AS WE SEE IT

Ecosystem services related to oyster restoration

Loren D. Coen1,*, Robert D. Brumbaugh2,**, David Bushek3, Ray Grizzle4, Mark W. Luckenbach5, Martin H. Posey6, Sean P. Powers7, S. Gregory Tolley8

1South Carolina Department of Natural Resources, Marine Resources Research Institute, 217 Fort Johnson Road, Charleston, South Carolina 29412, USA
2The Nature Conservancy, University of Rhode Island, Narragansett Bay Campus, South Ferry Road, Narragansett, Rhode Island 02882-1197, USA
3Haskin Shellfish Research Laboratory, Rutgers University, 6959 Miller Avenue, Port Norris, New Jersey 08349, USA
4Jackson Estuarine Laboratory, University of New Hampshire, 85 Adams Point Road, Durham, New Hampshire 03824, USA
5Virginia Institute of Marine Sciences, College of William and Mary, PO Box 350, Wachapreague, Virginia 23480, USA
6Department of Biology and Marine Biology, University of North Carolina, 601 S. College Road, Wilmington, North Carolina 28403, USA
7Department of Marine Sciences, University of South Alabama, and Dauphin Island Sea Lab, 101 Bienville Blvd, Dauphin Island, Alabama 36528, USA
8Florida Gulf Coast University, Coastal Watershed Institute, 10501 FGCU Blvd South, Fort Myers, Florida 33965, USA

ABSTRACT: The importance of restoring filter-feeders, such as the Eastern oyster *Crassostrea virginica*, to mitigate the effects of eutrophication (e.g. in Chesapeake Bay) is currently under debate. The argument that bivalve molluscs alone cannot control phytoplankton blooms and reduce hypoxia oversimplifies a more complex issue, namely that ecosystem engineering species make manifold contributions to ecosystem services. Although further discussion and research leading to a more complete understanding is required, oysters and other molluscs (e.g. mussels) in estuarine ecosystems provide services far beyond the mere top-down control of phytoplankton blooms, such as (1) seston filtration, (2) benthic–pelagic coupling, (3) creation of refugia from predation, (4) creation of feeding habitat for juveniles and adults of mobile species, and for sessile stages of species that attach to molluscan shells, and (5) provision of nesting habitat.

KEY WORDS: *Crassostrea virginica* · Restoration · Chesapeake Bay · Filter-feeders · Water quality · Ecosystem services

INTRODUCTION

Dramatic decreases in eastern oyster *Crassostrea virginica* populations have occurred in many estuaries along the USA Atlantic and Gulf coasts (e.g. Rothschil et al. 1994, Coen & Luckenbach 2000, French McCay et al. 2003, NRC 2004). Although the loss of this valuable fishery species is cause for concern, increasing recognition of the many ‘ecosystem services’ provided by healthy oyster reefs and by bivalve molluscs in general has led to a broader appeal for restoration of oyster reefs and other bivalve-dominated habitats (see ASMFC 2007). One of these ecosystem services, the grazing of phytoplankton populations, was the focus of a recent review (Pomeroy et al. 2006), which concluded that filtration by *C. virginica* in Chesapeake Bay, either at historical densities or at current restoration target densities, is insufficient for top-down control of the spring phytoplankton bloom and for reduction of...
summer hypoxia on a bay-wide scale. This central premise in Pomeroy et al. (2006) is the subject of a Comment by Newell et al. (2007, this volume) and is indirectly addressed by Cerco & Noel (2007) in a recent modeling paper.

Our aim here is to address arguments that advocates of oyster restoration have advanced to the effect that enhancing oyster populations ‘is an easy solution for controlling phytoplankton blooms’. We also seek to clarify the positions that researchers in this field have advanced as the rationale for oyster restoration, vis-à-vis localized impacts on water quality and the provision of habitat (i.e. ‘ecosystem services’). Our intent is to clarify our position as restoration scientists on the manifold ecosystem benefits of healthy population densities of filter-feeding bivalves, i.e. to demonstrate the attendant services of oyster restoration that are sometimes overlooked or misinterpreted (e.g. Lenihan & Peterson 1998, Coen et al. 1999, Coen & Luckenbach 2000, Grabowski & Peterson 2007).

ECOSYSTEM SERVICES PROVIDED BY OYSTERS

We take issue with 2 of the points highlighted recently by Pomeroy et al. (2006), who state that (1) native oyster restoration or (2) the introduction of an exotic (non-native) oyster species have been widely advocated in the scientific literature as solutions to eutrophication in Chesapeake Bay. In reviewing the goals and success criteria for native oyster reef restoration, Coen & Luckenbach (2000) and others (reviewed in ASMFC 2007, Coen et al. 2007, Grabowski & Peterson 2007) expressly noted that the system-level effects of oyster filtration have been poorly quantified, especially as they relate to any specific restoration project (but see Nelson et al. 2004, Newell 2004, Grizzle et al. 2006). The goals and success criteria emphasized by Coen & Luckenbach (2000)—and elaborated upon subsequently by Luckenbach et al. (2005), Coen et al. (2007) and S. P. Powers et al. (unpubl.)—have focused, among others, on the development of: (1) sustainable oyster populations; (2) enhanced species diversity; (3) trophic complexity; and (4) localized material fluxes to the benthos. Similarly, Grabowski & Peterson (2007) point out that although effects of oyster restoration on water quality in large water bodies are difficult to quantify, localized effects of oyster filtration (e.g. reduced turbidity) have been observed and, together with other ecosystem services (e.g. Meyer et al. 1997, Allen et al. 2003, French McCay et al. 2003, Peterson et al. 2003) provided by oyster reefs, constitute a strong case for restoration.

We are aware of only one peer-reviewed paper that expressly advocated the introduction of C. gigas to Chesapeake Bay for the purpose of improving water quality (Gottlieb & Schweighofer 1996). In advocating the consideration of introducing C. gigas to Chesapeake Bay for fisheries restoration, Mann et al. (1991) mentioned possible water quality benefits, but expressly stated that their commentary was directed towards recovery of a commercial fishery. Ruesink et al. (2005) were cited by Pomeroy et al. (2006) as suggesting that the Ocean Studies Board of the National Research Council recommended the introduction of an exotic species to Chesapeake Bay for controlling phytoplankton blooms; this is inaccurate (cf. NRC 2004). The potential benefits of filtration by oysters as stated in the popular press ignore the realities of the scale of restoration required to achieve such benefits, and we concur with Pomeroy et al. (2006) that using this position to support the introduction of an exotic oyster species such as Crassostrea ariakensis places the ecosystem at risk.

We welcome the effort to advance more realistic expectations for oyster restoration to policy makers, resource managers and the public, and to dampen the enthusiasm for the introduction of exotic oyster species, which is based on unfounded assumptions (see Newell et al. 2007, Pomeroy et al. 2007, this volume). Nevertheless, by attributing to oyster restoration a goal of system-wide water quality improvement and then proceeding to argue for the futility of that goal, while failing to mention the real and more tractable goals of oyster restoration, critics risk adversely affecting all other oyster restoration efforts in Chesapeake Bay and elsewhere. Specifically, Grabowski & Peterson (2007) have identified 7 categories of ecosystem services provided by oysters: (1) production of oysters; (2) water filtration and concentration of biodeposits (largely as they affect local water quality); (3) provision of habitat for epibenthic fishes (and other vertebrates and invertebrates—see Coen et al. 1999, ASMFC 2007); (4) sequestration of carbon; (5) augmentation of fishery resources in general, (6) stabilization of benthic or intertidal habitat (e.g. marsh); and (7) increase of landscape diversity (see also reviews by Coen et al. 1999, Coen & Luckenbach 2000, ASMFC 2007).

In the following section we highlight categories 2, 3, 5, 6 & 7, as summarized in Grabowski & Peterson (2007).

DISTURBANCE AND RESTORATION

The dramatic decline in oyster abundances in Chesapeake Bay and other estuaries along the Gulf and Atlantic coasts of the USA over the 20th century has led to concomitant reductions in hard substrate habitat in ecosystems dominated by sedimentary habitats (e.g. Rothschild et al. 1994, NRC 2004). Studies comparing invertebrate faunal abundance and diversity between restored and non-restored oyster reefs (e.g. Luckenbach et al. 2005, Rodney & Paynter 2006, L. D. Coen et al. unpubl.), between oyster reefs or reef mimics, and soft bottom habitats (e.g. Posey et al. 1999, Tolley & Volety 2005), and among oyster reefs of varying complexity (e.g. Coen & Luckenbach 2000, Luckenbach et al. 2005), consistently find higher abundances, biomass and species richness on the structurally more complex reef habitats. Densities of decapods and meiofauna on oyster reefs are similar to those in other structured habitats (e.g. Glancy et al. 2003, Hosack et al. 2006).

Abundance, biomass and species richness of finfish species are higher at oyster reefs than in unstructured estuarine habitats (reviewed in Coen et al. 1999, ASMFC 2007). Some of these species (e.g. gobies, blennies and toadfish) are obligate reef residents throughout their post-larval life, while other species are either facultative residents or transient associates (discussed in Breitburg 1999, Coen et al. 1999, ASMFC 2007). Though few studies have yet sought to quantify secondary production attributable to oyster reefs, Peterson et al. (2003) estimated that restored oyster reef habitat may yield 0.26 g m⁻² yr⁻¹ of fish and large decapod crustacean biomass in southeastern USA estuaries.

Habitat disturbance and/or loss are ranked worldwide as the principal threat to biodiversity, and are also responsible in part in declines in fisheries (Fogarty & Murawski 1998, Lenihan & Peterson 1998, Beck et al. 2001, NRC 2007). In the southeastern USA (southern North Carolina, South Carolina, Georgia, parts of Florida) and in Virginia and the Gulf of Mexico, oysters are predominantly intertidal, forming a protective breakwater that retards shoreline (primarily marsh) erosion (e.g. Meyer et al. 1997, Grizzle et al. 2002, Coen & Bolton-Warberg 2005, ASMFC 2007, NRC 2007). In addition to natural erosion, coastal development and boat traffic have accelerated disturbance of oysters and of the fringing saltmarsh, e.g. by increasing wave effects (Grizzle et al. 2002, Coen & Bolton-Warberg 2005, Piazza et al. 2005, Wall et al. 2005, NRC 2007, L. D. Coen et al. unpubl, L. J. Walters et al. unpubl). Oyster restoration can slow down disturbance effects on marshes and fringing oysters, and constitutes an alternative to the hard bulk-heading of shorelines (e.g. Meyer et al. 1997, Coen & Bolton-Warberg 2005, NRC 2007).

There is a need for rigorous establishment and clear articulation of the goals of oyster restoration, especially in the context of large public expenditures, as well as deliberations surrounding the introduction of an exotic species. Our central tenet is that ecological goals of oyster restoration are broader than the top-down control of phytoplankton production on a system-wide basis. The complex interactions between filter-feeders and their environment are not completely understood, but evidence is accumulating that native and introduced bivalves, including those on aquaculture farms, have significant impacts on seston and overlying phytoplankton communities on both local and larger scales (reviewed in Dame 1996, French McCay et al. 2003, NRC 2004, Cerco & Noel 2007, Grant et al. 2007). For example, Mercenaria mercenaria aquaculture in lower Chesapeake Bay appears to be enhancing seagrass abundance (see Grizzle et al. 2006). In Florida, seagrass beds often harbor dense American horse mussel Modiolus americanus populations (up to 2000 ind. m⁻²; Valentine & Heck 1993), and the activities of these and other filter-feeders enhance seagrass production further via a positive feedback loop (e.g. Reusch et al. 1994, Peterson & Heck 1999, 2001a,b, C. C. Wall et al. unpubl.). In their recent modeling paper, Cerco & Noel (2007) assess the impact of a 10% increase in oyster biomass in Chesapeake Bay, on 3 spatial scales, and suggest that the enhancement of submerged aquatic vegetation would be the greatest direct beneficiary of oyster restoration through water clarity.

CONCLUSIONS

Although it is difficult to determine empirically the system-wide effects of historical abundances of oysters and of restoration targets (Pomeroy et al. 2006, Newell et al. 2007), localized influence of oyster reefs on water quality has been verified. In situ measurements have demonstrated that oysters reduce the quantity of suspended solids and phytoplankton (chlorophyll a or other proxies) (e.g. Nelson et al. 2004, Grizzle et al. 2006). At the current oyster abundances in Chesapeake Bay, these effects are limited, but significantly enhanced abundances of filter-feeders can significantly improve water quality in shallow, mesohaline regions of estuaries (e.g. Newell & Koch 2004, Cerco & Noel 2007).

Acknowledgements. We thank J. Kraueter, R. Dame, J. Levin- ton, K. Walters, R. Newell, J. Grabowski, B. Peterson, P. Wilber, and F. Holland for their comments and critiques. A majority of the authors were part of the Oyster Restoration Metrics Working Group supported by Grants from NOAA’s South Carolina Sea Grant Consortium (NOAA# NA16RG-
2250) and the South Carolina Department of Natural Resources through its Marine Resources Research Institute. This is Contribution #616 from the Marine Resources Research Institute, South Carolina Department of Natural Resources, Contribution #451 from the Jackson Estuarine Laboratory, University of New Hampshire, and Contribution #2833 from the Virginia Institute of Marine Science.

LITERATURE CITED


Newell RIE (1988) Ecological changes in Chesapeake Bay: are they the result of overharvesting the eastern oyster (Crassostrea virginica)? In: Lynch MP, Krome EC (eds) Understanding the estuary: Advances in Chesapeake Bay research. Chesapeake Research Consortium Publ 129, Gloucester Point, VA, p 536–546


Peterson BJ, Heck KL Jr (2001a) Positive interactions between suspension-feeding bivalves and seagrass faculta-


---

**Editorial responsibility: Howard Browman [Associate Editor-in-Chief], Storebø, Norway**

*Submitted: April 19, 2007; Accepted: May 18, 2007*  
*Proofs received from author(s): June 1, 2007*