Oyster Reef Restoration: Best Management Practices

The Habitat Conservation Division of the National Marine Fisheries Service (NMFS) Southeast Region developed the following information to provide applicants in the Gulf of Mexico with best management practices (BMPs) in the development of oyster reef restoration projects. Restoration activities that are federally funded, authorized, and/or permitted and have the potential to adversely impact essential fish habitat (EFH) will require an EFH consultation with NMFS as required by the Magnuson-Stevens Fishery Conservation and Management Act. By following these BMPs, applicants should be able to avoid the need for an EFH consultation, while increasing the potential for a successful oyster restoration project. For more information on EFH consultations, please visit out NMFS Southeast Region Habitat Conservation Division website at http://sero.nmfs.noaa.gov/habitat_conservation/efh/index.html.

The BMPs for the planning and implementation of oyster restoration projects generally follow these categories: (1) determining restoration targets and goals, (2) site selection, (3) project design, (4) construction, (5) materials, (6) monitoring and adaptive management, and (7) reporting.

Determining Restoration Targets and Goals

The first step in performing oyster reef restoration is to establish the targets and goals for the project. For example, project goals may be to create a new oyster reef, reestablish an oyster reef in a historic location, or to enhance an existing reef. A restoration target may include: (1) the final size or physical dimensions of the reef and/or the amount of viable substrate for oyster attachment, (2) restoration or reestablishment of oyster habitat that closely resembles natural oyster reefs in terms of structure and function (often measured by reef height, reef areal coverage, oyster density, and oyster size-frequency distribution), and (3) a timeline for reaching restoration success (USACE 2012, Baggett et al. 2014).

Site Selection:

The restoration site must have conditions suitable to support oyster growth and to maintain a sustainable oyster population on the reef (Baggett et al. 2014). To aid in the planning and design of the restoration site, a detailed analysis of an existing oyster reef or “reference site” in close proximity to the proposed restoration area should be conducted. The selected reference site should be considered “healthy” by showing persistent oyster growth and a high degree of habitat function (Coen et al. 2004, Burrows et al. 2005). The reference site parameters assessed should include the reef height, reef areal coverage, water flow, depth at the reef, tidal range, spat recruitment rates, dissolved oxygen concentrations, salinity concentrations, water temperature, oyster density, and oyster size-frequency distribution (Baggett et al. 2014, Coen et al. 2004, Burrows et al. 2005). Design of the restoration reef should closely match these reference baseline parameters to ensure conditions are conducive to oyster growth. Ideally, the candidate restoration sites should be monitored for at least one year prior to selection to ensure the site conditions match reference conditions (Coen et al. 2004, Burrows et al. 2005). The reference site assessment can also be used to establish restoration goals and benchmarks for measuring project success (Baggett et al. 2014).

Other Site Selection considerations include:

- Sites should be located in areas where shellfish populations have historically existed based on published accounts, fishing records, navigation charts or bottom surveys (Brumbaugh et al. 2006).

- A detailed bathymetric survey should be conducted prior to reef design and construction. This will determine the site's water depth which can then be matched for compatibility with a reference site and serve as an informative guide to reef placement (USACE 2012).
- Sites should have average water salinity concentrations between 5-15 ppt under normal flow conditions (EOBRT 2007, Galtsoff 1964, Powell et al. 1995, Shumway 1996). The concentration of water salinity can have an adverse effect on oyster survival (Powell et al. 1994). Oysters will exhibit physical stress below 5 ppt (EOBRT 2007) and at concentrations above 15 ppt, oyster mortality increases greatly due to *Perkinsus marinus* (Dermo) infections (Craig et al. 1989, Powell et al. 1995, Powell et al. 1994, Shumway 1996) and predation from oyster drills, crabs and welks (Shumway 1996). Selecting a site with average salinity fluctuations out of the optimal salinity range is not recommended. Sites should also not be chosen if they are susceptible to drastic changes in salinity concentration due to rain events or freshwater outflows (Powell et al. 1995).
- Sites should have adequate water circulation. The ideal flow of water over an oyster bed is steady and non-turbulent (Brumbaugh et al. 2006). Water flow velocity should remain high enough to deliver food and oxygenated water, carry away waste by-products (Stanley and Sellers 1986), and balance the amount of sediment particles settling on the oyster reef (Lenihan 1999).
- The majority of areas within the Gulf of Mexico are not limited by natural oyster spat recruitment and may have adequate recruitment if proper substrate is available (Brumbaugh et al. 2006, Crowder et al. 2000). To ensure spat recruitment is adequate to support continued oyster growth, the use of spat collectors or "spat sticks" can be used to assess spat recruitment rates (Brumbaugh et al. 2006). Spat recruitment rates at the restoration site should be comparable to rates at the reference site (Baggett et al. 2014.) If recruitment rates are low at the restoration site, the site may not be able to be restored without the transplanting of seed oysters or oyster spat (Baggett et al. 2014, Brumbaugh et al. 2006).
- Sites should not be selected if they exhibit substantial vessel traffic and associated fishing activity within the area (e.g., clam dredging, shrimp trawling), that could lead to the re-suspension and mobilization of sediments or damage reefs directly (Dugas et al. 1997).
- Sites should not be selected if they are highly susceptible to impacts from land use (e.g., construction, dredging, agriculture activities), or breakwaters, bulkheads, dikes, and non-porous structures, that could restrict tidal flow, alter salinity, disrupt oyster larval distributions, and/or increase silt deposits (Ulanowicz and Tuttle 1992, Brumbaugh et al. 2006).
- Sites should not be selected if they exhibit extremely low dissolved oxygen concentrations or periods of hypoxia (O_2<2 mg L^{-1}) or anoxia (O_2< 0.5mg L^{-1}) (Baker and Mann 1992, Lenihan and Peterson 1998, Johnson et al. 2009).
- It is preferable for sites to be located in areas where they can be easily accessed for monitoring and maintenance needs (Brumbaugh et al. 2006).
- Project managers should consult with the state agency responsible for shellfish safety to get their advice when considering placing reefs in areas that are closed to oyster harvest.

Project Design

The design of the reef should seek to achieve the desired restoration goals and should incorporate reference site data, historical reef data, site conditions (i.e., hydrological influences, bottom substrate, etc.), availability of materials (i.e., cultch, reef construction materials, etc.), and the construction methods that are suitable for the area.

The design of the reef size, height, and orientation should be similar to other reference reefs within the area. The reef size may be limited by the amount of cultch material (oyster shell or alternative substrate) available, and the amount of suitable bottom to support reef construction (USACE 2012). The reef should be high enough to offset burial from sediments and have varying height contours (topographic heterogeneity). Reef segments should have some areas of separation by defined channels of unrestored bottom to provide some fragmentation in the reefs for circulation (USACE 2012, Harwell et al. 2011, Eggleston 1990). The material used in reef construction should be adequate for oyster spat attachment and should be placed in a manner that allows small crevices (interstitial spacing) to provide refuge areas for spat and other marine organisms that are found between shells on natural reefs (Nestlerode et al. 2007).

Other Design BMP considerations include:

- The reef height should be at least an average 12 inches higher than the surrounding substrate with no portion of the reef less than six inches, after materials have settled (Brumbaugh et al. 2006). If reefs are constructed in areas with low dissolved oxygen concentrations (DO), the reef may need to extend higher in the water column where oxygenated water is more readily available (Brumbaugh et al. 2006).
- The reef design should generally consist of parallel or singular segments constructed with a perpendicular or diagonal orientation to the tidal current (Brumbaugh et al. 2006). Oyster reefs segments should not continuously extend longer than 500 feet in length. There should be periodic defined channels of at least three feet between reef segments to allow for water flow and movement of marine species to traverse the reef sites.
- The sediment at the site should generally be stable, low deposition, with firm substrates. If the restoration site occurs on soft sediments, then the reef should be designed to prevent the reef from sinking into the substrate. For example, a layer of geotextile fabric can be placed under reef material to prevent sinking (USACE, 2012).
- The reef design should consider potential changes in environmental conditions including impacts from climate change (e.g., sea level rise, increased acidity, change in water temperature). For example, reef design should consider incorporating alternative substrates to provide a reef base that is resilient to increases in sea water acidity (USACE, 2012).

<u>Construction</u>

The construction process has the greatest potential to impact EFH and care should be taken to ensure that reef construction does not harm natural resources, alter environmental conditions, or degrade existing habitat functions.

Construction considerations include:

- The use of construction equipment or other physical disturbance of the restoration site during the placement of reef construction material may cause sediments to be displaced or re-suspended into the water column potentially causing impacts to natural resources (i.e., seagrass, benthic resources,) through burial or increased turbidity. Therefore, the deployment of substrate, cultch material, and reef construction materials should be placed in a manner minimizing the disturbance of surrounding sediments. In most areas, turbidity curtains can be deployed during reef construction to limit sedimentation on nearby existing reefs and seagrass beds.

- Construction activities should avoid potential impacts to existing seagrass, reef, and hard bottom habitats from construction vessel groundings and propeller scars. Construction access corridors with sufficient navigable depths should be identified and clearly marked. If possible, a minimum 500-foot construction buffer should be maintained from existing seagrasses, reefs, and hard bottoms.
- Care should also be taken not to damage upland or coastal natural resources (i.e., wetlands, mangroves, etc.) with the storage and transportation of materials and equipment for reef construction.
- Cultch material and reef structures should generally remain in place and have a low risk of being displaced by wave action. It is recommended that all deployed structures other than non-contained cultch material should be able to withstand the wave action produced by a 20-year storm event (Brumbaugh et al. 2006). Precautions, like anchoring structures to the sea floor, should be implemented to ensure displacement of reef structures or cultch material does not damage surrounding natural resources (i.e., seagrass, mangroves, etc.,) (USACE, 2013).
- Reefs should display proper signage, markers and/or lighting to inform waterway users of their presence and the reefs must meet all applicable federal navigational right-of-way and setback requirements (USACE, 2013).
- The construction of oyster reefs should be finished and cultch material should be settled and available for oyster spat attachment from March to November within the Gulf of Mexico (Brumbaugh et al. 2006).
- If loose cultch material is deployed, it is recommended that a detailed hydroacoustic survey be performed during pre- and post-construction in order to identify where the cultch was placed (Brumbaugh et al. 2006, Smith et al. 2001). Construction monitoring methods should also be developed to ensure loose cultch material is falling to its intended location and construction activities are not harming other natural resources (Brumbaugh et al. 2006).

The most common oyster reef construction techniques include:

- Bagged Cultch: Uses aquaculture grade mesh (≤1 inch mesh size) to create bags that are filled with cultch material. This design is often used in softer sediments, and they remain stable in areas with higher wave velocities (Brumbaugh and Coen, 2009).
- Caged Cultch: Cages similar in design to crab traps can be filled with cultch to form oyster reef building blocks that can easily be anchored. This technique is especially beneficial in areas of high wave energy and has been used where shoreline protection is a project goal (Brumbaugh and Coen 2009)
- Loose Cultch: Loose cultch, typically distributed from a barge, is placed either directly on the estuary floor or on top of core reef material to create a cultch veneer. This method is used most commonly for oyster reef enhancement, and is used primarily for large subtidal oyster reef restorations (Brumbaugh and Coen 2009). Loose shell may not be suitable in areas with moderate to high wave energy where cultch can easily be redistributed, or in areas where there is a high risk of burial (Brumbaugh and Coen 2009, Piazza et al. 2005).
- Other Methods: Vertical stakes, cement reef structures and cement oyster grates are alternatives to be considered depending on the project objectives and project site characteristics. Vertical stakes, which are grooved PVC enriched with calcium carbonate, have been shown to out-perform both bagged and caged cultch in high sedimentation conditions by providing vertical relief (Manley et al. 2009). Cement oyster domes have been very successful in areas of high sedimentation and high wave energy. The domes or similar designs are hollow cement structures that can be formed to various sizes to meet specific project needs. Other

lower profile cement structures, such as oyster grates, may provide a relatively inexpensive, stable substrate for oyster habitat restoration (Brumbaugh and Coen 2009).

Materials

- The reefs should be constructed with approved cultch to ensure there is adequate substrate for the attachment of oysters (Brumbaugh et al. 2006). The type of cultch used is highly dependent on the availability and cost of materials (Brumbaugh and Coen 2009). Cultch may include the following materials or a combination of: natural mollusk shells; fossilized mollusk shell; other fossilized aquatic organisms; and lithic materials such as limestone, granite and gravel, including crushed and graded concrete (Brumbaugh et al. 2006). Exceptions to this list of generally accepted cultch material should be specifically identified and approved for reef construction by the appropriate state authority. Typically, oyster shells or fossilized mollusk shells are the preferred material for use in oyster reef projects, since they closely emulate natural reefs (O'Beirn et al. 2000).
- All substrate, cultch materials, construction materials, cover nets, or designated markers placed on or in the water should be non-toxic and free of pollutants, contaminants, and non-indigenous flora and fauna (Brumbaugh et al. 2006).
- If fresh shell from non-local sources is used, it should be allowed to "age" or dry out on land for at least one to three months to ensure no transfer of parasites or disease (Bushek et al. 2004). Cohen and Zabin (2009) caution that longer periods of at least six months may be necessary to ensure highly tolerant exotic species are not transferred.

Monitoring and Adaptive Management

Projects should be continuously evaluated for their performance in achieving restoration goals, and adaptive management should be implemented to determine if there is a need to implement corrective management procedures. Baggett et al. (2014) provide detailed guidance on monitoring oyster restoration projects, including methods and suggested sampling frequencies, through "Universal Metrics" and "Universal Environmental Variables". The Universal Metrics include monitoring: (1) reef areal dimensions, (2) reef height, (3) oyster density, and (4) oyster size-frequency distribution. These metrics are used to evaluate the growth of the emergent reef structure, the density and age structure of the oyster population, and the growth and recruitment of new oyster spat (Coen et al. 2004, Burrows et al. 2005, Luckenbach et al. 2005). The Universal Environmental Variables aid in the interpretation of the Universal Metrics and include monitoring: (1) water temperature; (2) salinity; (3) dissolved oxygen; and (4) the presence of disease, predators, pests, and competitive species. During site visits the time of survey, weather conditions and measurement of environmental variables should also be recorded (Baggett et al. 2014).

Adaptive Management

If the reef is not reaching the established restoration goals or performance standards within a specified time period, then adaptive management should be implemented to improve the likelihood of project success. Adaptive management typically includes the altering of reef design to be more functionally productive, applying additional cultch material to provide more substrate for oyster attachment, removal of sediment causing burial of oysters, or the transplanting of cultured spat or seed oysters to increase oyster density (Baggett et al., 2014).

Reporting

In order to satisfy permit and grant requirements, monitoring reports are often required to ensure the project was properly constructed and demonstrate progress towards reaching the identified success criteria. Reports should include a description of the methods used, the criteria for selecting the restoration site and reef construction methods, and how the sites are surveyed and monitored. Reports should clearly identify project goals and show if those established goals are being achieved and trending towards success. All monitoring data to evaluate success criteria (i.e., reef height, areal coverage, live oyster density, and oyster size frequency distribution) should be included in the reports and be documented with still photographs. The reports should also include site maps of the restoration project that includes physical changes in reef dimensions and where sampling occurred.

References Cited

Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp.

Baker, S.M. and R. Mann. 1992. Effects of hypoxia and anoxia on larval settlement, juvenile growth, and juvenile survival of the oyster *Crassostrea virginica*. Biological Bulletin. 182: 881-897.

Brumbaugh, R.D., M.W. Beck, L.D. Coen, L. Craig and P. Hicks. 2006. A practitioners' guide to the design and monitoring of shellfish restoration projects: ecosystem services approach. The Nature Conservancy, Arlington, VA. 28pp.

Brumbaugh, R.D. and L.D. Coen. 2009. Contemporary approaches for small scale oyster reef restoration to address substrate versus recruitment limitation: A review and comments relevant for the Olympia oyster, *Ostrea lurida* Carpenter 1864. Journal of Shellfish Research 28:147–161.

Bushek, D., D. Richardson, M.Y. Bobo and L.D. Coen. 2004. Quarantine of oyster shell cultch reduces the abundance of *Perkinsus marinus*. Journal of Shellfish Restoration. 23: 369-373.

Burrows, F., J.M. Harding, R. Mann, R. Dame, and L. Coen. 2005. Restoration monitoring of oyster reefs. Pp. 175-249. In: Thayer, G.W., D.H. Merkey, T.A. McTigue, F.M. Burrows, R.J. Salz, and P.F. Gayaldo, eds. Science-based restoration monitoring of coastal habitats volume two: tools for monitoring coastal habitats. NOAA Coastal Ocean Program, Decision Analysis Series No 23. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD, 628 pp. plus appendices.

Coen, L.D., K. Walters, D. Wilber, and N. Hadley. 2004. A South Carolina Sea Grant Report of a 2004 workshop to examine and evaluate oyster restoration metrics to assess ecological function, sustainability and success: results and related information. Sea Grant Publication, 27 pp.

Cohen, A.N. and C.J. Zabin. 2009. Oyster shells as vectors for exotic organisms. Journal of Shellfish Research 28(1): 163-167

Craig, A., E.N. Powell, R.R. Fay, and J.M. Brooks. 1989. Distribution of *Perkinsus marinus* in Gulf Coast oyster population. Estuaries 12:82–91.

Crowder, L.B., S.J. Lyman, W.F. Figuera, and J. Priddy. 2000. Source-sink population dynamics and the problem of siting marine reserves. Bulletin of Marine Science 66:799-820.

Dugas, R.J., E.A. Joyce, and M.A. Berrigan. 1997. History and status of the oyster, *Crassostrea virginica*, and other molluscan fisheries of the Gulf of Mexico. pp 187-210. In: Funderburk, S.L., J.A. Mihurshy, S.J. Jordan, and D. Riley. 1991. Habitat requirements for Chesapeake Bay living resources. Habitat Objectives Workshop, Living Resources Subcommittee and Chesapeake Research Consortium, with assistance from Maryland Dept. Nat. Resources, Solomons MD.

Eggleston, D.B. 1990. Foraging behavior of the blue crab *Callinectes sapidus* on juvenile oysters *Crassostrea virginica*: Effects of prey density and size. Bulletin of Marine Science 46(1): 62-81.

EOBRT (2007). Status review of the eastern oyster (*Crassostrea virginica*). Eastern Oyster a Biological Review Team Report to the National Marine Fisheries Service, Northeast Regional Office. 105pp.

Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica*. Fishery Bulletin. 64: 1-480.

Harwell, H.D., M.H. Posey, and T.D. Alphin. 2011. Landscape aspects of oyster reefs: Effects of fragmentation on habitat utilization. Journal of Experimental Marine Biology and Ecology 409:30-41.

Johnson, M.W., S.P. Powers, J. Senne, and K. Park. 2009. Assessing *in situ* tolerances of Eastern oysters (*Crassostrea virginica*) under moderate hypoxic regimes; implications for restoration. Journal of Shellfish Research 28: 185-192.

Lenihan, H.S., and C.H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological Applications 8: 128-140.

Lenihan, H.S. 1999. Physical-biological coupling on oyster bars: How habitat structure influences individual performance. Ecological Monographs 69(3): 251-275.

Luckenbach, M.W., L.D. Coen, P.G. Ross Jr., J.A. Stephen. 2005. Oyster reef habitat restoration: relationships between oyster abundance and community development based on two studies in Virginia and South Carolina. Journal of Coastal Research Special Issue 40: 64-78

Manley, J., A. Power, and R.L. Walker. 2009. Comparison of techniques for off-bottom culture of the eastern oyster, *Crassostrea virginica* (Gmelin, 1791), in Georgia. Vol. 6, Occasional papers of the University of Georgia Marine Extension Service. 15 pp.

Nestlerode, J.A., M.W. Luckenbach, and F.X. O'Beirn. 2007. Settlement and survival of oyster *Crassostrea virginica* on created oyster reef habitats in Chesapeake Bay. Restoration Ecology 15: 273-283.

O'Beirn, F., M.W. Luckenbach, J.A. Neslerode and G. Coates. 2000. Toward design criteria in constructed oyster reefs: oyster recruitment as a function of substrate type and tidal height. Journal of Shellfish Restoration. 19: 387-395.

Piazza, B.P, P.D. Banks, and M.K. La Peyre. 2005. The potential for created oyster shell reefs as a sustainable shoreline protection strategy in Louisiana. Restoration Ecology 13:499-506.

Powell, E.N., J.M. Klinck, E.E. Hofmann and S.M. Ray. 1994. Modeling oyster populations. IV: rates of mortality, population crashes, and management. Fishery Bulletin. 92(2): 347-373.

Powell, E.N., J. Song, M.S. Ellis & E.A. Wilson-Ormond. 1995. The status and long-term trends of oyster reefs in Galveston Bay, Texas. Journal of Shellfish Research, 14:439-457

Shumway, S.E. 1996. Natural environmental factors. In: Kennedy, V.S., R.I.E. Newell and A.F. Eble, eds. The eastern oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, Maryland. pp. 467-513.

Smith, G.F., D.G. Bruce, and E.B Roach. 2001. Remote acoustic habitat assessment techniques used to characterize the quality and extent of oyster bottom in the Chesapeake Bay. Marine Geodesy 24: 171-18.

Stanley, J.G. and M.A. Sellers. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico) – American oyster. U.S. Fish and Wildlife Service Biological Report. 82(11.64). U.S. Army Corps of Engineers, TR EL-82-4. pp. 25.

Ulanowicz, R.E. and J. Tuttle. 1992. The trophic consequences of oyster stock rehabilitation in Chesapeake Bay. Estuaries 15:298-306.

USACE. 2012. Chesapeake Bay oyster recovery: native oyster restoration master plan. Prepared by the U.S. Army Corps of Engineers. 290pp.

USACE. 2013. Setback guidance for structures along certain federal channels. U.S. Army Corps of Engineers, Jacksonville, FL. http://www.saj.usace.army.mil/Portals/44/docs/regulatory/Items%20of%20Interest/FAQs%20Fact%20Sheet%20Regulatory%20Aug%202013_508.pdf