Changing a Management Paradigm and Rescuing a Globally Imperiled Habitat

Oyster reefs are the most imperiled marine habitat on earth, with a staggering 85 percent loss in just the past two centuries. A paradigm shift in the way we manage these critical coastal ecosystems is needed to ensure that they are restored and managed to sustain both human and ecological communities. Establishing restoration objectives that incorporate the full array of ecosystem services provided by oyster reefs could provide a much-needed impetus for reversing course and maintaining these vital habitats.

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A variety of species of oysters around the world once formed massive intertidal and sub-tidal reefs in many temperate estuaries, but as a functional habitat, these reefs have become vanishingly rare (Beck et al. *in press*; Jackson 2008; Lotze et al. 2006). In the United States, profound decreases in oyster abundance have been observed (Kirby 2004), with catastrophic ecological consequences (Jackson et al. 2001). As much as 99 percent of oyster reefs formed by the eastern oyster *Crassostrea virginica* have been lost from the Chesapeake Bay (Rothschild et al. 1994; NRC 2004) and the extensive beds once formed by Olympia oysters (*Ostrea lurida*) are essentially extirpated as a habitat from Pacific Coast estuaries (Kirby 2004; Beck et al. *in press*). While collapses in fisheries landings have long been discernable (Goode 1884; Winslow 1884; Smeltz 1898), managers and the scientific community alike have been slower to recognize the loss of the ecological functionality and valuable services provided by the diminishing area of viable oyster reef habitat (Hargis & Haven 1999).

The Nature Conservancy (TNC) recently convened a team of experts from five continents that conducted an analysis of global conditions and threats to native oyster reefs. The findings of that study demonstrate that the declines observed in the United States are representative of what has happened in most other countries—oyster reefs are likely the most degraded and, by extension, most imperiled type of marine ecosystem on earth. The estimate of loss globally is 85 percent, surpassing coral reefs, mangroves, and seagrass in the magnitude and geographic extent of loss (Beck et al. *in press*). In the United States, existing oyster reefs are functionally extinct habitats (less than one percent of historic reef area) or in poor condition (1-10 percent of historic area) within seven of eight marine ecoregions in the United States (Virginian, Carolinian, Floridian, Puget Trough, Pacific Northwest Coast, northern California, southern California). *At best*, oyster reefs were rated in fair condition in only one U.S. marine ecoregion (northern Gulf of Mexico). As a result, the quality of both human and ecological communities that depend on these ecosystems is diminished, and almost nowhere are even remnant reefs being managed explicitly for ecological function *as habitat*.

The world's oyster reefs are vanishing largely as a result of destructive fishing practices and overexploitation, as well as other human-induced changes to estuaries. The Deepwater Horizon oil spill in the Gulf of Mexico in April 2010 brought into sharp focus the importance of the region's wetlands, including oyster reefs, for supporting species biodiversity and human communities along the coast. The Gulf of Mexico was the last region in the Northern Hemisphere with both thriving oyster fisheries and oyster reefs with sufficient structural integrity to serve as functional habitat. While the damage done to these systems has not yet been fully assessed, the loss of any remaining reefs is troubling. As troubling is that fishing pressure, a primary stressor to reefs, remains high in many bays where reefs were assessed as being in poor condition (1-10 percent remaining) or extirpated as a habitat (less than one percent remaining). This is particularly true for U.S. estuaries. Clearly, a dramatic paradigm shift is needed to place a sharper focus on the full value of oyster reefs as functional habitat. The tide may be turning, with restoration projects reaching larger and more ecologically meaningful scales, but more deliberate action is needed for us to realize not just a no net loss of these particular habitats, but a dramatic net gain.

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Oyster Reefs as a Wetland Type

Oyster reefs fall within the classification scheme used by the National Wetlands Inventory as estuarine reefs (Cowardin et al. 1979). Internationally, rocky shores, coral reefs, sand bars, and shallow marine waters down to six meters in depth are all habitats that fall within the wetlands classification scheme used by the Ramsar Convention on Wetlands (http://www.ramsar.org/pdf/ris/key_ris_e.pdf, last visited Sept. 3, 2010).

More importantly, perhaps, is that the ecological services commonly associated with other types of wetlands are well-documented as services also provided by oyster reefs: large aggregations of oysters encourage cycling of nutrients between overlying waters and benthic sediments (reviewed in Newell 2004); their reef structure provides important nursery and foraging habitat for a variety of other resident and transient species of both ecological and economic significance (Coen et al. 1999; Peterson et al. 2003; Rodney & Paynter 2006; LRD & Layman 2009); and their reefs stabilize sediments in both sub-tidal and intertidal environments (Meyer et al. 1997; Piazza et al. 2005). Accordingly, they are considered ecosystem engineers, modifying local conditions in ways that facilitate not only their own growth and survival, but for many other species as well (Jones 1994). As was the case with vegetated wetlands in previous decades, society has been slow to prioritize the management of oyster reefs for the return of the full array of ecological services, resulting in a profound and continuing loss of these as integral components of larger coastal ecosystems.

Rescuing Oyster Reefs: Restoration for Ecosystem Function

TNC and many other regional conservation organizations have increasingly been working to restore oyster reefs with the primary objective of returning ecosystem services to ecologically meaningful levels (Coen et al. 2007). The profound ecological importance of shellfish, not surprisingly, typically results in their selection as conservation targets in Marine Ecoregional Assessments (ERAs) and Conservation Action Plans (CAPs) prepared by TNC and its partners (Beck & Odaya 2001; Geselbracht et al. 2008). In the past decade, TNC has supported or directly overseen more than 47 oyster reef projects in 15 U.S. coastal states. Most of these projects have been supported by an ongoing national partnership between TNC and the National Oceanic and Atmospheric Administration's (NOAA's) Community-Based Restoration Program. Projects have also been supported through the National Fish and Wildlife Foundation, the Estuaries Restoration Act, and investments from private funders, e.g., Kabcenell Family Foundation, Disney, Royal Caribbean, and Shell, to name a few). Very recently, several larger scale projects have been supported by NOAA funding through the American Recovery and Reinvestment Act (Recovery Act), and these in particular are designed to demonstrate the direct linkages between healthy habitats and social benefits, such as job creation, i.e., near-term jobs directly related to restoration activities and from restoration of sustainable fisheries and fishing-related jobs. Many of the projects are designed to restore the key attributes of functional oyster reefs, such as vertical relief (Lenihan 1999) and microstructure provided by oysters growing vertically on the surface of reefs (Soniat et al. 2004). Oyster fishing practices affect both of these attributes (Lenihan & Peterson 1998; Lenihan et al. 1999; Grabowski & Peterson 2003), so a strong emphasis is placed on creation of reefs that are managed as sanctuaries.

As with restoration of vegetated wetlands, increasing the scope and impact of oyster reef restoration requires a commitment to quantitatively assessing restoration outcomes to enable adaptive management and improvement of future restoration projects (Wagner et al. 2008). Guidance for the design and quantitative assessment of oyster reef projects is available (Thayer et al. 2005; Brumbaugh et al. 2006), and there are websites that are designed to facilitate the transfer of new approaches to the restoration science community (www.oyster-restoration.org).

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There is exciting progress being made with oyster reef restoration and with documenting ecologically meaningful outcomes at various scales. Marked increases in oyster recruitment were observed following small-scale reef restoration and stock enhancement efforts in the Lynnhaven River (Brumbaugh et al. 2000), a small tributary in the lower Chesapeake Bay, as well as at larger scales in the Great Wicomico River, another tributary in the mesohaline portion of the estuary (Schulte et al. 2009). Luckenbach et al. (2005) noted the relatively rapid development of benthic communities on restored reefs in both South Carolina and Virginia. Gray snapper show high site fidelity and occur at orders of magnitude higher abundance on small patch oyster reefs restored in the Loxahatchee River. These reefs also provide nursery habitat for fish species that ultimately migrate to reside on coral reefs in near shore waters outside the river (LRD & Layman 2009), demonstrating a potentially important connection between estuarine and near shore communities. Reef restoration appears to provide durable outcomes as well; Powers et al. (2009) found that restored reefs in North Carolina were fulfilling restoration goals after a decade or more post-restoration. A key to being able to define success in each of these individual projects is having clear and measurable goals: recruitment of young oysters; presence and behavior of key benthic or fish species on individual reefs; and long-term persistence of individual reefs following restoration.

While oyster reef restoration will not address all the challenges facing estuaries in the United States (Pomeroy et al. 2006), the restoration of ecosystem engineers has been advocated as a key component of restoration of ecosystems (Byers et al. 2006). Spatially explicit models suggest that even modest increases in oyster biomass could significantly increase water clarity and viability of seagrass meadows in the Chesapeake Bay (Cerco et al. 2007), and that targeted restoration efforts could remove a significant fraction of primary production in large tributaries to the estuary (Fulford et al. 2007). These ecosystem services do not account for the additional biodiversity benefits or enhancement of other fisheries that accrue with expansion of complex reef habitat (Peterson et al. 2003; Grabowski & Peterson 2007).

Photo courtesy of Jeff DeQuattro/TNC

Figure: Large-scale oyster reefs are being restored in Alabama as living breakwaters to protect adjacent salt marshes that are eroding in the face of rising sea level and impacts from storm waves and wakes from nearby shipping channels.

Changing the Management Paradigm

The conservation community and management agencies in some states are increasingly placing an emphasis on restoring oyster reefs for ecological services other than the harvesting of oysters. Traditionally, agencies focused their management efforts only on oyster landings, with little or no management focus on the myriad other services provided by reefs as habitat. A wholesale shift in the management paradigm is needed, however, to truly achieve restoration and long-term conservation at ecologically meaningful scales. Fisheries management agencies still focus their efforts primarily on replenishment or put-and-take management activities designed to enhance the amount of shell substrate available for oyster settlement and subsequent harvest. While oyster harvest is certainly an important ecosystem service, it is just one of many services derived from reefs. Moreover, the inherent destruction of structure that accompanies harvest can inhibit or prevent the delivery of other services (Lenihan 1999; Grabowski & Peterson 2007). In most instances, oyster fisheries enhancement activities involve the creation of flat, low-relief deployments of material designed specifically for ease of subsequent harvest. Complementing these kinds of fisheries-focused activities with restoration projects designed specifically for the return of other ecosystem services, e.g., habitat for fish or shoreline protection, seems a worthwhile investment, but has yet to be incorporated into the long-term plans for most estuaries in the United States.

Comprehensive planning can help with both prioritizing the locations and setting overall management objectives. The state of Maryland recently announced an oyster zoning plan that sets aside 24 percent of historic reef area as sanctuaries that enhance oyster reproduction and provide fish habitat and other environmental benefits (http://www.dnr.state.md.us/fisheries/oysters/2010GovEventhandoutNaylorFinal2.pdf, last visited Sept. 8, 2010). These sanctuary areas will complement other zones where further development of an emerging oyster aquaculture industry will be encouraged, as well as other areas that will continue to be managed for traditional oyster fishery production. This proactive and comprehensive approach to reconciling separate but related ecological services reflects a long-standing interest in the region's management and conservation community to dramatically increase oyster biomass in the estuary, and contributes to a larger effort to restore oyster abundance in the Chesapeake Bay under a presidential executive order signed in 2009. But this is just one estuary of many in the United States that should have functioning oyster reefs. To help set restoration targets, TNC is conducting a quantitative assessment of historic and present-day oyster abundance for estuaries throughout the United States, and estimating the ecosystem services (fish production, water filtration, and denitrification around reefs) that could be derived from varying amounts of restored reef habitat.

Restoring oyster reefs in areas with degraded water quality is another management challenge in need of resolution in some locations. Oysters, like other commercially or recreationally harvested species of bivalves, pose a potential human health risk if consumed from waters with high levels of bacterial contamination. Of course, reef restoration should be targeted in areas where it is ecologically most beneficial and where restoration objectives are most likely to be met from an ecological standpoint. Sometimes the most ecologically relevant sites may be in waters where commercial or recreational harvest is prohibited for water quality reasons. Agencies in some states have found ways to accommodate (if not promote outright) this kind of activity, even in areas closed to harvest these efforts have often proved quite successful both for encouraging recovery of reefs (Brumbaugh et al. 2000) and for spurring management actions that address the root causes of contamination. Some managers worry, however, that restoration in closed waters creates an attractive nuisance that could encourage illegal harvest. Among the solutions for this, presumably, are increasing public awareness and allocation of resources for enforcement, both of which can be incorporated into project design. Encouragingly, the Interstate Shellfish Sanitation Conference has recognized the significance of resolving these management needs and is supporting the development of a set of best management practices to ameliorate risks and maximize the environmental benefits of reef restoration in closed waters (http://www.issc.org/Committees/Shellfish_Restoration.aspx).

A key to changing the management paradigm is broader recognition of the benefits and ecological services provided by oyster reefs. A fundamental factor contributing to the decline of oyster reefs—and the relatively modest commitment thus far to invest in their restoration—is an overall lack of awareness of the ecology of oyster reefs and, by extension, the value of the services they provide. There are quantitative data describing the secondary productivity of oyster reefs that demonstrate convincingly their role as a habitat for fish and crustaceans (Peterson et al. 2003; Rodney & Paynter 2006). There is also a growing body of evidence that suggests they are valuable for protecting shorelines from erosion (Meyer et al.1997; Piazza et al. 2005), a service of increasing value in an era of accelerating sea-level rise (Church & White 2006). Translating this information for broader public awareness should be a priority for restoration practitioners and scientists alike. Indeed, projects should incorporate a strong outreach component to help bridge the gap in knowledge that appears to exist in management agencies that, all too often, separate habitat protection mandates from fisheries management objectives. Combining the objectives of oyster harvest with, for example, finfish production and shoreline protection could increase the impetus for funding restoration at larger scales. So it is important not only to conduct research and monitoring to describe these benefits in ways that scientists can appreciate, but to engage in broader scale outreach and marketing to ensure that the change in management paradigm is supported, if not driven, by the public. For example, a recent 2009 public opinion poll conducted in Louisiana and Texas by TNC revealed that there is strong support (greater than 80 percent) for making oyster reef restoration and protection a high priority for state management agencies, specifically for benefits such as shoreline protection, fish habitat, and water quality protection. With a 4.9 percent margin of error in the survey, 91 percent of Texas voters and 89 percent of Louisiana voters supported the use of oyster reef sanctuaries to ensure long-term protection of reefs for these benefits.

Fortunately, there are some near-term opportunities to better illuminate the role of oyster reefs in U.S. coastal waters and to document the services provided by restored reefs at larger scales. The Recovery Act provided $167 million in funding for NOAA to use for mid-scale projects around the United States. Several of these projects involve oyster reef restoration, including three that are led by TNC (http://www.nmfs.noaa.gov/habitat/restoration/restorationatlas/recovery_map.html, last visited Sept. 8, 2010). Two of these, in particular, are designed to protect miles of salt marsh shoreline in Alabama and Louisiana, where the effects of hurricanes, sea-level rise, and boat and ship wakes are accelerating the erosion of salt marshes (Figure). As such, these projects provide an opportunity to not only restore and increase the abundance of oyster reefs as a threatened habitat in the region, but are specifically designed to protect other adjacent wetlands, a regional management priority. Although these projects are still in the implementation phase, they will be monitored for ecological outcomes in the next few years (or longer, if additional funding can be secured) to help reveal the relationships between reef design (materials, architecture) and shoreline stability and accretion. Even in advance of these data, existing data is sufficiently robust to support the development of additional projects designed for such synergistic outcomes.

Summary and Conclusions

A valuable wetland type—oyster reefs—is in a global decline toward ecological extinction, and there is a profound need to encourage the restoration of oyster reefs to large-scale ecological relevance. Reversing this ongoing decline will require that quantitative restoration goals are established for entire estuaries and, by extension, for entire marine ecoregions around the United States. These goals, in turn, will need to be embraced by a wider array of agencies that have a role to play in managing shellfish ecosystems, including shellfish sanitation, i.e., public health agencies, habitat and water quality management agencies, and fisheries managers from local to federal levels.

Scaling restoration around the delivery of ecosystem services, particularly those with clear economic or social value, e.g., nitrogen reductions mandated by water quality improvement programs or reversing coastal marsh loss, may inspire restoration investment at scales that more closely match the restoration need. There is a growing body of literature on setting ecologically relevant goals (or, in the case of aquaculture, *upper limits*) for bivalve abundance. For example, Gibbs (2007) outlined sustainability performance indicators for shellfish aquaculture based on total water filtration amounts and relative removal of phytoplankton in estuaries. Such an approach could be adapted for restoration objectives where water quality improvements are an important ancillary management objective. Likewise, Newell et al. (2005) noted that managing oysters for their denitrification role in the Choptank River, Maryland, may provide greater economic benefits than the local oyster fishery. Scaling restoration for return of such a service may be appropriate where water quality issues are pervasive and land-side nutrient management approaches are insufficient to protect or restore water quality.

Other services may be similarly useful for setting restoration goals. Grabowski and Peterson (2007) estimated the value of fish production associated with restored and protected reefs in southeastern U.S. estuaries and noted the benefit of managing some reefs exclusively for this service. Scaling restoration around any one or a combination of these ecosystem service objectives may be a viable way of setting restoration goals at the scale of estuaries and, by extension, across entire ecoregions. In turn, goals that can be embraced and championed by a wide array of public management agencies, restoration practitioners, could set the stage for a national-scale initiative for improving an important ecosystem that is, at present, significantly degraded and at continued risk of degradation or extirpation throughout the United States. ■

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