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Environmental Effects of Shellfish Aquaculture in the Northeast

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Introduction

One of the great impediments to further development of shellfish aquaculture in the Northeast Region is a perception that industry expansion could have negative environmental effects on our coastal waters. Although considerable research over the last 25 years has focused on both the positive and negative effects of rebuilding mollusc populations, which could filter enormous quantities of algae, such studies are sometimes classed as environmental "impacts," which has a connotation of aesthetic loss and a perceived "loss of nature." The purpose of this fact sheet is to discuss the potential environmental effects of expanding shellfish aquaculture and social issues surrounding such expansion and to provide key scientific resources.

Bivalves as Filter Feeders

Research has shown that bivalve species such as oysters can filter, on average, 15-55 liters/day (4-14.5 gallons/day) of seawater (for oysters, see Powell et al. 1992; for quahogs, or hard clams, see Doering and Oviatt 1986). Filtration or grazing has been shown to control phytoplankton growth by removing them from the water (Cloern 1982; Officer et al. 1982) — this process is referred to as "top-down" population control. When not sufficiently grazed, phytoplankton populations can bloom excessively, which often leads to the deterioration of water quality. For example, extensive blooms block sunlight and prevent photosynthesis by submerged aquatic vegetation, or sea grasses — grasses then die and with them important habitat for juvenile fish (e.g., Kemp et al. 1983; Short and Burdick 1996; Newell and Koch 2004). SAV loss is not the only consequence of phytoplankton blooms: the ungrazed phytoplankton die and in settling to the bottom, biochemical processes occur that alter the quality of those oxygen-rich sediments to oxygen-less, or anoxic, sediments (Pearson and Rosenberg 1978).

The extensive loss of natural oyster reefs and clam beds due to over fishing and physical destruction of habitats has been implicated as major contributors to water quality degradation in the Chesapeake Bay and other estuaries (Officer et al. 1984; Newell 1988). This loss, again, is related to ungrazed phytoplankton blooms. During nighttime when phytoplankton populations are not producing oxygen through photosynthesis, they are still respiring and thus consuming oxygen. Heavy phytoplankton blooms have greater overnight oxygen demand, so it is likely that when anoxia or hypoxia (extremely low oxygen conditions) occurs at night or close to dawn, it could lead to fish kills. Thus, healthy shellfish populations can be a factor in maintaining healthy finfish populations in coastal waters as well.

Bivalves as Intermediaries in Cycling Nitrogen and Phosphorus

Nitrogen in its inorganic mineral form in coastal waters acts as a "fertilizer" or stimulant of phytoplankton growth. However, an oversupply of nitrogen, resulting in part from land runoff, airborne deposition, and waste discharges, can lead to phytoplankton blooms, microalgal growth, declines in submerged aquatic vegetation, all of which make waters more prone to low oxygen conditions (Nixon 1995). Filter feeding bivalves play a major role as intermediaries in cycling minerals, primarily nitrogen and phosphorus, that are important for maintaining aquatic productivity. Understanding the nitrogen cycle — the various ways that nitrogen is utilized, transformed and stored (Figure 1) — is helpful in understanding the ecological importance of bivalves. In most marine and estuarine ecosystems, inorganic nitrogen is the limiting factor in the production of organic matter, so the available ammonia or nitrate controls the growth of phytoplankton populations in what is often referred to as "bottom-up" processes.

In "top-down" processes, on the other hand, filter-feeding bivalves exert control over the amount of available mineral nitrogen to phytoplankton by sequestering nitrogen as protein in their meat and shell tissues (e.g., Rice 1999). At the same time, they deposit organic nitrogen-rich biodeposits to the bottom sediments that bacteria decompose, thus forming ammonium; ammonium is converted by nitrifying bacteria in oxygen-rich sediments to nitrate, which denitrifying bacteria in deeper sediment layers then then convert to nitrogen gas (Kaspar et al. 1985; Newell et al. 2004). Biodeposition by filter feeding bivalves is important in the transfer of organic nitrogen in phytoplankton and particulates in the water column to the sediments, a process known as benthic-pelagic coupling (Doering et al. 1987; Dame et al. 1989).

It is important to note that under some conditions if too many bivalves are farmed in a location, the resulting biodeposits could potentially overwhelm the capability of sediments to maintain nitrification processes. For example, there have been instances when mussels and other bivalves reared in suspended culture in nutrient-rich waters have produced such high biodeposits that sediments have "gone sour," that is, they have become depleted of oxygen; toxic sulfides and mats of sulfur bacteria are then produced, which disrupts normal benthic processes (e.g., Dahlback and Gunnarsson 1981; Tenore et al. 1982). This problem of anoxia is usually associated with stocking densities in suspended culture that exceed 2-5 tons/acre; it has not been observed in any on-bottom culture operations. (According to a U.S. Ninth Circuit Court of Appeals decision in 2002, biodeposits from shellfish farms are not considered "discharges" under the U.S. Clean Water Act.)

There should be little concern about "overloading" our coastal waters with shellfish in the Northeast because of their significant depletion since the early-to-mid 20th century (Jackson et al. 2001). This is true for all estuaries in the region — Chesapeake Bay, Narragansett Bay, Delaware Bay, Long Island Sound — which were once teeming with oysters (MacKenzie 2007). Nevertheless, it is in the economic interest of shellfish farmers to manage stocking densities by culturing shellfish in areas of good tidal flushing that will prevent depositional overloading of sediments (Crawford et al. 2003). If high stocking densities cause sediment fouling problems, they would also impair the rates of shellfish growth, thereby cutting into bottom line profits (Ferreira et al. 2007).

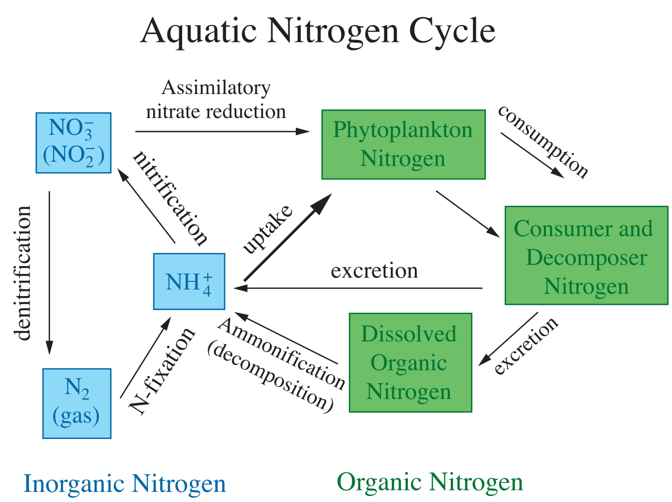

Figure 1. Nitrogen in the environment may be in the form of inorganic or mineral nitrogen (NO_3^-, NH_4^+), or organic nitrogen (Phytoplankton Nitrogen, Dissolved Organic Nitrogen, Consumer and Decomposer Nitrogen) in which the nitrogen is part of carbon-rich molecules either in living tissues or free in the environment. Bivalves are consumers and decomposers. Various chemical processes (i.e., arrows), usually mediated by bacteria or other microorganisms, can convert one form of nitrogen to another. Most nitrogen is relatively inert as nitrogen gas (N_2), in the earth's atmosphere. Mineral forms of nitrogen, ammonium (NH_4^+) and nitrate (NO_3^-), are important nutrients to support phytoplankton productivity. Mineral nitrogen may be removed from aquatic ecosystems through the process of denitrification, a bacterially mediated chemical process that occurs in sediments at the boundary between oxygen-rich top layers and lower anoxic sediment layers. Nitrogen gas formed by denitrification of nitrate eventually diffuses into the water and then into the atmosphere (see Rysgaard et al. 1994). (Figure by K.L. Schulz, SUNY College of Environmental Science and Forestry, Syracuse)

Bivalves also cycle nitrogen through their release of urinary ammonium in its dissolved form directly into the water column. Many species of phytoplankton have the ability to take up ammonium directly (Figure 1) as a stimulatory nutrient. Often, phytoplankton regeneration by ammonium released by bivalves is quite rapid (Ausmus and Ausmus 1991; Pietros and Rice 2003), thereby maintaining phytoplankton populations, despite the filter-feeding process. The cycle of filter feeding on rapidly regenerated phytoplankton by bivalve populations and the release of ammonium in turn is yet another mechanism by which bivalve populations can exert control over phytoplankton populations, thus moderating boom and bust cycles of intense blooms (Cloern 1996).

Bivalves then are a "keystone" species because they (a) exert "top-down" control of phytoplankton populations by filter feeding, or grazing; (b) exert "bottom-up" control through biodeposition and promotion of nutrient removal (i.e., burial and denitrification); (c) sequester nitrogen in the form of proteins in meats and shells; (d) stabilize phytoplankton growth dynamics through the moderation of ammonia cycling in the water column. For these reasons, many researchers have argued that shellfish restoration and policies that encourage expansion of shellfish aquaculture in coastal waters is of significant ecological importance in efforts in the Northeast for mitigating the effects of coastal development and human-induced increases of nutrient loading (Folke and Kautsky 1989; Ulanowicz and Tuttle 1992; Rice 2000).

Environmental Impacts of Shellfish Aquaculture Gear and Practices

In a review of environmental impacts of shellfish aquaculture, Kaiser et al. (1998) distinguish between impacts by cultured organisms and the practices required for growing and harvesting them. For instance, rearing oysters in subtidal rack and bag systems is a standard practice in Southern New England and some parts of the Northeast. Assessments of the impact of this gear type suggests that they act as refugia for a variety of marine organisms, including the juvenile stages of various species of commercially valuable finfish (DeAlteris et al. 2004; Tallman and Forrester 2007). There is also evidence that shellfish in suspended culture enhance fish and crab populations on the bottom (Iglesias 1981; Mattson and Linden 1983), and that fouling organisms on the mussel long lines can enhance populations of grazing and predatory fish (Tenore and Gonzalez 1976).

In some areas of the Northeast, quahog clams and softshell clams are farmed in intertidal flats where nets or plastic mesh are used for covering the shellfish and protecting against predators (Figure 2). Studies of impacts of this type of shellfish farming in England using the Manila clam *Tapes philippinarum* have shown buildup of fouling organisms on the netting and a concomitant increase in grazing molluscs and juvenile fish associated with the nets (Spencer et al. 1996). While preparation of the beds and harvesting of clams from the plots by various mechanical plows or hydraulic devices disrupts infaunal communities, recovery is rapid with original communities returning in less than a year (Spencer et al. 1998). Disturbance and accidental take of non-target organisms is unavoidable regardless of bed preparation and harvest mechanism; however, in the majority of cases increased diversity and abundance of species living in nooks and crannies of all shellfish compensates for temporary losses (Kaiser et al. 1996).

Figure 2. Shellfish farmer Joel Fox in a typical northern quahog, *Mercenaria mercenaria*, farm plot in Wellfleet, Massachusetts. Extensive sand flats during low tide are cultivated before planting hatchery-reared seed at about 50 clams/sq. ft. To protect against predation, netting is rolled out to cover the entire plot and either fastened to submerged rebar or nailed to boards buried in the sediments. The quahog aquaculture industry in Wellfleet has a long-standing reputation of cordial relations with seaside homeowners. (Photograph by Michael A. Rice)

Exotic Organisms, Hitchhiking Pests, Diseases, and Biosecurity

While introduced species for commercial aquaculture have been economically successful and have posed no environmental problems (Mann 1983), there are great concerns that the widespread movement of cultured species (broodstock, seed, or planting stock) will also facilitate the movement of disease-causing organisms and exotic species (Naylor et al. 2001), which pose potential dangers for both cultured and wild stocks (Ford 1996). In all political jurisdictions in the Northeast, policy and regulatory mechanisms are in place to assure biosecurity through review of proposed transfers of shellfish and proper quarantine procedures (e.g., Bushek et al. 2004). As a general rule, shellfish aquaculturists are mindful and strongly supportive of biosecurity policies and best management practices, because inadvertent aquatic animal disease and pest introductions could potentially be catastrophic to their own businesses (Shumway et al. 2003).

Aquaculture and the Public Trust

Nearly all shellfish aquaculture operations in the Northeast occur within the public waters of their respective states; they may also draw or discharge water into public trust waters of their state, thereby requiring oversight by government agencies (Duff et al. 2003). Many researchers have argued that the official review process should include predictive modeling of the various impacts of shellfish aquaculture in order to determine an upper end or carrying capacity. For instance, Grant et al. (1998) have suggested estimating annual phytoplankton production and comparing that production with the nutritional needs for all "natural organisms" within a bay: the results would then provide an estimate of the ecological carrying capacity of mussel farms that might be developed in the bay to feed on excess phytoplankton supply. Recently, Newell (2007), following ideas from Costanza and Folke (1997), argued that comprehensive ecological carrying capacity modeling of shellfish aquaculture operations could better inform our understanding of the economic value of shellfish aquaculture in providing ecosystem services. One outcome of such models might lead to economic credits to shellfish growers for their role in maintaining water quality in coastal water bodies (Ferreira et al. 2007).

While shellfish growers and environmental management agencies may well consider ecological carrying capacity of shellfish aquaculture on good environmental management grounds, there are reasons to expect that shellfish farming in the Northeast may be limited by socio-political pressure long before ecological carrying capacity of shellfish aquaculture has reached any of our estuaries (Figure 3). First, wild shellfish populations are at a fraction of historic highs and there is a long way to go to reach restoration parity; second, relatively affluent coastal populations often express reservations over the loss of recreation and aesthetic values that are often articulated in the rhetoric of environmental protection. Recognizing this dilemma, McKindsey et al. (2006) have proposed the concept of "social carrying capacity" as a modifying feature of ecological and economic models to account for such concerns.

Quantification of the value of aesthetics and other environmental and social non-market values is often a difficult and imprecise task, though estimates can greatly assist decision makers. For example, Johnston et al.

Figure 3. Recreational boaters, commercial fishers, coastal landowners, and coastal visitors are often competing for space in the heavily used waterways of the Northeastern United States. Wickford Harbor in Rhode Island is typical of many coastal waterways with multiple constituency groups who must not be overlooked when planning and operating a shellfish aquaculture operation. (Photograph by Michael A. Rice)

(2001) estimated the non-market amenity values of maintaining farmland in the Peconic Bay estuary system of Long Island, New York, an area with intensive development pressures. The use of various methodologies to assess non-market valuation of aquaculture is still in its infancy, with much of the prior work focused on non-market economic losses by environmentally destructive forms of aquaculture as practiced overseas (Gunawardena and Rowan 2005). Such economic assessments are an area fertile for continued research. Nevertheless, the known benefits of shellfish aquaculture in providing environmental services, and other positive non-market amenities in the Northeast are important and need to be considered by public agencies as guidance in their policy decisions.

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