# Mitigating the Effects of Excess Nutrients in Coastal Waters through Bivalve Aquaculture and Harvesting

Final Project Report
submitted to
The Cooperative Institute for Coastal and Estuarine Environmental Technology
(CICEET)

Hauke Kite-Powell, Porter Hoagland, Di Jin
Marine Policy Center, Woods Hole Oceanographic Institution

Dror Angel, Heidi Clark
Consultants

Kevin Kroeger
U.S. Geological Survey

October 2006

## Executive Summary

Nutrient loading is one of the most important agents of adverse ecological change in coastal ecosystems. Most efforts to address nutrient overenrichment problems have focused on source reduction of nutrient inputs. This tends to be difficult and expensive, as the main nutrient sources – septic systems, atmospheric deposition, and fertilizers – cannot be reduced without significant technological or behavioral change. In certain cases, it may be equally effective and less costly to mitigate the effects of nutrients after they have entered the water. One such approach involves removing nutrients and improving water quality in estuaries by using bivalve molluscs as natural biofilters.

Evidence from this project and from prior research suggests that the propagation and harvesting of bivalve molluscs can be a viable method for removing nitrogen from estuaries and improving coastal water quality. Shellfish sequester nitrogen in body tissues, and shellfish harvesting can remove a substantial amount of nitrogen directly from coastal waters. In addition, empirical and theoretical work indicates that filter feeders (including bivalve molluscs) can act as a control on algae by grazing off phytoplankton at high rates, thereby reducing the likelihood of algal blooms under increased nutrient enrichment. Finally, laboratory and field studies of benthic filter feeders have shown that shellfish greatly influence nitrogen transformations in aquatic systems. Filter-feeding shellfish produce biodeposits, the presence of which in sediments can increase the rate of denitrification -- the conversion of biologically active nitrogen ($NO_3^-$) into elemental nitrogen ($N_2$) that diffuses to the atmosphere.

In 2004 and 2005, we conducted a field experiment to investigate the nutrient-removing effects of shellfish aquaculture and harvesting in Waquoit Bay on Cape Cod. The Bay suffers from high nutrient levels, periodic hypoxia, declining seagrass beds, and

overgrowth of macroalgae; and removing nitrogen from the water column would likely help alleviate this situation and assist the recovery of some of the damaged habitats. Waquoit Bay as a whole presently receives more than 23,000 kg of nitrogen per year from wastewater (about 50%), atmospheric deposition (30%), fertilizer runoff, and surface flows from upgradient ponds. This is more than twice the rate of nitrogen input the Bay received in the 1930s. The increase has been correlated with development and population growth, and is the primary cause of algal blooms that have become a regular feature of Waquoit Bay.

This project examined the nutrient-removal characteristics of juvenile oysters (*Crassostrea virginica*) and quahogs (hard clams, *Mercenaria mercenaria*). Our field work shows that both oysters and clams can be grown successfully in the waters of Waquoit Bay. Clams are native to the sediments of the Bay; oysters require a substrate, such as plastic growout trays, since the seafloor in the Bay is devoid of hard structures suitable for oyster settlement. We found that oysters grow from seed to market size in the Bay in three years. Based on our growout experiments, a 1 $m^2$ tray containing 500 oysters will, over the course of three years, remove an average of 0.1 kg N/yr through sequestration and up to 0.1 kg N/yr through increased denitrification in sediments underneath the tray.

Shellfish aquaculture is a profitable commercial activity, and as such it is has a lower direct cost than upstream nitrogen removal alternatives. However, oyster farming imposes two types of indirect costs that must be taken into consideration: (1) it requires exclusive allocation of space in the Bay to the aquaculture activity, reducing the value of the Bay for recreational purposes; and (2) because the farming gear (trays, etc.) is at least partially exposed at lower tides, it also imposes aesthetic costs on residents and users of the Bay. From society's perspective, these costs are partially offset by the excess value generated by the commercial shellfish farming activity.

The net benefit (NB) of shellfish aquaculture is therefore a function of the area within the Bay that is devoted to shellfish aquaculture (SC), and is given by:

$$NB(SC) = NR + PS - AC - RC$$

where NR is the value of nitrogen removal due to aquaculture, PS is the economic benefit of the farming activity (producer surplus), AC is the aesthetic cost imposed by the presence of shellfish farming gear in the Bay, and RC is the cost associated with reduced recreational use of the Bay.

In determining the optimal mix of measures to achieve a specified reduction in nitrogen loading, economics suggest that managers should make use of the least-cost measures first. In this case, then, the question is at what scale ($SC_{max}$) of shellfish aquaculture in the Bay the net benefit of this activity becomes negative. The optimal approach to nitrogen reduction will rely on shellfish aquaculture up to $SC_{max}$, if necessary, and engage other more expensive alternatives only as necessary beyond that point.

To illustrate this approach, we consider as an example the region of Waquoit Bay known as "Head of the Bay," where our growout experiments took place. The Head of the Bay is some 57 ha in size and presently receives about 500 kg of nitrogen/year, or 275 kg/year above the levels estimated to have entered this part of the Bay during the 1930s.

As a proxy for the benefit of nitrogen removal through shellfish aquaculture, we use the avoided cost of upstream removal by other means (e.g. improved septic systems, an estimated cost of $100/house/year). We estimate producer surplus at 20% of sales for the shellfish farmer. Aesthetic costs are modeled as an increasing (square) function of the fraction of the Bay devoted to shellfish farming, and are based on the premium in real estate value associated with waterfront property on the Bay. Recreational costs are a linear function of area devoted to shellfish farming, and are based on annual user days and value per user day for the Bay.

The results are illustrated in Figure 1 below. Benefits increase linearly with area devoted to shellfish farming and flatten out when the nitrogen removal target (in this case, the net increase in loading since the 1930s, or about 275 kg N/yr) is reached. Indirect costs rise with area devoted to shellfish farming. Shellfish farming makes economic sense, from a social planner's perspective, up to $SC_{max}$, beyond which total costs exceed total benefits – in this case, about 2.5% of the region in question.

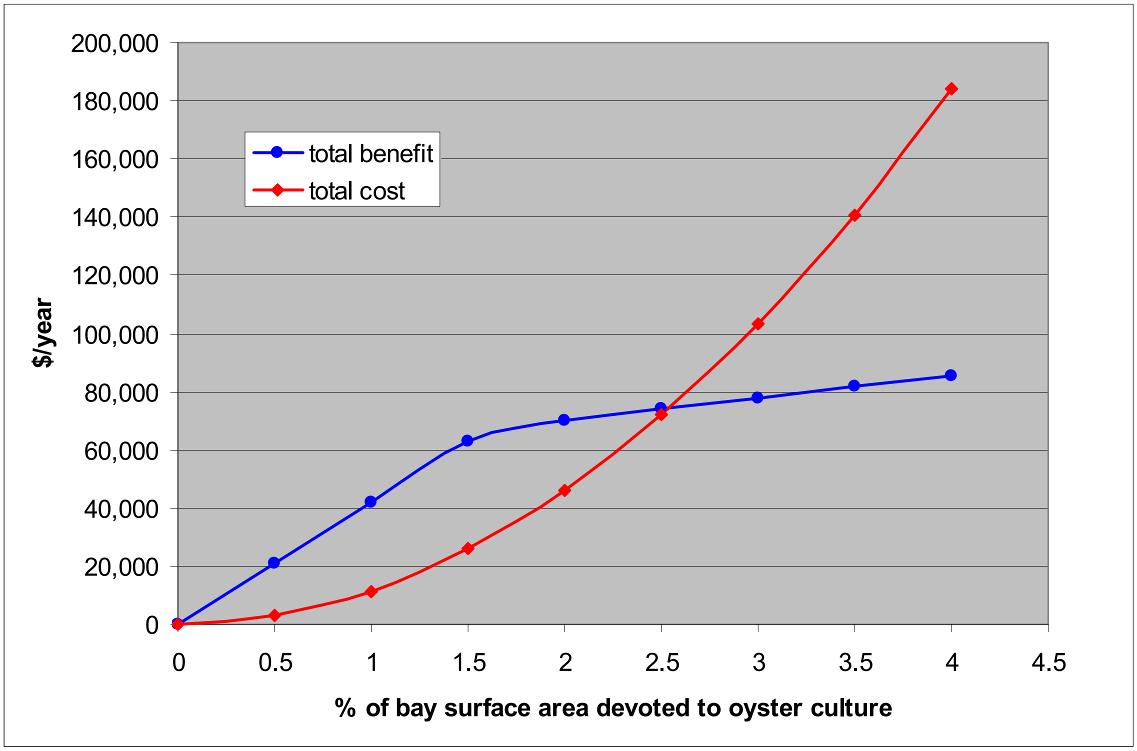

Figure 1: Estimated total benefit and total cost associated with oyster culture in the Head of the Bay region of Waquoit Bay, Cape Cod, Massachusetts.

Under these assumptions, then, it would be feasible and economically sound to devote about 1.5% of the Head of the Bay area of Waquoit Bay to shellfish culture, thereby removing annually an amount of nitrogen equal to the increase in N loading this area has experienced since the 1930s. Based on these results, we conclude that shellfish farming can make a substantial contribution to the management of nutrient levels in coastal waters in settings like Waquoit Bay.