THE ROLE OF COASTAL ENGINEERING IN AMERICAN OYSTERCATCHER CONSERVATION

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Our mission is to conserve and restore natural ecosystems, focusing on birds, other wildlife, and their habitats for the benefit of humanity and the earth's biological diversity.

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Executive Summary

Humans have engineered the coasts for centuries, trying to create stability for the built environment in a system that is inherently dynamic. Continued coastal development and sea level rise are increasing the demand for engineered coastlines. Simultaneously, restoration dollars made available by the Deepwater Horizon settlements in the Gulf of Mexico will likely fuel a boom of such projects—from oyster reefs to armoring. These projects are often designed to achieve one particular goal such as coastal protection, oyster restoration, or erosion control, yet often have unintended impacts that jeopardize declining populations of coastal wildlife. With advanced planning and consideration, coastal engineering projects can be designed to minimize impacts and in some cases provide benefits to these species. This report summarizes the impacts of coastal engineering on the American Oystercatcher and provides recommendations for permit applicants, project engineers, and regulatory reviewers to improve future projects for the benefit of these imperiled shorebirds.

The American Oystercatcher (*Haematopus palliatus palliatus*) is a species of high concern according to the U.S. Shorebird Conservation Plan and is included on most state imperiled species lists throughout its range. It is a large shorebird restricted to coastal habitats, feeds chiefly on mollusks, and nests on emergent shell or sand structures between March and August. Oystercatchers are imperiled because of habitat loss and nesting failure. High rates of nesting failure are caused by overwash of nests, recent increases in opportunistic predators such as raccoons and fish crows, and human disturbance of nesting areas that causes abandonment or contributes to depredation of eggs or young.

Coastal engineering is a critical concern for oystercatcher conservation. Structures placed within the coastal environment displace natural habitat and have profound impacts on historically dynamic coastal habitats – greatly diminishing their ability to meet oystercatcher needs for survival and reproduction. Seawalls and bulkheads drastically change the interface between land and water, eliminating intertidal and supratidal habitats that are used for foraging, roosting, and nesting. Beach stabilization and navigation structures (e.g., groins, breakwaters, and jetties) alter hydrodynamics and sediment transport, impacting the characteristics of intertidal habitats in the area. Beach nourishment reverses the effects of erosion on coastal habitats, but the process can eliminate important habitat features (e.g., tidal pools and flats) and smother macroinvertebrates on which oystercatchers feed.

The widespread harm caused by coastal engineering has led to a large and growing body of research aimed at ameliorating or eliminating such harm in the future. Perhaps the easiest change to enact involves small "enhancements" to the design of existing structures. Concrete structures can have their pH, surface textures, and shape modified to promote colonization by native fauna. Intertidal shelves can be added to seawall structures and living shorelines with offshore breakwaters can help provide erosion control while maintaining quality foraging habitat. Beach nourishment projects can be improved through better sediment matching with the donor site, avoidance of critical nesting or foraging times for wildlife, and methods that reduce invertebrate loss while promoting microhabitat diversity.

The preservation and restoration of natural coastal features provides the most potential for conserving oystercatchers while also contributing to resilient coastlines. In areas where options are limited, engineered structures that replicate aspects of natural features can be used to provide flood and erosion control as well as conservation value. The United States Army Corps of Engineers (USACE) refers to this use of Natural and Nature-based Features (NNBF) as a core strategy in their recent Engineering

with Nature (EWN) initiative. The USACE post-Hurricane Sandy evaluations of goods and services provided by natural areas show substantial benefits from these systems and can help guide future coastal projects.

Any engineering project affecting our coastal systems should be evaluated for its impacts to oystercatchers and other species of concern, even when the goal is habitat restoration. Oyster reef restoration is a growing practice throughout the range of the oystercatcher; reef builders should ensure their methods do no harm at a minimum, and they should preferentially employ designs that benefit oystercatcher foraging and roosting. Dredged material islands are common in coastal areas and can be designed and managed to benefit oystercatchers. Islands should have erosion control measures that support natural shorelines and be adjacent to, or very near, foraging areas. Vegetation and predator management programs on islands are necessary to maximize nesting productivity.

The following oystercatcher habitat needs should be considered by all projects that alter coastal habitats (additional details are available within the body of the report):

Nesting: areas above high water line with shell or minimal vegetation, free of mammalian predators, adjacent to or within sight of quality foraging areas. Avoid construction during nesting season to eliminate potential take.

Foraging: primarily shellfish beds, beaches, and intertidal flats where they feed on macroinvertebrates. Should have nearby roosting areas to minimize energy lost to flight.

Roosting: a variety of supratidal areas should be available near nesting and foraging areas. Limited vegetation and lack of nearby trees or perches for predators preferred.

Disturbance: critical nesting, foraging, and roosting sites should be free from human disturbance. Appropriate buffers are needed for boat and foot traffic as well as recreational activities.

Additional research on aspects of oystercatcher biology and coastal engineering practices will improve the evaluation, design, and execution of coastal projects. Research is needed to improve habitat models that help evaluate project design and quantify the ecological value of structural enhancements. Some best practices for artificial reefs and living shorelines can be synthesized from the available data on these techniques, but further research is needed to quantify wave attenuation and erosion control benefits. Work is needed to facilitate the incorporation of conservation, restoration and nature-based solutions into coastal engineering plans. Specifically, improvements in monetizing benefits and permitting procedures are needed for these approaches to be on equal footing with the evaluation and permitting of traditional structures.

Table of Contents

Relevant ecology of the American Oystercatcher

The eastern subspecies of American Oystercatcher (*Haematopus palliatus palliatus*) is a large shorebird that uses coastal habitats along the Atlantic and Gulf Coasts of North America. Oystercatchers face a variety of threats including habitat loss, habitat degradation, recreational disturbance, and nest depredation. These threats and relatively low population estimates have resulted in their identification as a species of high concern in the U.S. Shorebird Conservation Plan (Brown et al., 2001) and in their listing as endangered, threatened, or of special concern by most states along the Atlantic Coast. More robust conservation efforts are required to avoid declines in oystercatcher populations and eventual listing under the federal Endangered Species Act.

Oystercatchers are restricted to coastal habitats throughout their entire life, primarily due to their feeding specialization on marine invertebrates of the intertidal zone. Foraging habitat primarily includes beaches, tidal flats, and shellfish beds, and to a lesser extent rocky shorelines. The times at which oystercatchers forage varies with the tide and among habitats. Oystercatcher diet varies somewhat throughout their range, but generally includes oysters, mussels, clams, polychaetes, and mole crabs. For a more thorough review of diet and foraging habitat, see American Oystercatcher Working Group et al., (2012).

Nesting habitat includes emergent oyster rakes, sand and shell beaches, dunes, and occasionally rock or other surfaces such as gravel-covered rooftops (Douglass et al., 2001). Nesting can also occur in wrack deposits, fringing beaches, and higher elevation areas within salt marshes (Wilke et al., 2005). Oystercatchers have been documented to nest on spoil islands in many areas (Hodgson et al., 2008; Rappole, 1981; Toland, 1992). The diversity of nesting habitats used by oystercatchers and apparent changes in nesting distribution during recent decades raise questions regarding optimal nesting conditions. Current oystercatcher nesting choices may reflect a movement towards sub-optimal habitats as historic nesting areas become unsuitable through development, predation, or disturbance (Virzi, 2010).

Nesting behavior begins with pair formation, which usually occurs shortly after both birds have arrived at their nesting territory. Time of arrival varies by latitude but will generally be somewhere between late February and early April (American Oystercatcher Working Group et al., 2012). In South Carolina birds reside year-round and pairs can be found on their territories throughout the year (Sanders et al., 2004). First clutches are usually laid between March and April, starting earlier in southern states, though Hockey and Freeman (2003) found a nest in Texas on January 22nd. Oystercatchers may re-nest throughout June if eggs or young are lost. Eggs hatch in approximately 27 days and young fledge in approximately 35 days.

Overwash and predation are the two leading causes of nest failure in oystercatchers, with the addition of disturbance in areas of human activity.

Overwash and predation are the two leading causes of nest failure in oystercatchers (McGowan et al., 2005; Thibault, 2008; Virzi, 2008), with the addition of disturbance in areas of human activity (Virzi, 2010). Nesting is more successful when parents can forage near nesting areas (<100 m) (Nol, 1989; Thibault et al., 2010). Greater attendance of chicks and open views between foraging and nesting areas are likely driving factors of success,

allowing parents to stay vigilant against predators. Nesting areas with suitable shoreline habitat allow chicks to forage and supplement the food provided by their parents (Ann Paul and Mark Rachal, pers. comm.). The proximity of foraging areas to nesting areas is important; high-quality foraging habitat away from nesting areas may not be used by parents while nesting (Schwemmer et al., 2016).

Oystercatchers are more sensitive to human disturbance than many shorebirds and require larger buffers. Koch and Paton (2014) measured distances from approaching humans at which shorebirds initiated flight and calculated a recommended buffer zone for oystercatchers of 165 m. Shorebirds frequently nesting near human activity can habituate to the disturbance, but there is concern this may lessen escape responses and lead to increased chick mortality (Baudains and Lloyd, 2007).

Oystercatchers benefit from roost sites that are close to high-quality foraging areas and minimize the energy costs of flight. Favorable characteristics of roost sites for shorebirds include: open views, large size, height above spring tides, and variability in direction of wind breaks.

The availability of suitable roost sites is another, perhaps easily overlooked, facet of conservation planning for shorebirds like the oystercatcher. The intertidal areas used by foraging oystercatchers are covered with water much of the day. Oystercatchers benefit from roost sites that are close to high-quality foraging areas and therefore minimize the energy costs of flight (Dias et al., 2006; Van Gils et al., 2006). Favorable characteristics of roost sites for shorebirds include: open views, large size, height above spring tides, and variability in direction of wind breaks. Peters and Otis (2007) found oystercatcher roost selection was partially correlated to substrate (shells) and number of boats within 1000m (fewer being better). Research in the Big Bend region of Florida found that oystercatchers use roost sites lacking, and away from, areas with woody vegetation, possibly to avoid mammalian and avian predators (Brush et al., in prep.).

Effects of Coastal Engineering on the American Oystercatcher

While there are many published studies on the environmental effects of coastal engineering projects (see Dugan et al., 2011 for an overview), there are few that have examined impacts to American Oystercatchers directly. However, impacts can be inferred by examining how coastal engineering projects alter nesting and foraging habitats used by oystercatchers and the availability of oystercatcher prey. This rationale is used below to examine a variety of commonly employed coastal structures and management practices.

Effects of Hard Engineering Solutions

There are a variety of hard structures frequently used to manage the movement of water and sediment in coastal environments (a process often referred to as coastal armoring). They include riprap, seawalls, revetments, bulkheads, breakwaters, groins, and jetties, and may be used along open and sheltered coasts. These structures are used to reduce erosion, provide flood protection, or keep inlets and channels open for navigation. Hard structures are numerous throughout the range of the American

Oystercatcher and their use is anticipated to increase as coastal development continues and sea level rises.

There are several negative consequences common to all hard structures placed along shorelines. The first impact is placement loss, the loss of habitat associated with the physical placement of the structure. Once placed, engineered structures are novel habitat types within the local environment and can foster ecological communities not formerly found in the area as well as support the spread of invasive species (Bulleri and Airoldi, 2005). Structures made with Portland cement are often smooth and have a pH around 13 – characteristics that likely contribute to their limited use by many intertidal species. The critical underlying problem with hard structures is that they are static components within an inherently dynamic system; they interrupt the natural processes that shape coastal systems and begin a cascade of effects that are ecologically harmful and necessitate frequent management. Such alteration of coastal habitat is especially problematic for obligate coastal species like the oystercatcher, and is likely a significant factor in their population decline.

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Seawalls and Bulkheads

Shorelines are often protected from erosion using wood, rock, or concrete structures that include seawalls, bulkheads, revetments, and riprap. This type of armoring protects property yet interrupts natural processes and creates significant impacts on the fronting beach (Dean, 1986). Shoreline armoring can lead to a reduction or complete elimination of the intertidal zone in which oystercatchers feed (Pilkey and Wright, 1988). Modification of the intertidal zone alters the distribution, abundance, and diversity of macroinvertebrate prey and diminishes the utility of this habitat for oystercatchers. Armoring also can lead to severe impacts on the supratidal habitats of beaches, reducing or eliminating the dry-sand upper beach areas in which shorebirds including oystercatchers often nest (Dugan et al., 2008; Jackson and Nordstrom, 2011).

Direct impacts to oystercatchers from the construction of seawalls have been documented in Hillsborough Bay, Florida, through research by Audubon Florida's Florida Coastal Islands Sanctuaries (FCIS) program. Audubon has been protecting and monitoring birds in the Tampa Bay area since 1934. Real estate development within the region has led to an increase in seawall construction to safeguard private property from erosion. In almost all cases this has led to the loss of suitable oystercatcher nesting and foraging habitat in those locations (M. Rachal, pers. comm.). While seawalls offer roosting sites for oystercatchers, they are not suitable for nesting and have reduced the number of nesting pairs using these islands (Hodgson et al., 2008).

Groins and Jetties

Shore-normal structures (those perpendicular to the shore), like jetties and groins, have large impacts on local hydrodynamics and sediment transport. Groins are employed to trap sand moving through longshore sediment transport and reduce erosion or create additional beach. This can result in changes

to sediment deposition and sediment characteristics that alter the distribution and abundance of the resident macroinvertebrate assemblage (Walker et al., 2008). Groins are often placed in series (a groin field), increasing the scope of their effect on a shoreline.

Jetties are structures that block longshore currents and increase inlet water velocities to help maintain navigable inlets and harbors. They disrupt sediment transport within the region, altering the configuration of nearby beaches and shoals (Hansen and Knowles, 1988), and changing tidal flow and sediment transport into marshes (Komar, 1996). The resulting alteration and loss of intertidal habitat at stabilized inlets negatively impacts oystercatchers.

Figure 1. Jetties at Humboldt Bay, California. Image by Robert Campbell, USACE Digital Library.

Breakwaters

Breakwaters are shore-parallel structures that change hydrodynamics and sediment accumulation characteristics in the surrounding area as sand movement is blocked or redirected. As with the shore-normal structures discussed previously, changes in sediment deposition can lead to changes in the distribution, abundance, and spatial variation of local macroinvertebrate assemblages (Walker et al., 2008). Breakwaters are occasionally referred to as oyster reefs or artificial reefs due to their assumed ability to provide substrate for marine invertebrates. This is often not the case; specific planning and design considerations are required to create useful habitat (see recommendations below).

Effects of Soft Engineering Solutions

Soft engineering solutions for coastal management are those based on the use of sediment and vegetation to achieve project goals. These practices are often employed to preserve the ecological, recreational, or aesthetic values lost through hard engineering solutions. Soft engineering practices like

beach nourishment and dune or ridge creation are used in a variety of coastal areas, while marsh creation or restoration is used in lower-energy environments like sheltered coasts. It is important to realize that habitat restoration has species-specific effects; increased vegetation in an area may reduce the value of that habitat for oystercatchers.

Beach nourishment

Beach nourishment is often a preferred strategy to armoring because of its potential to preserve more of the environmental, social, and aesthetic qualities expected from coastal habitats. The primary benefit of nourishment is that it increases the size of the beach, and thus habitat that is essential to oystercatchers. However, it also brings relatively large and abrupt changes to the environment that can negatively impact wildlife – especially avifauna like oystercatchers – that utilize the intertidal zone. Speybroeck et al. (2006) provide a concise yet thorough overview of the ecological impacts associated with nourishment activities. They use an ecosystem-level approach that considers how quantity, quality, and compaction of sand can translate into a wide range of habitat and biological effects. Impacts that are of concern for oystercatcher conservation include decreases in prey abundance (short-term, from burial) and loss of quality foraging habitat (long-term, from changes in sediment composition).

Figure 2. Beach renourishment and breakwaters. Photo courtesy Florida Park Service.

Foraging opportunities for oystercatchers may be limited on recently nourished beaches. The newly placed sediment can bury benthic organisms, causing severe mortality or total extirpation from the site. In their review of studies on macroinvertebrate recovery on nourished beaches, Wilber et al. (2009) found that recovery times could span from a few weeks to 2 years. They noted studies with shorter

recovery times often involved good sediment match (geotechnical compatibility) and avoided the spring periods of high larval recruitment.

Nourishment using sediments of low compatibility (i.e., where the borrow material has different characteristics than the native beach sediment) can have lingering impacts that may reduce prey availability for oystercatchers and other shorebirds for years. Peterson et al. (2014) studied sediment composition and beach fauna after nourishment projects using course sediments. Changes to sediment composition and decreases in the abundance of infaunal invertebrates (including *Donax* spp.) persisted until the end of their monitoring period 3-4 years after the nourishment project. This was accompanied by decreased abundance of predators including ghost crabs and shorebirds.

The structure of nourished beaches may negatively impact shorebirds like the oystercatcher that feed in intertidal areas. Convertino et al. (2011) found that altered geomorphology of nourished beaches was the most likely explanation for decreased use by plovers on beaches of the Florida Gulf Coast. Nourished beaches may differ from those formed by natural forces and lack features like ephemeral pools and tidal flats. While nourishment projects will increase the amount of beach; the changes in beach structure, microhabitats, and infaunal assemblages will determine if the beach is of any value to oystercatchers.

Artificial dunes and ridges

The placement of sand to form artificial dunes is another approach to prevent flooding of near-shore areas. Depending on the location and structure of the dune, this practice can produce the undesirable effect of increasing erosion rates by altering the hydrodynamics of incoming waves to increase scouring (depending on steepness of the engineered beach). Further, artificial dunes can prevent normal overwash events and eliminate overwash fans that are important habitat for oystercatchers and other shorebirds (Riggs, 2011).

Recommendations for Improving American Oystercatcher Conservation

Traditional structural approaches to coastal defense provide flood and erosion protection at the expense of many ecological and societal benefits generated by more natural coastlines. This has important ramifications for oystercatcher conservation given the prevalence of such structures throughout the oystercatcher's range, compounded by the predicted increase in coastal structures that will be needed due to continued coastal development and sea level rise. As plans for coastal defense move forward, there are a variety of approaches that can be used to benefit oystercatcher conservation that range from relatively simple modifications of current practices to novel approaches that will require considerable coordination and effort. The simpler approaches start with minor design modifications to commonly employed structures to maintain or replace some of the ecological benefits lost by their use. The more complex approaches involve the maintenance or restoration of natural components of the landscape to provide flood protection and a wide range of associated benefits.

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Structural enhancements to benefit oystercatchers

Commonly used structures can incorporate small modifications to their design to provide ecological benefits,

features commonly referred to as enhancements. Some enhancements involve small changes in the way the physical structures are built and include openings, holes, surface textures, and pits. Other enhancements are made by modifying the design of a project to adjust its placement, height, etc., or to incorporate elements that provide habitat for certain species.

Firth et al. (2014) compiled several recommendations for coastal armoring projects based on their work with the THESEUS Project funded by the European Commission (a clearinghouse of coastal resilience information found at www.theseusproject.eu). They acknowledge the negative ecological impacts of armoring and that artificial structures will never support the same diversity as natural shorelines. Yet, their work has shown that improvements can be made to increase the biodiversity supported by these structures – mostly resulting from modifications that result in an increase in habitat heterogeneity. Modifications that increased species diversity and abundance included drilling holes and creating pits in cast concrete structures and using precast structures with openings and surface features. Some of these enhancements, mainly the drilling of holes and creation of small pits, can easily be added to structures that are already in place. Both of these modifications increased the number of mollusks using the structures and could be used to augment oystercatcher foraging.

In Israel, a breakwater was created using modular armoring units designed to be more biologically active (Ido and Shimrit, 2015). The units were made from a proprietary concrete mix and featured a modified surface texture and design compared to standard units. The modified units supported greater biodiversity than standard units made from Portland cement. Oysters and other invertebrates recruited to the surface further increasing the complexity of the structure and potentially improving its function as a breakwater. Several other recent studies have shown that small modifications to the surface of coastal structures made from cement or rock can increase biodiversity (Coombes et al., 2015; Martins et al., 2010; Perkol-Finkel and Sella, 2015). Perkol-Finkel and Sella (2014) also saw positive effects from using modified concrete matrices with altered pH and air composition.

Some enhancements to traditional coastal structures involve more significant modifications to their overall design. Toft et al. (2013) describe a “habitat bench” enhancement that was added to a seawall during renovation of the shoreline in Seattle, Washington. Sediment of appropriate composition was added along almost 300 meters of the base of the existing seawall to create shallow-water habitat. The bench was a relatively flat area of sediment extending away from the seawall at the Mean Lower-Low Water line, with a riprap toe on the seaward end to limit erosion. Within 1 year, taxa richness of invertebrates was higher at the habitat bench location compared with traditional riprap and seawall sites.

Audubon Florida worked with Port Tampa Bay to alter plans for armoring a dredged material management area so that quality oystercatcher habitat could be preserved. Original plans for shoreline stabilization calling for onshore riprap were changed to create an offshore limestone riprap breakwater. The breakwater initially created a quiet-water lagoon behind the structure and the slope of the dike was graded creating suitable oystercatcher nesting habitat. Soon after placement, strong storm-driven waves overtopped the structure and cut a sharp escarpment into the dike. Unlike previous storm erosion events, the sand was held behind the breakwater and not lost to the bay. The distribution of the sand filled parts of the lagoon and created additional nesting habitat. Up to three oystercatcher pairs have nested behind this structure each year since its installation, compared to no previous nesting due to severe erosion (M. Rachal and A. Paul, personal communication).

Beach nourishment strategies

Several general recommendations for limiting the ecological impacts of nourishment projects have emerged. From their review of the literature, Speybroeck et al. (2006) produced a set of guidelines for planners of nourishment projects to consider.

1. Match sediment composition of donor site and recipient beach.
2. Avoid short-term compaction by plowing or tilling sand immediately after deposition.
3. Avoid nourishing during times critical for resident wildlife (e.g., shorebird nesting and benthic larval recruitment).
4. Choose a number of smaller projects rather than one large project to reduce mortality of infauna (through layering or by leaving unimpacted areas as source populations).
5. Select a nourishment technique that is most suitable given the ecology of the site.

Leaving pockets of beach that are not nourished allows survival of benthic source populations to improve colonization of new sediments.

Based on results of Powilleit et al. (2009), layering sand and limiting layer thickness can improve survival of macroinvertebrate infauna. This strategy will help preserve existing infauna where limited sources for recolonization are available or when preservation of slowly reproducing or dispersal-limited species is required. Proposed depth of layers will depend on the species present at the receiving beach. Leaving pockets of beach that are not nourished allows survival of benthic source populations to improve colonization of new sediments.

Convertino et al. (2011) recommend that nourishment projects account for beach morphology, possibly through the use of features like geotextile units, and maintain the original beach profile when there are desirable features that may otherwise be lost (e.g., tidal pools, flats, or other intertidal features that serve as foraging habitat).

The Use of Natural and Nature-based Features

As part of the recent trend towards larger, system-level coastal engineering, the USACE Engineer Research and Development Center (ERDC; www.erdc.usace.army.mil) has created an initiative that may play a key role in future coastal management. Their Engineering with Nature initiative is described as "the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental and social benefits through collaborative processes" ("ERDC launches Engineering with Nature website," 2013). A key component of this initiative is their work on the use of Natural and Nature-based Features (NNBF) to achieve project goals.

The preservation and restoration of natural features (i.e. features created and sustained by nature) along coastlines is the best strategy for sustaining oystercatchers and other shorebirds. Where this is not possible, the use of nature-based features (i.e. features constructed to mimic natural features) is the next best alternative. The primary concern is the ability of NNBF coastlines to provide sufficient protection for people, property, and infrastructure of coastal communities. Recent work by the USACE has shown promise in this regard. Bridges et al. (2015) performed an evaluation of the goods and

services produced by three coastal restoration sites that were impacted by Hurricane Sandy. The results showed that benefits were moderate to substantial, with notable benefits for both rare species habitats and property value enhancements.

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Living Shorelines and Oyster Reefs

The Living Shorelines program from the National Oceanic and Atmospheric Administration (NOAA) is another important effort that coastal planners should be familiar with. It is another example of the NNBF approach, encouraging the use of soft materials (i.e. plants) that prevent erosion of sheltered coasts without disconnecting the land-water interface (NOAA, 2015). Living shoreline methods advocated by NOAA often include breakwaters or sills to dissipate wave energy and limit erosion of the planted shoreline (called hybrid stabilization by some). These structures can support recruitment of oysters (Bilkovic and Mitchell, 2013) resulting in foraging areas for oystercatchers. The guidance document from NOAA (2015) includes guiding principles, technical support available from NOAA, and information related to NOAA's regulatory and programmatic roles in living shorelines.

Oyster reef restoration is a growing and evolving practice along the Gulf of Mexico and Atlantic Coast, the latter estimated to have lost between 90% and 99% of historic oyster reefs (Beck et al., 2011). Restoring oysters is an attractive strategy for oystercatcher conservation since oyster reefs are primary foraging areas and they provide diverse ecosystem services. Grabowski et al. (2012) estimated the value provided by oyster reefs at \$5,500 to \$99,000 per hectare, with shore stabilization as the most valuable potential service. Techniques for restoring oysters, though, are developing and vary by location. The Oyster Restoration Workgroup (www.oyster-restoration.org) provides guides for restoration and monitoring (see Brumbaugh et al., 2006), links to suppliers, research, and many other resources. Another useful resource for planners is the recently completed summary of shellfish permitting and programs in 21 coastal states (Mississippi-Alabama Sea Grant Legal Program, 2014).

Figure 3. Oyster reef breakwater to protect the shoreline at Whiskey Stump Key, Hillsborough Bay, FL. Photo courtesy Tampa Bay Watch.

Dredged Material (Spoil) Islands

Islands preclude many predators and have always been a preferred habitat for nesting birds. Dredged material islands – a common feature of coastal engineering projects - can serve as important nesting and roosting habitat for oystercatchers if constructed and managed appropriately. Island morphology and erosion control measures should be designed to benefit oystercatchers and other shorebirds. In general, this means erosion control that allows access to a natural shoreline (important for foraging chicks) and vegetation management appropriate for the nesting species. As recommended for all nesting habitat, islands will need adjacent or nearby feeding areas and possibly predator management for successful fledging of chicks (McGowan et al., 2005). The design requirements could be included in permits for dredging operations with environmental impacts. Information on the beneficial use of dredged material islands for shorebirds can be found in a report by Audubon Florida (2013).

Maintenance of islands and removal or addition of new material should avoid nesting periods or be managed in such a way that impacts to nesting oystercatchers are avoided. The USACE, U.S. Fish and Wildlife Service, Florida Fish and Wildlife Conservation Commission, and Tampa Port Authority, in consultation with Audubon FCIS, developed a series of recommendations that have allowed dredge material storage on spoil islands in Tampa Bay during the oystercatcher nesting season without causing nesting failures (Port Tampa Bay et al., 2014).

Project Planning and Design Recommendations

Resilience is a concept that has many definitions, but generally includes the ideas of anticipation, resistance, recovery, and adaptation.

Many coastal engineering projects have proven harmful to oystercatchers and coastal wildlife habitat due to their focus on a limited set of goals at specific points of interest. Successful conservation of oystercatchers will depend on planning efforts that incorporate short-term and site-specific goals into a more robust program for coastal conservation that considers a wide range of societal and ecological goals. This approach is being discussed more frequently in many coastal communities through efforts aimed at coastal resilience. Resilience is a concept that has many definitions (CARRI, 2013), but generally includes the ideas of anticipation, resistance, recovery, and adaptation (Rosati, 2014). The needs of oystercatchers and other imperiled species should play an important role in guiding these efforts.

It is critical that planning efforts consider more than just the traditional, hard engineering solutions to coastal issues. Planners should apprise themselves of new methods and materials as well as new means of incorporating solutions into projects that rely on cost-benefit analysis (historically a problem for more natural solutions with ecological benefits that are difficult to quantify). Expertise from the USACE Engineer Research and Development Center (ERDC), academics, and conservation professionals engaged in the growing research on creating sustainable coastlines should be sought out and incorporated. Planners should contact the American Oystercatcher Working Group (amoywg.org) to find experts that can help inform their efforts.

While solutions using natural and nature-based features (NNBF) are favorable due to their diverse benefits, there may be situations where existing conditions place limits on planners. It is important that a thorough understanding of the attributes of NNBF approaches is developed and made widely

available. The Environmental Defense Fund performed a literature review and convened a panel of experts to gather information regarding the utility of NNBF approaches. The report lists nine features and describes their potential uses, strengths, weaknesses, uncertainties, and research needs among other details (Cunniff and Schwartz, 2015). Recognizing that many coasts will require a combination of approaches, Sutton-Grier et al. (2015) describe hybrid approaches that combine natural and structural features to achieve project goals. Included in their discussion are case studies from the United States and policy challenges facing hybrid approaches.

Site-specific hydrodynamic and sediment transport information is crucial to the long-term success of coastal projects. Coastal systems are very dynamic and can experience rapid change due to the actions of wind and water, especially during storm events. Short and long-term structural integrity or performance of coastal engineering installations can vary significantly by location, with most shorelines along the U.S. Atlantic Coast being highly dependent on the configuration of underlying geological units (Riggs et al., 1995).

A summary of considerations to improve coastal planning efforts:

- Consider coastal engineering issues within the wider scope of coastal resiliency.
- Seek expertise from USACE ERDC, academics, and conservation professionals including the American Oystercatcher Working Group.
- Prioritize NNBF solutions, or use a hybrid approach when necessary.
- Identify any policy challenges that may limit the use of NNBF approaches.
- Consider ecological benefits and impacts, even when using NNBFs.
- Perform site-specific analysis of hydrodynamics and sediment transport that considers underlying geology.

The following questions should be asked when reviewing coastal engineering plans to evaluate benefits and impacts to oystercatchers.

Nesting considerations

- Can the project be designed to provide supratidal habitat with shell or minimal vegetation?
- Can access to oystercatcher nesting areas by mammalian predators be limited?
- Are potential nesting areas adjacent to or within sight of quality foraging areas?

Foraging considerations

- Does the project affect the size or health of shellfish beds in the area?
- Can the project include augmentation, preservation, or reconstruction of area shellfish beds?
- Does the project impact beach or intertidal habitats, or reduce the availability of macroinvertebrate prey?
- Can the project include augmentation or reconstruction of intertidal habitats that will sustain or increase the availability of macroinvertebrate prey?

Roosting considerations

- Does the project provide supratidal roosting areas near nesting and foraging areas?

- Are a variety of roost sites available? Are they free from significant vegetation and located away from trees or other predator perches?

Disturbance considerations

- Are areas for walking and recreational activities located away from oystercatcher habitat, with a goal of providing 165 m buffers (or larger for motorized vehicles)?
- Will construction or other potentially disruptive activities be performed outside of oystercatcher nesting season (approximately March through August, but may vary by location)?

Shoreline habitat considerations

- Does the project result in shorelines that provide foraging opportunities, especially those by nesting areas to be used by chicks?
- Has the project considered living shorelines (e.g., those described in NOAA's Living Shoreline work) and artificial reef breakwaters in place of traditional shoreline armoring (e.g., riprap placed near the mean high water mark) to preserve suitable habitat for oystercatchers?

Research Needs

There are many issues that require additional research to improve the conservation value of coastal engineering projects. The ecology of oystercatchers, ecological and engineering efficacy of structure designs, methods for habitat restoration, and the role of political and regulatory frameworks in shaping resilient coasts all require additional research. It is important that the results of this research are shared widely and incorporated into coastal planning efforts as quickly as possible.

Research is needed to refine our understanding of optimal habitat conditions for oystercatchers. This information will improve planning efforts on all scales, from large ecosystem conservation efforts to small details of structural design. Researchers will need to address the concern that oystercatchers are currently using sub-optimal habitat in response to habitat loss, disturbance, and predators (Stocking, n.d.). Particular areas of research include:

- A better understanding of how the local landscape composition of foraging, nesting, and roosting habitats impacts oystercatcher survival and nesting success.
- Development of habitat models to help evaluate the impacts and benefits of coastal engineering projects and better plan restoration efforts.

Research is needed to better understand the ecological value of natural and engineered habitats. There are many studies that have shown the promise of ecological engineering, from structural enhancements to restoration of natural features in the landscape. Additional work is needed to more clearly specify, and in some cases quantify, the value of proposed techniques. Priority areas of research include:

- Documentation of oystercatcher use of the prey base created by engineered habitat. Studies of structural enhancements (e.g., pits and surface textures) and artificial reefs show they support oystercatcher prey, but exploitation of this prey source needs verification. Studies should evaluate the foraging value of structures during nesting and wintering seasons.

- Quantification of the value of ecosystem services provided by coastal habitats. Perkins et al. (2015) note the lack of such information prohibits the proper evaluation of impacts from coastal structures and limits the evaluation and assignment of benefits that should be ascribed to ecological engineering solutions.
- Detailed engineering information on the wave attenuation and erosion control of NNBF breakwaters and hybrid designs.
- Review of existing studies on breakwaters (including artificial reefs designed for this purpose) to assess their ability to function as habitat. Studies that compare the ability of breakwater designs to support prey items (e.g., Scyphers et al. (2015)) or promote biogenic reef growth will help guide future projects.
- Identification of best practices to achieve erosion control with oyster reef restoration. This is a priority due to its widespread support, growing use, and established ecological benefits.

Research is needed to facilitate the incorporation of conservation, restoration, and nature-based features into coastal engineering plans. The USACE has developed a strong case and framework for incorporating such features into coastal planning efforts (Bridges et al., 2015). However, additional work is needed to ensure these strategies meet the requirements of current planning methods, especially given the political and regulatory challenges involved (Sutton-Grier et al., 2015). Research topics include:

- Monetizing the value of storm and erosion protection benefits from NNBF infrastructure.
- Monetizing the value of co-benefits (e.g., habitat or recreation) of NNBF infrastructure.
- Evaluating permitting processes to ensure NNBF infrastructure is not more difficult to permit than standard hard engineering solutions.

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