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AN ECOSYSTEM SERVICES APPROACH

A PRACTITIONERS GUIDE TO THE

Design & Monitoring of Shellfish Restoration Projects

The mission of The Nature Conservancy is to preserve the plants, animals and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive.

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I. Preface

Bivalve shellfish restoration projects are becoming increasingly common in the United States, spurred by increased public awareness of their important ecological role in coastal waters and increases in funding (primarily federal) available for such efforts. Community groups, school classes and others interested in promoting healthier coastal ecosystems are joining forces with government agencies at the local, state and federal level to help restore these important components of coastal ecosystems. This increased interest in restoration is due, in part, to the dramatic declines in shellfish fisheries that were once the mainstay of many coastal communities. This is also likely due to greater public awareness of the imperiled state of coastal environments in general, and a desire to restore the ecosystems such as oyster reefs, marshes, seagrass beds and mangroves that contribute to an overall healthier environment. The elements of shellfish restoration may appear complex, especially for those who are unfamiliar with bivalve ecology or the basic tenets of restoration science. As a result, it may be difficult to know where to begin.

This guide was written to help restoration practitioners design and monitor shellfish restoration projects that restore not only the populations of target shellfish species – primarily clams, oysters, scallops – but also the 'ecosystem services' associated with healthy populations of these organisms. As a primer for conservationists, resource managers and others interested in understanding basic approaches to the design and implementation of shellfish restoration projects, this publication provides advice on:

1. **Making the case for shellfish restoration**
2. **Identifying candidate species and an appropriate restoration strategy (or strategies)**
3. **Choosing sites for restoration projects**
4. **Monitoring project outcomes**
5. **Creating effective partnerships for restoration projects**

II. Introduction: The case for shellfish restoration

A Lost Resource

Bivalve shellfish have historically been a prominent component of benthic, or bottom dwelling, communities of temperate and subtropical estuaries and coastal baysBivalves also have been and continue to be an important food source for people throughout the world, serving as both as a delicacy and a staple. In coastal communities throughout the U.S., shellfish are cultural icons, reflecting traditions and a way of life dating back generations. It is not surprising therefore that until very recently resource management agencies have focused almost exclusively on maximizing short-term returns from commercial and recreational bivalve harvest.

Once considered nearly inexhaustible, many shellfish populations around the world have declined precipitously – some to commercial extinction - over the past two hundred years. These declines are due in large part to over-exploitation as well as from the related overall decline in the condition of estuaries (Gross and Smyth 1946; Cook et al 2000; Jackson et al 2001; Edgar and Samson 2004; Kirby 2004). In recent decades the translocation of shellfish parasites and diseases between coastal areas has contributed to further losses and has exacerbated the effect of habitat loss (Kennedy et at 1996).

While bivalve fisheries in many places have produced substantial landings, traditional management efforts for shellfish have generally failed to sustain shellfish populations or the fisheries that depended on them. Few bivalve fisheries, if any, have been managed with any evidence of long-term sustainability, both in the U.S. and in many other parts of the world. Oysters and mussels in particular have posed a unique challenge to fishery managers since fishing activities for these species, unlike most fish and other mobile organisms, tends to simultaneously remove their habitat. Various approaches for countering fishery declines have been implemented, ranging from hatchery based put-and-take fisheries to introductions of non-native species, often with mixed results. By managing bivalves and their habitats almost exclusively for recreational and commercial fishing, many facets of their ecology that contribute to maintaining the overall condition of our coastal bays and estuaries have been ignored.

Engineers at Work

With the decline of shellfish populations we have lost more than the fisheries and economic activity associated with fishing. A growing body of research in recent decades has illuminated the profoundly important ecological roles that shellfish play in coastal ecosystems. These roles include filtering water as bivalves feed on suspended algae, providing structured habitat for other species, and protecting shorelines from erosion by stabilizing sediments and dampening waves. In fact, many bivalve shellfish have been labeled 'ecosystem engineers' (Jones et al 1994; Lenihan 1999) in recognition of the multiple roles they play in shaping the environments in which they live. Restoring shellfish populations to our coastal waters, therefore, represents a powerful way to restore the integrity and resilience of these ecosystems.

The Water Filter

Shellfish are suspension-feeders that strain microscopic algae (*phytoplankton*) that grow suspended in surrounding waters. In some coastal systems shellfish, through their feeding activity and resultant deposition of organic material onto the bottom sediments, were abundant enough to influence or control the overall abundance of phytoplankton growing in the overlying waters. This control was accomplished both by direct removal of suspended material and by controlling the rate that nutrients were exchanged between the sediments and overlying waters (Officer et al 1982; Dame 1996; Newell 2004). For example, it is widely touted that in the late 19th century oysters were so abundant in the Chesapeake Bay that they likely filtered a volume of water equivalent to the entire volume of the Bay in less than a week (Newell 1988). This feeding activity contributed to greater water clarity and allowed seagrasses to thrive in more areas of the estuary than is observed today (Newell and Koch 2004).

Similar ecological impacts have been attributed to other species of bivalves as well. Hard clams in Long Island's Great South Bay were likely abundant enough, until about two decades ago, to prevent outbreaks "brown tides" caused by planktonic algae that cloud the water and prevent light from reaching seagrasses growing in the bay. As these algae die, sink to the bottom and decay, they also rob the Bay of oxygen (Kassner 1993; Cerrato et al 2004). The uptake of nutrients and localized impacts on water quality documented for blue mussels, Mytilus edulis, using flume experiments (Asmus and Asmus 1991) and field observations in European estuaries suggest that robust populations of mussels are capable of consuming a considerable fraction of the phytoplankton from overlying waters (Haamer and Rodhe 2000).

Ecosystem modeling and mesocosm studies have indicated that restoring shellfish populations to even a modest fraction of their historic abundance could improve water quality and aid in the recovery of seagrasses (Newell and Koch 2004; Ulanowicz and Tuttle 1992). Field studies have also revealed positive feedback mechanisms from shellfish populations that promote greater seagrass productivity (Peterson and Heck 1999).

The Habitat Provider

In addition to their impacts as filter feeders, some species of bivalve shellfish such as oysters and mussels form reefs or complex structures that provide refuge or hard substrate for other species of marine plants and animals to colonize. For example, the eastern oyster Crassostrea virginica, forms three-dimensional reefs as generations of oysters settle and grow attached to one another (Zimmerman et al 1989; Hargis and Haven 1999; Steimle and Zetlin 2000). Reefs can occur subtidally, often associated with edges of channels, as well as in intertidal habitats, keeping pace with sea-level rise (DeAlteris 1988; McCormick-Ray 1998 and 2005; Hargis and Haven 1999). These reefs represent a temperate analog to coral reefs that occur in more tropical environments. Both kinds of reefs are "biogenic", being formed by the accumulation of colonial animals, and both provide complex physical structure and surface area used by scores of other species as a temporary or permanent habitat. A single square meter of oyster reef may provide 50 square meters of surface area in its cracks, crevices, and convolutions, providing attachment points and shelter for an array of plants and animals (Bahr and Lanier 1981). Given the variety of species and complex interactions of species associated with oyster reefs, they have been suggested as "essential fish habitat," which is an important distinction for fisheries management in the U.S. (Coen et al. 1999). Unfortunately, many of the reefs that were once so prevalent have been mined away through fishing and dredging activities, and their remnant 'footprints' have been silted over in the past century (Rothschild et al. 1994, Hargis and Haven 1999).

The Shoreline Protector

In some regions, intertidal oyster reefs and, likely, mussel beds serve as natural breakwaters that can stabilize shorelines and reduce the amount of suspended sediment in the adjacent waters. This reduction in suspended sediment improves water clarity and protects shellfish, seagrasses and other species. Shellfish restoration, therefore, offers a way to recapture this important ecosystem service (Meyer et al 1997) in some locations.

Given the increased understanding of the various roles that shellfish play in nearshore ecosystems, there is increasing interest in re-establishing robust and self-sustaining native shellfish populations as a component of coastal ecosystems. Indeed, the restoration of shellfish is increasingly invoked as a key strategy for rehabilitating and conserving marine and estuarine systems because of these anticipated ecosystem services. However, surprisingly little effort has been made to document the degree to which these ecosystem services are provided through restoration activities in actual practice.

As more restoration efforts are initiated, it is important to document and publicize the broader ecological and economic returns from restoration activities to garner the long term support necessary for large scale restoration efforts.

To balance the many services provided by shellfish and the objectives of multiple stakeholders and agencies, we must incorporate into our restoration and management goals the many ecological linkages between shellfish and the surrounding sediments, waters, and other species within coastal systems (Coen and Luckenbach 2000; Peterson et al 2003). Despite an incomplete knowledge of these linkages it is reasonable to conclude that the ultimate goals of restoration – whether for economic or ecological gain – depend to some degree on increasing the abundance and overall biomass of a targeted shellfish population (Coen and Luckenbach 2000; French McCay et al 2003; Newell 2004).

Of course, not all shellfish provide the same kinds or degree of ecosystem services and there are many ways that shellfish biomass can be increased without returning all of the desired ecosystem services or even cause additional environmental stress. Intensive shellfish aquaculture, for example, may provide filtration benefits but may not provide much in the way of habitat (Newell 2004) and the extensive use of nets, docks, cages, and mechanical harvesters can create significant environmental stress. Non-native species that are brought in to new environments may indeed exert a top-down control on phytoplankton biomass (Cloern 1982) but can also compete with native species, negatively affect food webs (Kimmerer et al 1994; Strayer et al 1999), and bring in new diseases and other undesirable species (NRC 2004).

III. How shellfish work

To restore any species, it is important to understand its life cycle, and how various life stages interact with and are influenced by their surrounding environment. Applying this information to shellfish restoration projects will aide practitioners in selecting appropriate sites, understanding and abating threats and measuring progress.

Basic Life Cycle

Most bivalve shellfish have separate sexes (i.e., they are dioecious) and many change sex during their lifetime (i.e., they are hermaphroditic). For example, the eastern oyster begins life as a male and becomes female as it ages and grows larger (see Kennedy 1996 for thorough review). The typical bivalve shellfish lifecycle involves a planktonic (free-floating) larval stage, and a sedentary benthic (bottom dwelling) juvenile and adult stage (Figure 1).

Eggs and sperm are released into overlying waters where fertilization occurs. The eggs hatch and rather quickly develop into a larval stage called a 'veliger' that spends days (scallops) to weeks (oysters) drifting with currents, feeding and growing while suspended in the water. The larval stage bears little resemblance to the adult stages, and is well adapted for this planktonic phase in their life cycle. While their swimming ability is generally limited, they are equipped with tiny hairs called 'setae' that they use to control their depth in the water column. Beyond a basic ability to control their depth, they are largely at the mercy of wind and tidal driven currents that transport them horizontally and this larval stage is essentially the only period during the bivalve life cycle that allows any significant horizontal movement from one location to another. Juvenile and adult clams can burrow into sediments with their muscular foot, scallops can 'swim' by clapping their valves together, and mussels can even jockey for position within a mussel bed by manipulating the tiny byssal threads used for attachment to surfaces. However, the distances traveled are much shorter by comparison than the distances traveled as larvae. The actual distance that shellfish larvae travel depends on many factors, including behavior that affects their placement within currents moving in various directions, and the overall pattern and strength of local currents and tides.

> ***Significance for Restoration Project Design:*** *a general knowledge of local tidal current patterns can be useful for predicting where larvae might be transported to—or from—and in turn can help with selection of a restoration* site.

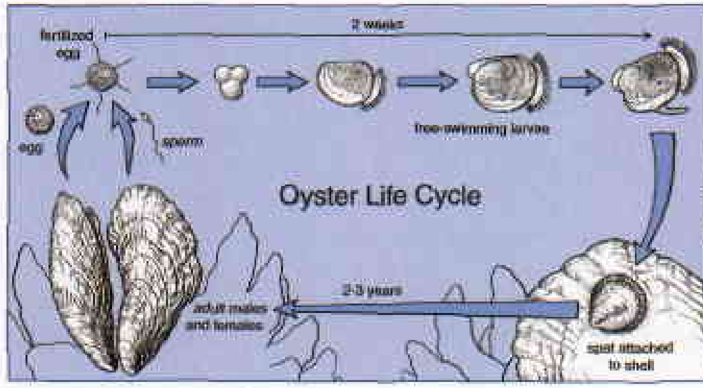

FIGURE 1: Basic lifecycle diagram for the eastern oyster, *Crassostrea virginica*. Image reprinted courtesy of John Norton and MD Sea Grant. http://www.mdsg.umd.edu/oysters/garden/seed.html

Settlement and Substrate Selection

When shellfish larvae have grown large enough (days to weeks) they begin the benthic portion of the life cycle and settle to the bottom. At this point, they select an appropriate habitat in response to both chemical and physical cues from the environment. Cues can include substances exuded by adult shellfish of the same species or vegetation associated with their preferred habitat, and physical characteristics such as surface roughness (Rodriguez et al 1993). Upon settlement the larvae undergo metamorphosis and transform into juvenile stages that more closely resemble the adults. Since most bivalve species have only a limited ability, if any, to move after settlement, it is critical that larvae select the habitat that provides the best chance of growth and survival to adult stages.

> ***Significance for Restoration Project Design:*** *It is important to know what kind of settlement substrate – or bottom material – is preferred by the species under restoration. Providing the correct kind of material can help to attract and protect young shellfish that settle and accumulate there. Ideally, the substrate material can also serve as a refuge that protects newly settled shellfish from predators.*

* Exceptions to Every Rule:

Given the marvelous diversity of bivalve shellfish, it is not surprising that there are several variations on this generalized life cycle. Some species, such as the Olympia oyster, *Ostrea choncaphila*, fertilize and brood their eggs in the female oyster's mantle cavity, rather than broadcasting them directly into the overlying waters. The larvae of some species of freshwater mussels attach to the gills of fish and are then transported upstream as 'hitchhikers' rather than drifting with currents as plankton. Scallops use tiny hook-like hairs to attach to settle first onto underwater grasses and seaweeds prior to settling directly on the bottom.

IV. Getting to the bottom of it all: Restoration by design

Perhaps the most fundamental step for successful shellfish restoration is to carefully consider and define restoration goals for a specific project (Coen and Luckenbach 2000; Shumway and Kraeuter 2003; Luckenbach et al 2005). Given the commercial and social significance of many bivalve species, fishery production has been for decades the primary and often sole motivating factor in shellfish enhancement projects. The literature describing techniques for enhancing commercial and recreational production of shellfish is extensive (MacKenzie 1989; Kennedy et al 1996; Arnol et al 2002) and has typically focused on increasing short-term fisheries production. In contrast, until very recently few restoration initiatives have defined as their primary goal the rebuilding of natural capital – reefs and robust spawning populations capable of sustaining both fisheries and the health of coastal ecosystems (Breitburg et al 2000). Given the multifaceted ecological roles played by bivalves in coastal systems, ecosystem restoration is becoming a primary motivating force for at least small scale restoration projects (Brumbaugh et al 2000a & b; Hadley and Coen 2002). With these issues in mind, we offer in this guide a suite of 'Better Management Practices" to help practitioners design and monitor shellfish restoration projects with ecosystem services in mind, i.e., to document and enhance the services provided by shellfish ecosystems.

Systematic identification, design and monitoring of shellfish restoration using The Nature Conservancy's "5-S Approach"

The need for systematic approaches within a given region for the identification, design and monitoring of conservation, management, and restoration projects is widely recognized (e.g., Groves 2003; Groves et al. 2002; Margules & Pressey 2000; Pressey et al 1993; U.S. Commission on Ocean Policy 2004). The Nature Conservancy uses such an approach, called 'Conservation by Design' (TNC 2000), to identify biodiversity conservation objectives at regional (Ecoregional) scales. As a systematic approach to defining restoration needs and identifying strategies for shellfish restoration projects, Conservation by Design has four discrete steps: (1) identifying priorities, i.e., compiling data and information to identify representative sites that account for the full range of biodiversity across regional ecosystems (Beck and Odaya 2001, Beck 2003), (2) developing site and multi-site strategies for preserving or restoring those sites to fullest functionality, (3) implementation of those strategies, (4) measuring the effect of implementation. This guide assumes that shellfish restoration is a conservation strategy that has been identified through some form of regional-scale assessment, and the balance of our discussion will focus on the restoration strategies that are applicable at individual sites or multiple sites within an ecoregion.

Once a biodiversity conservation approach – e.g., shellfish restoration – has been identified through an Ecoregional Assessment, the specific actions to take at the site and multi-site scale must be defined, implemented and monitored for their outcomes. To accomplish these tasks, TNC employs a "5-S" methodology to identify the System, Stresses and Sources of stress to the system, Strategies for abating stresses, and Success measures to determine whether a conservation or restoration objective has been achieved. For the purposes of this guide the System is the bivalve shellfish ecosystem – more specifically oysters, clams, scallops and mussels and the other associated species. It is recognized that these are connected to other types of Systems (e.g., marshes and seagrass meadows) within estuaries or coastal lagoons.

The second and third "S" when embarking on a shellfish restoration project is to identify the Stress and Sources of Stress affecting the abundance of shellfish at a given site. Here we combine these somewhat within three broad categories – fisheries mortality, habitat limitation and recruitment limitation. At many sites, all three types of stress are present. Later we will discuss potential Strategies and appropriate Success measures (or indicators) to track the outcome of restoration activities.

Sources of Stress: Fishing mortality, habitat loss, recruitment limitation

The Sources of stress affecting shellfish populations can include fishing, channel dredging and destruction of habitat, and degraded water quality (i.e., anoxia, sedimentation, harmful algal blooms). Depending on the source of stress it is helpful to view restoration activities within a 'hierarchy of intervention actions' that represent the range of potential strategies to be considered when designing a project (Shumway and Kraueter 2003).

Stress Category 1: Fisheries Mortality encompasses a group of stresses that can depress and hold population biomass below levels necessary to return economic or ecological benefits. There are many stresses within this category such as excessive take

Box 1: Considerations for Site Selection

- Identify areas where reefs or target shellfish populations historically existed. Data on historic distributions can be obtained from published accounts, fishing records, and navigation charts or other bottom surveys. It is predicted that these sites are the most likely to be able to further support shellfish.
- Evaluate bottom conditions to determine if the bottom will support addition of shell or other materials used for habitat enhancement. It may be necessary to restore the bottom for example by removing excess sediments or other debris such as wood waste from logging operations.
- Determine whether this area is a "sink" for larvae being transported in from other areas. Populations have a higher chance of recovering most rapidly in areas that are "sinks" for larvae (Crowder et al 2000). Deployment of spat collectors – devices used to attract larvae to settle – or sampling the bottom within areas that are known for supporting shellfish can help to gauge the level of 'recruitment' likely for a given restoration site.
- Assess the current velocity. Shellfish growth is generally higher where currents are greater, delivering food and oxygenated water and carrying away waste by-products.
- Determine what threats exist in areas formerly populated by shellfish. *Examples include sources of sedimentation* (e.g., erosive banks, poorly buffered shorelines), stormwater or other point sources of pollution.
- Determine whether the overlying waters are well oxygenated. Small, poorly flushed coves may become sub-oxic or anoxic, particularly in the summer when the water is warmest. This can affect shellfish directly (e.g., reduce recruitment and survival, Breitburg 1992) and indirectly (e.g., fish and crabs escaping areas of low oxygen may converge on reefs or nearby shellfish populations and alter community structure through predation or competition, Lenihan et al 2001).
- Consider locating restoration projects within small, replicable sub-estuaries. Such areas are sometimes referred to as "trap estuaries" (Pritchard 1953), denoting areas with a high degree of retention of water circulation, which can help promote recruitment of shellfish larvae and other colonizing species. These small systems can serve as testing grounds for measuring potential ecosystem service impacts to water clarity and quality.
- Consider placement of restoration projects in areas where illegal impacts can be deterred. For example projects can be placed where shellfish harvest is banned for human health reasons. Such areas represent de-facto sanctuaries. Other *areas may lend themselves to enforcement such* as areas where there have been well established lease or ownership rights or areas near bridges, research stations and nature preserves where there are potential partners to monitor the project. These are also likely to be urban areas where community support and involvement in restoration for strictly environmental reasons may be garnered (Brumbaugh 2000b).
- Consider using submerged lands that are privately leased or owned to maintain investments in restoration on project sites. Submerged lands are available for lease and ownership in all coastal states (Marsh et al 2002; Beck et al 2005). Many of these lands have traditionally been used to grant exclusive access for shellfishing. They can however also be used to protect investments in restoration and allow groups greater stewardship opportunities for the natural resources that they have enhanced at sites.

Box 2: Addressing Genetic Consequences of Stock Enhancement Programs

Because there are potential genetic consequences when using stock enhancement as a strategy to restore shellfish populations, there are several fundamental guidelines for reducing these potential risks (Allen and Hilbish 2000):

- Transplant wild broodstock animals collected from local sources. Shellfish that are collected in the immediate vicinity or purchased from fishermen working nearby can be transplanted at higher densities to improve the likelihood of reproductive (fertilization) success. This is a way to tap into the local gene pool and minimizes the chances of "genetic bottlenecking".

- Use locally collected broodstock for spawning in hatchery-based stock enhancement It may be necessary to collect wild shellfish for artificial propagation if little natural settlement is occurring in local waters, and when importing large numbers of shellfish from another location would produce undesirable results (e.g., would diminish the ecosystem services or fishery stock in a given location). Collecting broodstock from an area close to your project can reduce the loss of local genetic characteristics (Peter-Contesse and Peabody 2005).

- Use pair-wise crossings of animals in the hatchery to maximize 'effective population size' (Ne) and to minimize "genetic bottlenecking". Maximizing the number of animals spawned in the hatchery (i.e., getting close to Ne) and using pair-wise crosses can maximize the chances of maintaining genetic diversity in a broodstock enhancement program.

- Characterize the genetics of broodstock (for wild and hatchery-origin stocks) to aid in the tracking of progeny in the field. This is an expensive and time consuming process (both the genetic characterization and the identification of offspring in field samples), but allows for 'proof of restoration impact' and also for monitoring of genetic changes over time. Efforts to use genetic markers to track the offspring of oysters transplanted to selected Chesapeake Bay restoration reefs are underway and are intended to provide a quantitative basis for improving future restoration projects (Mann 2004; Millbury et al 2004).

and destructive fishing practices that impact habitat directly, or removal of species as bycatch. In some instances, restoration may be as "simple" as reducing fishing pressure or modifying other activities such as dredging and filling (see Habitat Limitation below) that damages or removes shellfish (Abadie and Poirrier 2000; Maguire et al. 2002). The reduction of fishing mortality can promote an increase in the numbers of adult shellfish that help to bolster the spawning population over time, assuming that habitat (e.g., bottom characteristics and water quality) remains abundant and in good condition to allow young shellfish to accumulate and grow. As an example of this approach, Jordan and Coakley (2004) have postulated based on results of a population dynamics modeling exercise that eliminating fishing pressure on the Chesapeake Bay's remaining oyster populations would allow for a 10-fold expansion of the population in less than ten years.

Of course, the political will necessary to amend fishing regulations can be challenging to build. It should also be noted that reductions in fishing effort need not involve absolute closures or prohibitions of fishing activity. Rather, reductions may be achievable through some combination of controls on overall harvest numbers, size limits, locations, or timing of harvest depending on the overall status of the population. Fundamentally, restoration efforts that are intended to enhance the total value of ecological services must first and foremost reduce stresses that are affecting the population and not just consider how to maximize landings.

Stress Category 2: Habitat limitation is a stress that occurs when there is no longer a sufficient amount of habitat to support all life history stages of the population and, as a result, the population cannot be sustained over long periods of time. Relevant subcategories of stress include habitat modification, degradation, and loss. For example, physical degradation of three-dimensional oyster reefs throughout much of the eastern oyster's range is considered a limiting factor for populations throughout its range. Since the 1800s, the three-dimensional reef habitat has been destroyed leaving only rubble 'footprints' of oyster reefs (Rothschild et al 1994; Hargis and Havens 1999). The reduction of vertical relief has relegated oysters to living lower in the water column where dissolved oxygen levels cause stress that increases their susceptibility to diseases (Lenihan and Peterson 1998). As another example, the global decline of seagrasses as a result of nutrient over-enrichment and disease (Orth and Moore 1983, Green and Short 2003, Short and Wyllie-Echeverria 1996, Duarte 2002) likely limits populations of shellfish species such as hard clams and scallops that recruit first as juveniles to these beds of vegetation (Pohle et al 1991; Heck and Crowder 1991; Irlandi et al 1995, 1999).

To abate the stress of habitat limitation, therefore, it may be necessary to develop and implement strategies that involve direct manipulation of the habitat available to juvenile or adult shellfish. Habitat manipulation, such as placement of shells on the bottom or restoration of seagrass beds, represents a much higher degree of intervention than just regulating harvest alone and care should be taken to select the appropriate sites for habitat enhancement (See Box 1 for some considerations).