).

Granite. Other alternative materials such as granite show excellent potential for oyster habitat restoration. Although historical oyster reefs in the Lynnhaven River, Virginia, near the mouth of the Chesapeake Bay have been almost entirely obliterated, a significant remnant population exists on hard structure throughout the river, and annual recruitment is high (several hundred to 1,000 spat per m^2 annually). A survey of rip-rap along shorelines in the Lynnhaven River found high densities of oysters on rock surfaces (978 oysters per m^2) (Burke 2007). Restored reefs constructed using oyster shells in the same river harbored much lower densities of oysters, ranging from 97-240 oysters per m^2 (Burke 2007). These observations, as well as a shortage of oyster shell, prompted further investigations into the potential use of alternative materials.

The results demonstrated that granite is an excellent attachment substrate for oysters (Table 1, Figure 5). It is important to note, however, that the type of limestone marl used was extremely rugose, and this seemed to exert a negative influence on oyster attachment (Burke 2007). Other studies have indicated that concrete may be just as effective as granite, particularly if calcium carbonate is added to the mixture, either as gypsum or shell fragments (LDWF 2004).

Table 1. Comparison of oyster densities (per m^2) (± standard error) on various alternative materials in the Lynnhaven River, Virginia (Burke 2007).

Substrate Type	Oyster Density				
	Fall 2005	Spring 2006	Fall 2006	Spring 2007	Fall 2007
Crushed Concrete – Very Small	284 ± 99	304 ± 97	1,052 ± 174	858 ± 215	1080 ± 203
Granite Large	747 ± 119	696 ± 120	1,620 ± 273	1,288 ± 235	2083 ± 235
Granite Small	781 ± 141	695 ± 111	1,649 ± 262	1,330 ± 272	2299 ± 215
Limestone Marl Large	144 ± 42	193 ± 66	284 ± 91	277 ± 54	451 ± 110
Limestone Marl Small	143 ± 42	189 ± 57	327 ± 101	305 ± 44	439 ± 95
Oyster Shell Unconsolidated	316 ± 89	226 ± 62	753 ± 118	748 ± 142	1678 ± 159

Limestone. Despite the lower oyster recruitment rates on limestone marl in the Lynnhaven River (Table 1), excellent results have been achieved using limestone for oyster restoration in other areas. In North Carolina, several sanctuary reefs have been successfully constructed with a combination of natural oyster shell and Class B limestone rip-rap. A typical sanctuary reef contains an array of 2-m (height) rip-rap mounds, each containing about 150 tons of material (*http://www.ncfisheries.net/shellfish/sanctuary1.htm*). Several studies in Louisiana have reported successful settlement of oyster larvae on crushed limestone or limestone marl (Haywood et al. 1999, Burton and Soniat 2005). Limestone marl seemed to attract more oyster spat (> 2,000 spat per bag (a bag covered 0.3 m^2 of marl bottom area)) than the *Rangia* clam shells that had been used in the region (Burton and Soniat 2005). Limestone marl attracted approximately eight times as many spat per bag of material when compared to sandstone (Burton and Soniat 2005).

Figure 5. Intertidal granite rip-rap base oyster reef, Lynnhaven River, Virginia.

A larger study, also in Louisiana, compared costs and effectiveness of crushed concrete, crushed limestone, and oyster shell fragments (LDWF 2004). The oyster shell fragments were similar in size to the dredged oyster shells often used in both fishery enhancement and ecological restoration projects. These shell fragments are considered inferior to large whole shells as oyster reef substrate (LDWF 2004). The stone materials were crushed such that the pieces were approximately the same size as the oyster shell fragments. Costs of the various materials were roughly equivalent at approximately \$50/yd^3. Monitoring results found approximately 3-4 times as many live oysters on the alternative materials compared to the oyster shells (LDWF 2004). They found 429.6 oysters/m^2 on concrete, 309.6 on limestone, and 86.4 on oyster shells.

Pelletized coal ash. Pelletized coal ash has been used as a substrate for oyster habitat, but results have been mixed. In some cases, pelletized coal ash has performed at least as well as oyster shell (Mueller 1989). In other cases, coal ash reefs experienced lower oyster survival rates than nearby restored shell reefs (O'Beirn et al. 2000), with roughly a six-fold higher number of oysters on the shell reefs compared to the coal ash reefs. Large reefs constructed of this material in Galveston Bay, Texas in 1993 performed exceptionally well, experiencing oyster recruitment and survival not seen in the area in 40 years (Baker 1993). The reefs were also colonized by other sessile marine fauna, with over 90 percent of the available attachment sites on the reef being occupied. Moreover, various structure-dependent fish used the reefs for shelter and foraging sites.

From an environmental standpoint, issues have been raised regarding the potential for contamination. Coal ash contains environmental toxins, including various metals. However, this material appears to be stable in the marine environment and oysters growing on it do not appear excessively contaminated with metals or other toxins from the material (Homziak et al. 1989). Due to the mixed results, it might be worthwhile to consider using it in conjunction with other alternative materials, or possibly as a base material upon which limited supplies of oyster shells could be placed. However, supplies may be difficult to obtain since this material is now in demand for other purposes, particularly in construction as road bed material.

Economic Considerations: Compared to dredged or shucking house shell, alternative materials are usually more expensive. Typical costs to place dredged shell range from \$20-25/yd^3. Costs to place a similar amount of granite or limestone marl are often more than double this cost. However, shells can cost considerably more per cubic yard, depending on their scarcity and the means and depth of deployment. If transport is involved, shucking house shells can equal the cost to place various stone materials. Information on actual costs can be found at: *http://chesapeakebay.noaa.gov/alternativesubstrates.aspx*.

Despite the cost differences between dredged shells and alternative materials, the long-term persistence of the alternative materials compared to shells is an attractive feature. Alternative materials provide a longer window of opportunity to construct an effective substrate for oyster colonization and growth. Their use prevents most types of oyster harvest, especially oyster tongs and dredges, the two techniques commonly used throughout the nation. As a result, reefs formed partly or wholly out of alternative materials are less likely to be poached, or opened for harvest in the future. While this characteristic is in direct conflict with economic utilization, it has several long-term benefits. There is a growing consensus in the scientific community that restoration of oyster habitat for ecological purposes is not compatible with commercial fishing, as the harvest of oysters destroys the restored habitat (Coen and Luckenbach 2000; Maryland Oyster Advisory Commission 2008; Mann and Powell 2007). Fishing pressure can reduce the lifespan of a restored oyster reef to a mere handful of years, thus compromising the original purpose of the project (Mann and Powell 2007; Lenihan and Peterson 1998; Smith et al. 2005). As a result, creation of oyster sanctuaries has to be an integral component of long-term plans to restore oyster reef habitat nationwide. The relative longevity and resistance to harvesting of oyster reefs constructed from alternative materials seems ideally suited to incorporation in such efforts. At the very least, reefs constructed of alternative materials should play an important role in balanced efforts to restore both ecological and economic benefits associated with oyster reefs.

Multipurpose Reefs—Use of Alternative Materials as Shoreline Stabilization. Reefs constructed using artificial materials are also being considered for their value as shore protection. The Terrebonne Bay Shoreline and Oyster Reef demonstration project is one example in Louisiana (Cowan 2003). Several different structures were proposed for evaluation including concrete mats, gabion mats, A-Jacks™ (interlocking concrete structures in the shape of the child's toy), Reefballs™ (circular concrete structures), and Reefblocks™ (triangular concrete frames). The project was scheduled for construction in September 2007, so no information on the relative efficacy of the structures is presently available. Campbell (2004), Ortego (2006), and Hall et al. (2007) also describe results from modeling and field testing of "oysterbreaks," mortar-covered PVC pipe frames that act as a breakwater after colonization by oysters. These structures have the advantage of being lighter in weight than traditional artificial material structures and relatively easy to modify and transport.

Ecosystem Approaches to Coastal Habitat Restoration. Where appropriate, ecosystem approaches that include the creation and restoration of multiple habitat types (e.g. oyster reef and submerged aquatic vegetation or marsh) should be considered. One such restoration project proposed near Panama City, Florida, involved plans for a constructed salt marsh using dredged material, a concrete oyster reef in the shallow subtidal waters seaward of the marsh shoreline, and a seagrass restoration planting between the concrete reef and the marsh shoreline. Near a recent successful coastal wetland creation project in North Carolina, plans are currently underway to reconfigure an existing granite breakwater to enhance oyster colonization and conduct a trial planting of submerged aquatic vegetation. Such projects would more closely resemble the natural spatial arrangements of these habitats in the coastal environment, and could result in higher levels of ecological function and increased habitat stability. For example, the Norfolk District is planning to construct oyster reefs as natural breakwaters to prevent erosion of restored coastal wetlands in Virginia as mitigation for a port expansion. Similarly, construction of persistent oyster reefs near seagrass beds could enhance water clarity, and promote seagrass survival and proliferation. These ecosystem-based restoration approaches may result in long-term ecological and economic benefits that would be less likely to succeed and more costly if attempted in isolation.

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