An Economic Evaluation of the Nutrient Assimilation Potential for Commercial Oyster Aquaculture in the Chesapeake Bay

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(ABSTRACT)

The Chesapeake Bay states continue to struggle to achieve the water quality goals set out in the Chesapeake Bay Agreement. While policy efforts to combat eutrophication tend to focus on reducing nutrient loads at point and nonpoint sources, waters of the Bay can be improved through an increase in the assimilative capacity of the ecosystem, which would remove nutrients (called nutrient assimilation services) from ambient waters. The filtering capacity of the native oyster, *C.virginica*, is a widely recognized means to enhance water quality. With an increase in the number of oysters in the Bay, and no decrease in wild stocks, oyster aquaculture has the potential to also increase the nutrient assimilation capacity of the ambient environment.

Yet the expansion of commercial aquaculture in the Bay has been limited by financial constraints. Increased water quality services might be forthcoming if oyster aquaculturists received financial compensation for the nutrient removal services they provide. Based on previous research, this study develops a procedure for estimating annual nutrient removal from a given size oyster aquaculture facility. Next, a firm level bio-economic simulation model was constructed to estimate the amount of compensation needed by a commercial oyster aquaculture firm to make a new investment in oyster aquaculture. The amount of compensation needed is interpreted as the cost of providing nutrient removal by oyster aquaculture. Results indicate that under many circumstances, nutrient removal services can be provided by oyster aquaculture facilities at a per unit cost comparable with some non-point and point source nutrient removal technologies. Finally, a select number of funding resources were identified as potential outlets for creating payments and demand for nutrient assimilation services.

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Chesapeake Bay Water Quality and the Study Objectives

1.1 Introduction

Covering a total area of 11,000 km^2, with a population of 15 million people in its six-state watershed of 167,000 km^2, the Chesapeake Bay is the largest estuary within the United States (Boesch, Brinsfield, and Magnien 2001). Deteriorating water quality throughout the past four decades, however, has limited the habitat for Bay biota (Butt and Brown 2000). Increasing nutrient loading, primarily from nitrogen (N) and phosphorus (P), is a significant cause of low dissolved oxygen concentrations in the main stem of the Bay and directly contributes to the decline of a variety of aquatic resources (Butt and Brown 2000; Chesapeake Bay Watershed Blue Ribbon Finance Panel 2004). Excess nutrient loading accelerates phytoplankton growth, which ultimately depletes the water column of vital oxygen needed to foster biotic life cycles (Butt and Brown 2000). Nutrient loading into the Bay is derived from nonpoint and point sources throughout its watershed. Nonpoint sources include runoff from agricultural lands (crop, pasture, hay) and developed areas. Point sources are primarily derived from public wastewater sewage treatment plants and industrial dischargers. The single largest contribution of N and P comes from agricultural lands (Boesch, Brinsfield, and Magnien 2001).

In 1983, the Chesapeake Bay Program was formed in order to facilitate collaborative actions between the Environmental Protection Agency (EPA), Maryland, Pennsylvania, Virginia, and the District of Columbia (Chesapeake Bay Program 2008a). Through working together, these parties represent the Chesapeake Bay Executive

Council. Signatory authorities later developed and signed the 1987 Bay Agreement stating that N and P entering the Bay should, by the year 2000, be reduced by 40 percent from a 1985 baseline (Chesapeake Executive Council 1987). The Chesapeake Bay Program recommitted themselves in 2000 through an agreement that outlined a roadmap for achieving their goals. The partners want to "achieve and maintain the water quality necessary to support the aquatic living resources of the Bay and its tributaries and to protect human health" as well as to "continue efforts to achieve and maintain the 40 percent nutrient reduction goal agreed to in 1987…" (Chesapeake Executive Council 2000). Achieving these goals, however, has been challenging (Butt and Brown 2000).

1.2 Achieving the Chesapeake 2000 Agreement

Charged with the goals of the Chesapeake 2000 agreement, the Chesapeake Bay Program implemented a variety of programs aimed at reducing source nutrient loading. These include voluntary and subsidy initiatives for nonpoint sources, regulatory requirements, and capital subsidies for point sources. With agriculture and urban runoff representing a significant source of nutrient pollution from the Bay region, farmers and municipal governments have a substantial influence on N and P loading. States have facilitated conservation initiatives through education, outreach, and technical assistance and have called for the use of agency identified Best Management Practices (BMPs). A BMP is a management or physical practice (such as an agricultural buffer strip) designed to reduce quantities of nutrients and sediment runoff entering Bay waters. The use of conservation tools such as BMPs is largely voluntary. To encourage BMP adoption, states use a variety of subsidy (or cost-share) programs (Boesch, Brinsfield, and Magnien

2001). These programs typically reduce landowners total out-of-pocket costs to less than 30 percent of a state approved BMP (DCR 2007a). From 1992 to 2006, Virginia distributed approximately 60 million dollars (in 2008 dollars) for their agriculture BMP program (Moore 2007). Until recently, state efforts for controlling nutrient loading from point sources were also characterized by similar voluntary processes coupled with cost-share inducements, and point source reductions were achieved by subsidies to facilitate the construction of biological nutrient removal technologies at wastewater treatment plants (Shabman and Stephenson 2007).

Bay states have recently initiated a series of laws and programs to require permitted point source dischargers to limit nutrient discharges into waters and tributaries of the Bay. For example, the Virginia General Assembly passed the *Chesapeake Bay Watershed Nutrient Credit Exchange Program* in 2005 (Virginia code § 62.1-44.19:12-19), which established mandatory nutrient control obligations for Virginia point sources discharging into the Chesapeake Bay watershed. Under such market-based programs, industrial and municipal wastewater point sources are required to limit the total pounds[1] of N and P discharged at or below a stringent, agency-identified nutrient mass load limit, called a wasteload allocation (WLA). The sum of all point source WLA's makes up a total nutrient load 'cap' that legally cannot be exceeded. If individual point source wasteload allocations are not met, the point source may acquire point source credits from another point source that discharged less than the established wasteload allocation. A point source credit is the quantification and recognition of the total mass load of N or P below the WLA. If a point source is unable to meet a WLA—either within the plant or by

[1] 1 pound (lbs) ≈ .45 kilogram (kg).

purchasing point source credits—point sources might sponsor reductions at nonpoint sources (Shabman and Stephenson 2007).

Despite these diverse efforts, the goal of reducing nutrient loading by 40 percent from the 1985 baseline has not been met. Although reductions have occurred, current nutrient loading into the Bay is far from meeting the established goal. In 2005, overall N loading was 266.3 million pounds, compared to the goal of 175 million pounds. Phosphorus loading was 18.5 million pounds, versus the goal of 12.8 million pounds (Blankenship 2007). Even with a fully implemented point source regulatory program, these goals will not be achieved by a regulated point source program alone due to the fact that point source loading constitutes less than one quarter of the total loading of nutrients into the Bay (Chesapeake Bay Watershed Blue Ribbon Finance Panel 2004).

With the influx of nearly a million residents every ten years within the Bay watershed, meeting nutrient goals will become increasingly challenging as treatment methods approach the limits of technology and face escalating costs (Butt and Brown 2000; Chesapeake Bay Watershed Blue Ribbon Finance Panel 2004). Regarding nonpoint sources, the goal will be difficult to reach, as state planning efforts call for a significant voluntary increase in the use of BMPs and, as a result, the cost of further nonpoint source nutrient reductions is expected to significantly increase (Chesapeake Bay Watershed Blue Ribbon Finance Panel 2004). Additional management options beyond source reductions may be needed to achieve Bay water quality goals.

1.3 Moving Past Source Reduction

Over and above limited point and nonpoint nutrient loading, Bay water quality can be improved through an increase in the assimilative capacity of the ecosystem

(Shabman and Stephenson 2007). Nutrient assimilation is the capacity of an ecosystem to reduce nutrients within the ambient environment through biological processing, sequestration, and bioaccumulation. In doing so, the ecosystem becomes more able to accommodate the discharge of additional nutrients from point or nonpoint sources without deleterious effects on the aquatic biota or overall water quality (Cairns Jr. 1997). Three examples of ways to increase the assimilative capacity are the use of wetlands, algal turf scrubbers, and bivalve aquaculture.

Wetlands are often referenced as a means to reduce eutrophication in nearby water basins (Daily 1997). Nutrients are reduced by wetlands through denitrification, attaching nutrients to sediments, and incorporating nutrients within plant biomass. By some estimates, coastal wetlands have the potential to remove about 90 percent of N and P from wastewater effluent (Day Jr. et al. 2004). As a result, wetlands have been utilized through intensive management or construction as a water quality management tool (Fisher and Acreman 2004).

The algal turf scrubber grows filamentous algae in a raceway structure to bioaccumulate nutrients from seawater, brackish, and freshwater. Source water can be ambient water, storm-water runoff, as well as municipal and industrial waste effluent. Nutrients in the ambient water supply a source for algal growth. Nutrients are removed from the ecosystem when algae are harvested. The algal turf scrubber has been used commercially throughout the world, including in the highly eutrophic Florida Everglades and Lake Okeechobee. These systems are extremely effective in removing nutrients (Adey and Loveland 1991, 1998, 2007).

Nutrients are also removed from ambient water through filter feeding aquatic animals. For example, native Chesapeake Bay oysters, *C. virginica,* have been shown to remove nutrients as they filter ambient waters for phytoplankton and zooplankton (Newell 2004; Newell et al. 2005). They do so by pumping large amounts of water through their gills, trapping microscopic food particles using mucous. Previous studies indicate that filter feeding bivalves remove nutrients through three different pathways: oyster biomass, denitrification, and nutrient burial (Newell 2004; Newell et al. 2005). Oysters convert nutrients contained in phytoplankton into meat and shell. Harvesting or removing oyster biomass from the system removes the associated nutrients (Newell 2004; Newell et al. 2005). Oysters also transform inorganic and organic nutrients into feces and pseudofeces that are deposited on the substrate. Under appropriate physiochemical conditions, microbiological nitrification and denitrification convert a portion of the organic N into an inert gaseous state (N_2) that is released from the aquatic ecosystem. Other nutrients are reconfigured and released back into the ecosystem and are later removed through algal biomass consumption and reprocessing, while a percentage are buried in anaerobic substrate (Newell 2004; Newell et al. 2005).

While the filter feeding ability of oysters to diminish nutrient concentrations is well documented, current populations are two percent of mid—20th century densities (Chesapeake Bay Watershed Blue Ribbon Finance Panel 2004). Oyster populations have declined for a variety of reasons, including the parasitic diseases MSX and Dermo, reduced oxygen from submerged aquatic vegetation loss, increased sedimentation, and eutrophication (Jackson 2001; Newell et al. 2005). Substantial efforts have been made to restore natural oyster reefs to the Bay; however, such attempts have been plagued by the effects of disease, habitat degradation, and predation (Fahrenthold 2004; Chesapeake Bay

Program 2008b).

Oyster cultivation within an aquaculture setting has been shown to be effective due to increased growth rates and management of disease (Gangnery, Bacher, and Buestel 2001; Paynter and Dimichele 1990). Oyster aquaculture is the high-density cultivation of oysters through the utilization of suspension floating trays or off-bottom cage culture (Luckenbach, Francis, and Taylor 1999). Managed culture practices and subsequent increased growth rates have contributed to reduced mortality from the oyster diseases MSX and Dermo. Contemporary advancements in genetics, through selective breeding of *C. virginica*, have also enabled oyster culture to effectively combat disease (Brown et al. 2005a; Brown et al. 2005b; Brown et al. 1998).

One aspect of oyster aquaculture that has not previously been investigated is the selective placement of aquaculture facilities within ambient conditions that are conducive to nutrient removal. If intensive oyster culture facilities, for example, were to be placed within watersheds that are in need of nutrient reductions, bivalve aquaculture might be even more effective in removing nutrients within marine estuaries. One example occurred in Sweden, where blue mussel aquaculture resulted in a 20% reduction in nitrogen at the mouth of the Gullmar Fjord (Lindahl et al. 2005). Oyster aquaculture in the United States also has the potential to achieve documented reductions of nutrients.

1.4 Problem Statement

Although oyster aquaculture may remove N and P by harvesting and nutrient transformation, unfortunately, there are relatively few oyster aquaculture enterprises within the Bay. Between 2004 and 2007, fewer than 150 aquaculturists were employed by the Virginia oyster aquaculture industry (Murray and Oesterling 2006, 2007, 2008). In 2007, about five million oysters or 12,500 bushels[2] were sold by Virginia oyster aquaculturists as compared to the approximately 3.35 million bushels of oysters harvested in Virginia from private grounds in 1959 (Murray and Oesterling 2008; Oesterling 1993).

Further expansion of oyster aquaculture appears to be limited due to financial constraints. Recent research suggests that oyster production is only profitable under certain market conditions (Lipton 2007). Labor and equipment costs and investments in oyster aquaculture are costly. Similar to traditional terrestrial agriculture, any form of cultivation requires investments as well as continuous care and attention to animals and equipment (Paynter, Mallonee, and Shriver 1992). Oyster aquaculturists typically sell a majority of their oysters to the halfshell market. The halfshell market is where oysters are sold whole in the shell, such as to seafood shops or restaurants. In a restaurant they are usually shucked and served on the halfshell. Any remaining oysters that are unmarketable in the halfshell market are typically sent to a processing market, where they are shucked and packaged. The difference between oyster prices in the halfshell market versus the shucked market is considerable (Bosch et al. 2008). Halfshell oysters within the fresh Atlantic market demand up to $0.55 per market-sized oyster with the average halfshell price around $0.30 (Bosch et al. 2008; Kallen et al. 2001). Shucked oysters, however, obtain an average price of about $0.11-$0.20 (Bosch et al. 2008; Kauffman 2008). These studies indicate that given current production technology and costs, oyster aquaculture is only profitable when oysters are sold at the prices currently being charged in the halfshell market (Lipton 2007). Although the halfshell market demand is largely undocumented, it

[2] It is assumed that one-bushel contains approximately 400 market-sized oysters.

is arguable that this demand is currently being met by local production (Lipton 2007). Thus, significant expansion of nutrient assimilation services from oyster aquaculture is not likely under existing input costs and output prices.

Increased nutrient assimilation services, through new investments in oyster aquaculture, might occur if oyster aquaculturists received financial compensation for the nutrient services and reductions that they provide. The creation and sale of nutrient assimilation services could provide additional revenue for oyster aquaculture, beyond the sale of market oysters. What financial payments would exist for such services and the level of compensation a potential oyster aquaculture facility could receive for providing assimilation services remain to be determined. First, the compensation necessary for nutrient assimilation services can be interpreted as the cost to provide such services. If these services can provide nutrient removal at a per unit cost comparable to or lower than nonpoint source and point source nutrient removal, then oyster aquaculture might be an economically attractive policy option for helping achieve the water quality goals of the Bay.

However, state and federal water quality programs do not currently offer financial incentives or payments for providing nutrient assimilation services. Nutrient assimilation services that are documented, quantified, and recognized by the state, are called "nutrient assimilation credits." Credits are certified reductions in mass load of nutrients from ambient waters and are legally equivalent to source reductions. Existing polices and programs could be modified to allow such payments to occur. For example, state cost-share programs, such as the Virginia Water Quality Improvement Fund (WQIF), are dedicated to subsidizing nutrient reductions. In other cases, parties facing nutrient discharge limits might have the opportunity to enhance assimilation services as a way to maintain compliance within their WLA limits. Regulated point source discharge facilities that are facing binding nutrient caps could possibly use investments in nutrient assimilative reductions as another compliance option. Changes to existing programs, however, would be required in order for nutrient assimilation credits to be recognized and paid for, and data for these changes are yet to be forthcoming.

1.5 Objectives

The following are the objectives of this thesis:

1. Estimate the compensation an oyster aquaculture firm would need to receive to provide nutrient assimilation credits. This figure is interpreted as the cost of providing nutrient assimilation services.

2. Identify the policy options that could create financial incentives to provide waste assimilation services and to identify possible policy changes necessary to create financial payments for such services.

1.6 Methods

Objective one was achieved through the creation of a bio-economic simulation model. The model calculated internal rates of return and net present values of representative oyster aquaculture production facilities. The model also calculated the price of a nutrient assimilation credit that an oyster firm would need to receive in order to achieve a targeted rate of return (TRR) (i.e. the cost to the oyster firm to supply the credit). Sensitivity analysis was subsequently conducted in order to better understand how changes in key determinants influence the financial viability of oyster enterprises. Chapter Two presents the general firm level bio-economic model. Results of the simulation model and sensitivity analysis are presented in Chapter Three.

The second objective was formulated through a literature synthesis and discussion of incentive-based source reduction programs in Chapter Four. Prefaced by a conceptual overview of the economic incentives available within the water quality management realm, a compilation of different types of funding programs were investigated. Opportunities for creating demand for nutrient assimilation credits in the Chesapeake Bay were analyzed and are presented as they relate to administrated markets, public funding programs, and private voluntary contributions. For each potential funding resource, the opportunities and constraints to creating demand for nutrient assimilative credits were analyzed. Emphasis was placed on identifying funding sources that compensate oyster aquaculturists on a performance basis (i.e. pounds of nutrients removed).

The final chapter includes a summary of findings and an overall assessment of the opportunities to use—and the barriers to using—oyster aquaculture as a water quality management tool for meeting the Bay partners' goals. Suggestions and recommendations for future research are also presented.

Chapter 2

The Oyster Aquaculture Enterprise Bio-economic Simulation Model

2.1 Introduction

The objective of this chapter is to describe the bio-economic simulation model used to estimate the cost of nutrient removal services from oyster aquaculture in the Chesapeake Bay. First, the production and biological processes necessary to produce oysters and nutrient removal services using contained oyster production units—cages and floats—in the Chesapeake Bay are summarized. Key production characteristics that influence growth and mortality of oysters in a contained oyster production facility are described. Next, the water quality services oysters provide during the production process are explained as they pertain to the nutrient removal services they create. The second half of the chapter describes the firm-level bio-economic model. The financial simulation model uses inputs, input prices, output prices, and oyster production characteristics specified by the user to estimate an Internal Rate of Return (IRR) of a potential investment in an oyster aquaculture facility. The IRR specifies the rate of return the enterprise will produce given defined parameters in the absence of a nutrient credit. Annual firm total sales for the IRR calculation are derived from the sale of oysters. The model can then estimate the price of a nutrient assimilation credit needed to meet a targeted rate of return (TRR) or financial objective for a contained oyster aquaculture enterprise in the Chesapeake Bay (i.e. the additional sales or payments needed from nutrient credits in order to meet the TRR).

2.2 The Oyster Aquaculture Enterprise

Chesapeake Bay oyster aquaculture, the active human management of raising *Crassostrea virginica,* has been practiced in the Bay since the 1800s. Historically, wild oyster aquaculture consisted of harvesting juveniles and transplanting them to private growing grounds (Oesterling 1993). Bottoms designated for private leases were historically classified as barren or unfertile oyster ground. Private oyster growers could lease ground from the state government with exclusive harvest rights to any oysters grown there. Oyster growers could then make investments through improving bottom conditions (shell planting) to raise oysters. Private grounds were planted with seed, cultivated, and harvested with tongs or dredges (Maryland Sea Grant 1987). Oysters harvested in Virginia from private grounds reached a maximum of 3.35 million bushels or about 80% of total oyster harvest in Virginia in 1959 (Oesterling 1993; Santopietro 1986).

Contained aquaculture methods were employed as early as the 1930's when the Chesapeake Corporation placed over 11,000 off-bottom containment structures along the shores of Virginia's York River. Although the Chesapeake Corporation reported that such methods produced a well-shaped, high quality oyster in a reduced amount of time, the practice was costly relative to other growout options and was not economically viable at the time (Oesterling 1993). The oyster aquaculture method of transplanting wild seed to private lease grounds for growout continued until the onset of disease in the 1960's, and it eventually changed the scope and nature of the oyster aquaculture industry (Oesterling 1993).

The oyster diseases *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* (Dermo) are single-celled protozoa that cannot infect humans through contact or consumption but can lead to significant oyster mortalities (Luckenbach, Francis, and Taylor 1999). *Haplosporidium nelsoni* (MSX) is a spore-forming protozoan that infects all ages of susceptible oysters from summer to autumn. Infections originate within the gills and mantle and eventually spread throughout these oysters. The life cycle of MSX is largely unknown, but it is believed to interact with an intermediate host (VIMS 2005b). *Perkinsus marinus* (Dermo) is a parasite that thrives during the warm months from May to October. The disease is transmitted among oysters as they filter feed. Initial infections initiate in the digestive gland tissue and eventually spread throughout an oyster's system (VIMS 2005a). Environmental influences, especially salinity, influence the severity of both diseases. At salinities greater than 15‰, MSX thrives, and Dermo thrives at salinities greater than 12‰ (Ewart and Ford 1993).

Due in part to disease pressures, public natural harvest and private bottom planting harvest have fallen steadily since the 1960's. For example, oyster harvest from private grounds in Virginia fell to only 47,247 bushels in 1991 (Oesterling 1993). Additionally, natural harvest on public grounds also has fallen to record lows. Although these diseases devastated wild oyster populations, which were needed for traditional oyster cultivation on private growing grounds, the problem subsequently produced an impetus to research disease-free hatchery cultivated seed and improved growout technologies and methodologies (Oesterling 1993).

The recent trend for oyster aquaculture in the Chesapeake Bay has been a shift from planting shell on the bottom to the use of intensive contained aquaculture (Murray and Oesterling 2006). Growout methods used today throughout Virginia and Maryland are similar to those of the Chesapeake Corporation, as they have primarily focused on holding oysters in various types of contained or off-bottom containment systems such as cages or floats (Luckenbach, Francis, and Taylor 1999). In addition to improved production units, oyster production methods have focused on reducing oysters' susceptibility to disease. Common methods include manipulating the timing of planting and harvesting, rapid disease analysis, genetically improved disease resistant seed, and faster growing oyster seed that can reduce the vulnerability of diseases from decreased amounts of time in the water (Luckenbach, Francis, and Taylor 1999). However, the cost of this type of production technology is still a challenge. While the amount of leased oyster bottom in Virginia used for contained oyster aquaculture increased approximately 6% from 2004 to 2005, total contained oyster aquaculture production remained negligible relative to historical numbers (Murray and Oesterling 2006). Oysters sold by oyster aquaculturists in Virginia increased from approximately 843,842 oysters or 2,110 bushels in 2005 to approximately 4,800,900 oysters or 12,002 bushels in 2007 (Murray and Oesterling 2008).

2.2.1 The Oyster Meat Production System

Oyster production in a contained oyster aquaculture setting involves six general stages (Figure 2.1). These stages include the following: hatchery, nursery, growout phase 1, growout phase 2, harvest, and market. Labor activities and equipment requirements vary across the stages of the production cycle (Figure 2.2). The stage at which oyster aquaculturists enter the production cycle can also vary across firms. Hatcheries usually specialize in larval development, whereas oyster aquaculturists focus on oyster growth and production (Louisiana Sea Grant 2007). Oyster aquaculturists typically start the production cycle at the nursery or the growout (phase 1) stage.

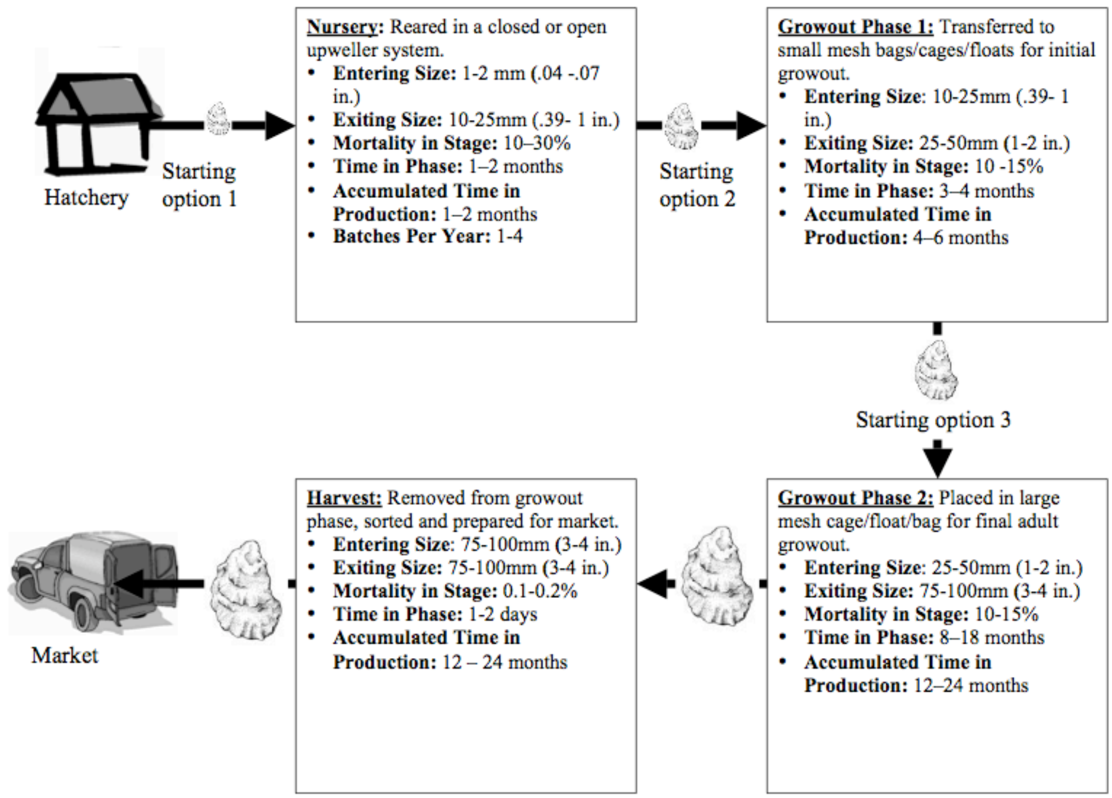

Figure 2.1. Average Commercial Oyster Aquaculture Production Process.
(Figure created by Alexander Miller)

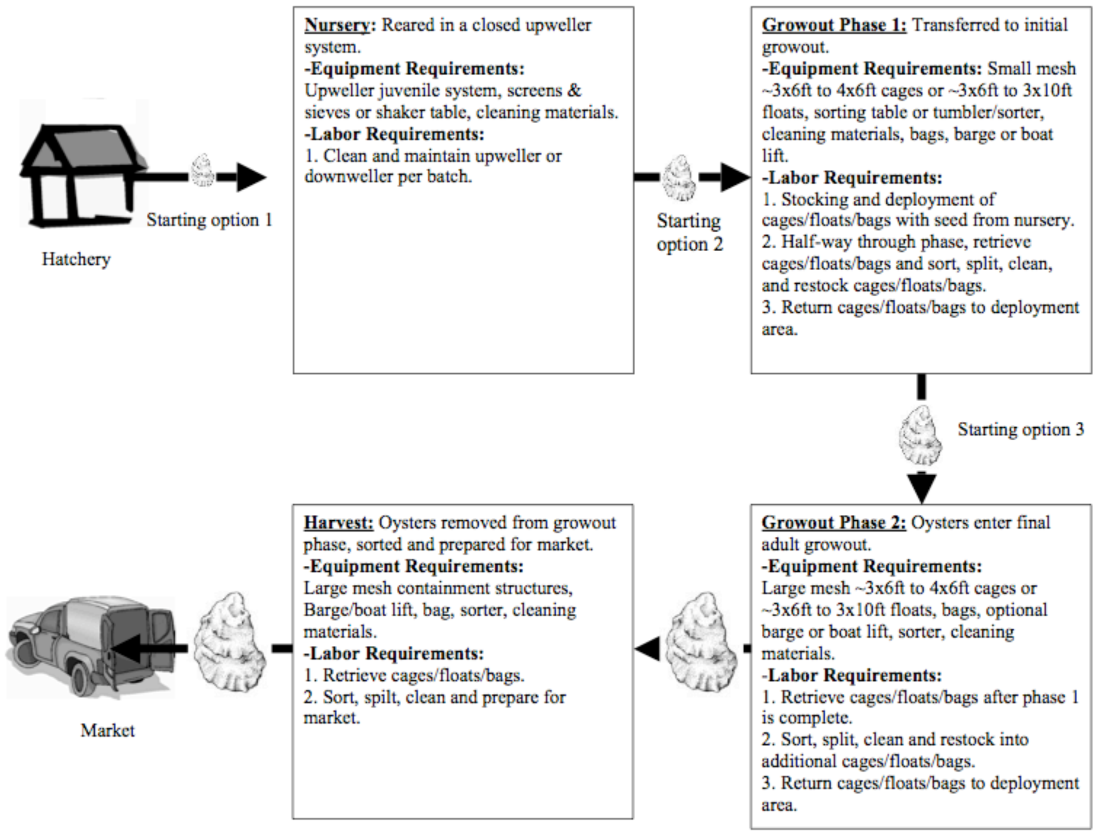

Figure 2.2. Average Labor Activities, Time Requirements, and Equipment Needs for an Average Commercial Oyster Aquaculture Facility. (Figure created by Alexander Miller)

The first stage of oyster aquaculture production occurs in a hatchery. Juvenile oysters, commonly known as seed or spat, are produced in the hatchery, typically during the spring of the year when the water temperature and food availability increases (Stanley and Sellers 1986). Gametogenesis, the production of sperm and eggs, and spawning, the mixing of sperm and egg, occurs when stimulations to broodstock oysters from water temperature changes take place (Stanley and Sellers 1986). Broodstock are male and female oysters used for spawning that are selected based on a number of different characteristics including size, shape, cohort, and family (Luckenbach, Francis, and Taylor 1999). Hatchery production makes selective breeding possible.

Once spawning occurs, eggs hatch into free-swimming oyster larvae. During this planktonic phase, larvae are held in tanks and must be fed a cultured phytoplankton diet as they transform through different stages of growth and ultimately develop a straight-hinge shell, pigmented eyes, and the ability to swim. Eventually, oyster larvae must 'set' or attach to a hard substrate (Stanley and Sellers 1986). In a hatchery setting, this process of settling and development into "spat" or "seed" takes place on either a discarded oyster shell, called cultch, or on fragments of sand or shell, called cultch-less seed. When well shaped, halfshell market oysters are being produced, cultch-less seed is often the choice for aquaculturists. The process of spawning and spat set usually takes approximately two weeks (Horn Point Laboratory 2008; Louisiana Sea Grant 2007). Oysters leave the hatchery about two weeks after setting occurs, or when they reach about 1-2 mm or .04 - .07 inches in length (Congrove 2008).

A hatchery has the option of producing different strains of oysters: diploids or triploids. Diploid oysters have two copies of each chromosome, whereas triploids have three copies of each chromosome and are generally thought to be sterile. To produce triploids, fully fertile tetraploid males (those with four copies of each chromosome) are used to fertilize the eggs of diploid female oysters, which in turn, creates a triploid oyster (i.e. 4n male x 2n female) (McCombie et al. 2005; Nell 2002). Being infertile, triploids invest more energy into growth and have been documented to exceed the growth of diploid oysters in optimal growing areas (Nell 2002). Barber and Mann (1991) found that triploid *C.virginica* oysters reached market size five months prior to diploid oysters and also weighed 29% more. Matthiessen and Davis (1992) found that triploids incurred lower morality from MSX than did diploids.

Hatcheries also have the ability to select for improved growth and disease resistance through the use of genetic lineages, particularly by selecting native *C.virginica* oysters that originate from different geographic heritages (e.g., North Carolina, Louisiana, or Chesapeake Bay). Brown et al. (2005a); Brown et al. (2005b); Brown et al. (1998) found that different geographic oyster strains can significantly influence oyster growth and disease resistance. Through the use of selective breeding, in which growth and disease resistance characteristics are selected for, oysters are better able to withstand the disease pressures from the parasites MSX and Dermo (Brown et al. 2005a; Brown et al. 2005b; Brown et al. 1998).

After reaching 1-2 mm (.04 - .07 inches), oysters are typically moved from the hatchery to the second stage of production, the nursery stage (Figure 2.1). During this stage, oyster aquaculturists might purchase seed from hatcheries to stock their nursery systems. The nursery stage consists of an upweller system. The system places oyster seed in a confined container to reduce predation. Pumps or paddle wheels move ambient water into the container, and this water is eventually circulated back to receiving waters. Sufficient densities of food, carried by the pumped ambient water, are supplied as water travels upward (i.e. upweller) from a central cavity in the container. The system is typically made of steel, aluminum, fiberglass, or plastic and placed on a dock or floated in the water.

Oysters usually are held in a nursery system until they reach 10-25 mm (.39 to 1 inch). In the Chesapeake Bay region, this stage usually takes about four to eight weeks on average. Mortality in the nursery ranges from 10-30% (Erskine 2008). Ambient water quality is routinely checked and seed are cleaned, sized, and often sorted several times

(Figure 2.2). Cleaning the nursery typically involves scrubbing, rinsing, and pressure washing to remove mud and associated epifauna, such as barnacles, sea squirts, and hydroids from the upweller and oysters. To size and sort oysters, aquaculturists use screening or sieving techniques. For large quantities of nursery oysters, a shaker table, a screened flat surface that shakes, is sometimes used. Nurseries are often stocked three or four times a year during the spring and summer months, when seed and food are available. Frequency of stocking is based on production needs, facility constraints, and seed availability (Erskine 2008).

Juvenile oysters enter the growout phases (third and fourth stages of production) when they are placed in containment structures and deployed directly into ambient waters (Figure 2.1). Containment structures are designed to protect oysters from predators and siltation, allow oysters to be placed in areas conducive to good growth and low mortality, and facilitate recovery at harvest. The two common methods for culturing oysters in the Chesapeake Bay are off-bottom cages and surface floats (Figures 2.3 and 2.4).

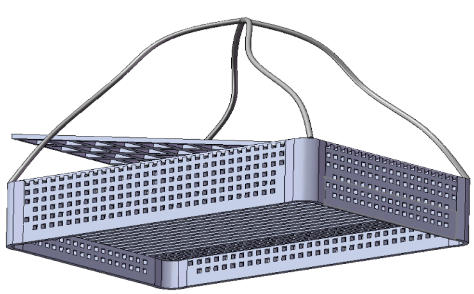

Figure 2.3. Off-bottom Oyster Cage.[3]

Figure 2.4. Off-bottom Taylor Oyster Float.[3]

[3] Figure 2.3 and 2.4 created by Alexander Miller and Scott Tarcy

Off-bottom cages typically have wire or steel footers that elevate oysters off the bottom and away from sediments. Cages are typically constructed of wire mesh and surrounded with a metal rectangular frame. Cages are placed in 3-6 feet (1-2m) of water with a float or buoy attached to a rope to mark the location of the structure (Figure 2.3). Being a rigid and secure structure, cages allow large densities of oysters to be handled easily. The average oyster cage is constructed of 1-inch to 3-inch (25mm to 76mm) steel wire mesh, which is either galvanized or plastic coated (Figure 2.3). Heavy-duty aluminum or steel is often used as a frame. Cages range in size from approximately 3'x 6'x 4" (1m x 2m x .1m) to 4'x 6'x 12" (1.2m x 2m x.3m) and can typically hold 1,000 - 10,000 oysters, depending on the size of the oysters (Erskine 2008; Wieland 2007). Cages with smaller mesh, designed to hold many thousands of oysters directly from the nursery, are often called nursery cages, while larger mesh standard growout cages are used for fewer larger oysters. Cages may be divided into multiple layers, which separate oysters to improve water movement around oysters and thus improve growth rates. Regardless of the architecture of the cage in phase one, oysters may be initially placed in bags within the cage or on sheets attached to the cage, which are both made of 1/8-inch to 1-inch (3mm to 25mm) plastic mesh. Retrieving cages typically entails using a barge or boat with a boom and crane arrangement that lifts the cage onboard.

Floating rafts also serve as a means for commercially culturing oysters. Usually rectangular in shape, floats are typically constructed of polyvinyl chloride (PVC) pipe, typically 4-inches (~102 mm) in diameter and sealed together to create buoyancy (Figure 2.4). One version of the oyster float, called a Taylor float, attaches coated plastic wire mesh to construct a hanging cage (Figure 2.4) (Luckenbach, Francis, and Taylor 1999).

Oysters are cultured in $\frac{1}{8}$-inch to 1-inch (3mm to 25mm) plastic mesh bags within the float. In other cases, oysters are placed into plastic mesh bags that are strapped directly onto the floats. Sizes of floats typically range from 3' x 6' (~1m x 2m) to 3' x 10' (~1m x 3m) and usually hold 600 to 1,000 adult oysters at harvest (Wieland 2007). Usually attached to one another in arrays of up to 10 per line, floats are secured to a bottom anchor or to a fixed structure, such as a dock, piling, or tree. Floats are often accessed using a small boat/raft or through workers donning waders. An oyster float is used when aquaculturists prefer that oysters reside in the upper portions of the water column where algal concentrations and dissolved oxygen saturation are higher and have been shown to increase growth rates (Paynter and Dimichele 1990).

Regardless of the containment structure they use, oyster aquaculturists can start the production cycle during the first growout phase. To do so, growers purchase oyster stock directly from a seed supplier. Whether purchased elsewhere or grown onsite, post-nursery oysters are stocked in cages or floats and deployed in order to start the growout stage.

Growout may be divided into two phases. Smaller oysters can be stocked at higher densities in the cage or float. If oysters are stocked at small sizes, the growout stage may be divided into two different phases (growout phase one and growout phase two). This process usually involves using two different types of production units, such as cages or floats with small and large mesh, respectively.

Phase one may require oyster numbers to be split when oyster densities are too high. Oysters are retrieved, then cleaned, sorted, and restocked into additional cages or floats, and redeployed to the growout area. This process is completed onboard a vessel or at a dock facility. Cleaning includes pressure-washing mud and associated fouling epifauna from cages or floats, bags, and oysters. Oysters are sized and sorted according to length and split into different size classes. Sorting entails the use of a sorting table, mechanical sorter, or tumbler. As hand sorting is a labor-intensive process, the use of a sorter, which can handle about a bushel of oysters in one minute, is often used (Wieland 2007). Once sized and counted, oysters are restocked into appropriate containment structures.

Phase one typically ends when oysters reach an average size of about 25-50 mm (1 – 2 inches). Oysters are redeployed in large mesh cages or floats for the fourth stage of production—phase two of growout or final adult growth. Oysters are retrieved from phase one growout, cleaned, sorted, split, and restocked into additional cages or floats, if needed. Containment structures are subsequently returned to the deployment area for additional growth. Mortality can range between 10-60% during each of the growout phases depending on physicochemical conditions of the water and resulting differences in seston and disease (Erskine 2008).

During growout phases, oysters may be inspected for predators or fouling. Common predators include flatworms, clamworms, crabs, and snails. Mammalian predators, such as river otters and raccoons, have also been known to cause problems (Luckenbach, Francis, and Taylor 1999). Insuring that lids and bags are fastened properly often mitigates such problems.

Growth and mortality in the growout stages are influenced by a number of different variables. Environmental parameters at the site location such as salinity, hydrodynamics, algal concentrations, and temperature have been shown to influence growth and mortality rates for oysters (Kennedy, Newell, and Eble 1996). Salinity and temperature have been documented to be most influential to growth rates. For example, the effects of salinity and temperature influence how oysters feed, use their food reserves, ward off diseases, and grow (Kennedy, Newell, and Eble 1996). Oyster growth and mortality are additionally influenced by intrinsic physiological factors of oysters and management strategies by oyster aquaculture facilities (Luckenbach, Francis, and Taylor 1999; Paynter and Dimichele 1990).

Through the upper reaches of the Bay, where salinity averages below 10‰, growth rates of *C. virginica* are reduced as compared to those in the lower reaches of the Bay, where salinity tends to be higher (Allen and Frank-Lawale 2008; Luckenbach, Francis, and Taylor 1999). At this salinity range average native diploid genetic strains take approximately 24 months or more to reach market size (approximately 76mm or 3 inches), whereas triploids take roughly 14 months when starting from a seed size of approximately 25mm or 1-inch (Allen and Frank-Lawale 2008). With a similar entering seed size of 25mm or 1-inch and a salinity range of 11-20‰, diploid growth rates increase to an intermediate rate of about 20-22 months to reach market size, whereas triploids take nearly 13 months. When salinities reach 21-30‰ at the southern portions of the Bay, diploid oysters have the highest growth rates and achieve a time to market of 16-18 months, whereas triploids take about 12 months (again, with a starting seed size of 25mm or 1-inch) (Allen and Frank-Lawale 2008).

There is, however, a trade-off between growth rates and mortality rates. Oyster diseases, dermo and MSX, thrive at salinities above 15‰ and decrease when salinities drop below 10‰ (Luckenbach, Francis, and Taylor 1999). Salinities also change throughout the year in the Bay and can increase and decrease growth rates as well as the impact of diseases. During heavy rain events, typically in the spring, salinity regimes are decreased due to large quantities of freshwater entering the Bay (Santopietro 1986). When salinities are highest, through drought conditions or geographic location, disease pressures are elevated, and, as a result, can increase mortality rates (Luckenbach, Francis, and Taylor 1999).

Hydrodynamics —water flow and mixing—and increased food or algal densities have also been documented to influence oyster growth. Lenihan, Peterson, and Allen (1996) found that growth of juvenile *C. virginica* oysters monotonically increased when food concentrations and flow velocity independently increased. Furthermore, oyster aquaculture management practices have been documented to increase growth rates when oysters are placed higher in the water column where algal concentrations are higher (Gangnery, Bacher, and Buestel 2001; Paynter and Dimichele 1990).

Temperature is also a key component to oyster growth. As Kennedy, Newell, and Eble (1996) point out, growth increases in warmer water or during the warmer parts of the year—spring and summer months. Dame (1972) also found that growth rates for intertidal oysters decreased with lower temperatures. Growth rates throughout the year are therefore not homogenous, and they fluctuate as a function of temperature.

The influences to growth and mortality presented above for the oyster production process are also influenced by intrinsic physiological factors of oysters (Paynter and Dimichele 1990). Oysters exhibit considerable variation in growth within the same age-class. For instance, 25% of a given batch of oysters may be ready for harvest in 12 months, whereas 50% will be ready in 14 months, and the final 25% will be ready in 18 months (Erskine 2008). As a result, oyster aquaculturists may be able to place oysters from one cohort in the market throughout the year.

Management strategies can reduce disease-related mortality and enhance growth (Luckenbach, Francis, and Taylor 1999). Allen and Frank-Lawale (2008) found that mortality was lower for triploid *C. virginica* oysters as compared to diploids at an intermediate to high salinity where disease susceptibility was more intense. Using genetic lineages and selective breeding of oysters may also help to increase growth rates and combat disease pressures when oysters are tailored to specific salinity regimes, diseases pressures, and aquaculture constraints (Luckenbach, Francis, and Taylor 1999). To further reduce the risks from disease, some suggest that following a management plan that subjects oysters to only one summer of disease susceptibility—when salinities are increased—may also increase survival (Luckenbach, Francis, and Taylor 1999). Implicit in this strategy is to hold seed oysters through the summer in a low salinity high productivity area and wait to deploy them on site until disease levels have subsided in the late autumn.

The harvesting process, the fifth stage of the production process, occurs after an approximate total time of 12-24 months in growout phases one and two or when oysters reach 75-100 mm (3-4 inches) (Figures 2.1 and 2.2). High productivity waters may have high levels of coliform bacteria (the source of which may be contested). Thus, in some instances, prior to harvesting oysters from the water, oysters may be required to be moved from the growout area and relayed to waters that have sufficiently low coliform counts, as pursuant to federal and/or state laws. In Virginia, for example, § 28.2-810 of the Code of Virginia specifies that aquaculture enterprises cannot harvest, market, or consume shellfish from waters that have been condemned (VMRC 1998). Shellfish can, however, be cultured in areas with high bacteria counts with the intention of future consumption if they are transplanted to approved waters through "relaying." Relaying is a process in which contaminated shellfish are moved to an approved area where bivalves can flush their systems of bacterial pathogens (VMRC 1998).

Harvest includes retrieving oysters, cleaning, sorting, and preparing for market (Figures 2.1 and 2.2). The harvest process for a large-scale operation of a few million oysters usually takes 1-2 days. Once harvested, oysters may enter a post-harvest treatment process that targets the elimination of pathogenic bacteria, such as *Vibrio*. State and federal laws do not currently require post-harvest treatment processes. However, state management agencies have been considering making the process mandatory (Muth et al. 2002). *Vibrio* species occur naturally in the environment and have been shown, in some instances, to be fatal to immunocompromised humans, particularly when oysters are consumed raw (Colwell 1984). Typical options for inactivating *Vibrio* include holding oysters in refrigerated units, quick-freezing, pasteurization, and hydrostatic pressure (Jahncke 2008; Muth et al. 2002).

The sixth stage of the production process is the transfer of oysters to market. Oysters are either shipped or delivered directly by growers. Oyster aquaculturists typically sell a majority of their oysters to the fresh or halfshell market (Kallen et al. 2001). This often includes selling oysters directly to internet seafood sites, restaurants, bars, seafood markets, or wholesalers (Kallen et al. 2001). The fresh, or halfshell, market is composed of oysters that are sold whole to consumers who purchase them opened and on one shell, hence ready to eat. Oysters may instead be sent to a processing center where they are shucked (oyster meat removed from the shell), canned, and packaged within different sized containers.

The difference between oyster prices in the halfshell and shucked markets is sometimes considerable. Murray and Oesterling (2008) found that average Virginia oysters prices for halfshell and shucked oysters received from growers for 2005 to 2007 ranged between $0.15 - $0.58, with the 2007 median price per oyster being $0.28. Kallen et al. (2001) reported a price range for oysters on the fresh halfshell Atlantic market between $0.30 - $0.55 per market sized oyster. Bosch et al. (2008); Kauffman (2008) reported that oysters in the shucked market demanded an average range in price from $0.11-$0.20 per shucked oyster. Most oyster aquaculturists market oysters to the halfshell market because they can obtain better prices in the halfshell market than when they sell oysters to a shucking house.

2.2.2 Nutrient Assimilation Services

Oysters naturally provide a variety of water quality services (Newell 2004; Newell et al. 2005). Oyster feeding behavior filters large quantities of water. Through the filter feeding process, oysters remove phytoplankton and suspended particles (seston) from the water, increasing water clarity. Oyster feeding and filtering can also remove algal bound nutrients from the water column (Newell 2004; Newell et al. 2005). The nutrient removal capacity of oysters is of particular interest to water quality managers throughout the Bay states.

Nutrients such as nitrogen (N) and phosphorus (P) are naturally occurring and found throughout the Chesapeake Bay (Boesch, Brinsfield, and Magnien 2001). Nutrient inputs are derived from land-based point sources, such as publicly owned wastewater treatment plants and diffuse sources such as runoff from agriculture, forests, and urban and suburban lands (i.e. nonpoint source). Nitrogen may also enter the Bay through atmospheric deposition. Nitrogen, the limiting nutrient throughout the Chesapeake Bay, causes deleterious effects to the ecosystem when increased (Boesch, Brinsfield, and Magnien 2001). Nitrogen can enter the water as an inorganic form from minerals in fertilizers, or as a component of organic compounds such as manure and sewage (Cornwell et al. 1996).

In combination with energy from the sun, primary production takes place. While sunlight, carbon dioxide, and water are needed for photosynthesis to produce sugars, nutrients are needed to transform sugars into organic compounds such as proteins and nucleic acids. Through these processes, organic algal biomass production occurs (Castro and Huber 1992). Thus, nutrients are essential for algal or phytoplankton biomass growth (Figure 2.5).

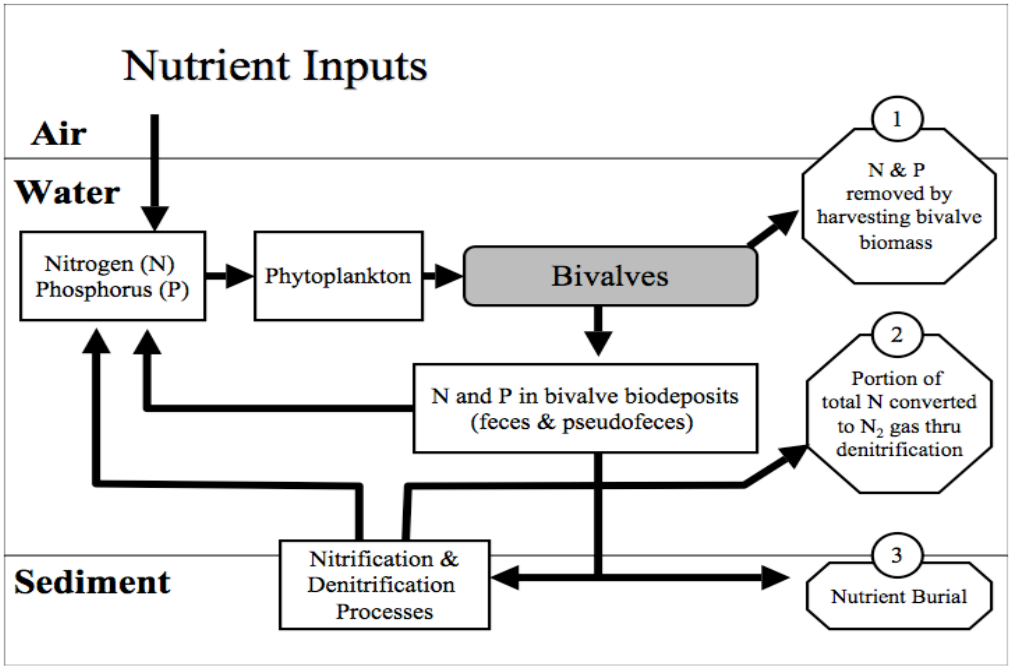

Figure 2.5. Conceptual Diagram of the Environmental Effects of Filter-feeding Oysters in Removing Nutrients from the Water.
Source: Adapted from (Newell 2004; Newell et al. 2005).

The eastern oyster, *C. virginica,* is an active filter-feeding bivalve that removes N bound seston particles—phytoplankton and sediments—from the ambient water column (Newell et al. 2005). Seston particulates captured by the oyster are categorized based on nutritional quality. Particulates of nutritional quality enter the oyster gut where they undergo metabolic digestion (Newell et al. 2005). As compared to other bivalve suspension-feeders, such as the hard shell clam *M. mercenaria*, *C. virginica* is unusual in its ability to maintain a high filter-feeding rate for removing and processing seston particles even when seston densities exceed the oyster's nutritional needs (Newell et al. 2005). On average, oysters convert 20% to 90% of food taken into their system into useable material (Newell et al. 2005). Of the ingested material, oysters convert some N and P embodied algal biomass through metabolic processing into tissue (meat) and a shell. Newell et al (2005) stated that an oyster with a tissue dry weight of 1g and a 150g shell weight contained ~7% N and ~0.8% P in the tissue or meat and ~0.3% N and ~0.1% P in the shell. Nitrogen and P are subsequently removed from the system when oyster biomass is harvested and put to market. This is the first way N is removed from the water (Figure 2.5, part 1).

The remains of ingested particles that are digested are excreted as feces (Newell et al. 2005). Particles lacking nutritional quality or exceeding the capacity of the oyster's stomach are voided as a mucus-bound package known as "pseudofeces." Biodeposits (feces and pseudofeces) that contain organic and inorganic N travel to the benthic community where they serve as food for microorganisms thriving throughout the aerobic sediment layer (Newell et al. 2005). When reaching the bottom, microorganisms begin a process of breaking down or decomposing portions of the organic N in biodeposits into a useable ammonium (NH_4^+) form needed for nitrification. Inorganic N does not undergo a transformation, as it is already in the ammonium NH_4^+ form. Under aerobic conditions, bacteria, *Nitrosomonas* and *Nitrobacter*, eventually break ammonium NH_4^+ into nitrites (NO_2^-) and nitrates (NO_3^-), the oxidized forms of nitrogen, through a process called nitrification (Novotny 2003). These two compounds, NO_2^- and NO_3^-, either make their way into the anaerobic sediment below or are resuspended back into the water column above.

A portion of NO_2^- and NO_3^- in the anaerobic sediments undergoes a denitrification process in which NO_2^- and NO_3^- are converted into inert N_2 gas, which is released into the atmosphere (Newell et al. 2005). An important component of the process is that denitrification generally occurs where aerobic sediments that contain nitrifying microbes are closely in contact (or coupled) with anaerobic sediments containing denitrifying microbes (Newell et al. 2005). Variation in the percentage of N denitrified is dependant on biodiversity of the sediment as well as seasonal and physicochemical fluctuations such as temperature, benthic oxygen concentrations, and flow rates (Newell et al. 2005).

Nowicki et al. (1997) found that highest rates of denitrification occurred in benthic environments where the material consisted of rich organic sediments, while significantly decreased rates were observed for sandy low-organic sediment bottoms. The conversion of N-rich biodeposits into N_2 gas is a second way in which oysters can facilitate removal of nutrients from marine waters (Figure 2.5, part 2). This process is similar to the second stage nitrification-denitrification process used by conventional wastewater treatment plants to remove N from sewage and municipal wastewater.

As a result of biodeposition, N that is not broken down through the nitrification and denitrification processes can reenter the water column through a process called regeneration or resuspension. Through diffusing back into the water column, N is subsequently available to algal and eventually benthic communities. Nitrogen that is not regenerated can be buried within the anaerobic sediment (Figure 2.5, part 3). A portion of the P from biodeposits and nutrient inputs may also be buried directly in anaerobic sediment with the ability to eventually become immobilized within aerobic sediment as PO_4^{3-} (Newell et al. 2005).

2.3 Financial Returns to Oyster Aquaculture

While native oysters can be successfully raised in a confined aquaculture setting, the financial feasibility of such enterprises is more uncertain. Prior research has concluded that oyster aquaculture in the Chesapeake Bay is only marginally financially viable under the best of circumstances (Lipton 2007). The bio-economic model developed here expands on existing research by evaluating whether oyster aquaculture operations can be a viable means to provide nutrient removal services for the Chesapeake Bay.

Previous financial analysis, often using an enterprise budget, has focused on specific incurred costs and anticipated revenue for a particular type of operation, such as float or cage oyster production techniques. An enterprise budget is a list of all revenue and costs, or expenses, for a specific enterprise and time period. Enterprise budgets are sometimes constructed for actual pilot operations. Models of increased complexity include financial simulations and bio-economic modeling software programs. These models differ from enterprise budgets, as they integrate abiotic (non-biological) and biotic (biological) characteristics, such as oyster growth rates under a time horizon. Variables are manipulated in order to determine their influence on costs and net returns for a particular enterprise. Such models offer the ability to investigate changes in costs and returns under certain conditions as opposed to listed expenses and returns for an actual pilot or ongoing aquaculture facility through an enterprise budget. Prior modeling analysis, aimed at determining the financial viability of oyster aquaculture enterprises, has largely concluded that high oyster prices, achieved by marketing to the halfshell market, are necessary in order for the high cost of contained oyster aquaculture to be overcome (Lipton 2007).

A study by Aprill and Maurer (1976) was an early effort to examine the likelihood of financial success for contained oyster aquaculture. These researchers grew market size oysters in rafts (floats) in the Delaware Bay. Investment costs and operating expenses were used in an enterprise budget form to determine net revenue and gains for the enterprise. The analysis concluded that oyster prices were not high enough to offset high production costs and sustain an oyster raft culture enterprise at the time of the study.

Paynter, Mallonee, and Shriver (1992) examined the economic feasibility of floating raft oyster aquaculture in the Chesapeake Bay through deploying and growing oysters to market size in floating rafts in the Wye River in Maryland. Using similar economic analysis methods as Aprill and Maurer (1976), Paynter estimated the cost of raising oysters in the Bay. They concluded that based on their research, experiences, and market prices for oysters at the time of the analysis, floating raft oyster aquaculture in the Chesapeake Bay would be challenging given high production costs and related risks.

Kallen et al. (2001) created a sustainable business-marketing plan for small-scale oyster aquaculture for the Bay. The project consisted of collecting information from oyster farmers as well as conducting a small pilot project that started with about 20 oyster floats on Smith Island, Maryland. Using an enterprise budget, they concluded that oyster aquaculture could potentially be viable if oysters could be sold to a high-end halfshell market throughout the Washington, DC metropolitan area. It was noted, however, that the enterprise might take about five years before total build-out of the business could occur, even under favorable economic conditions.

Wieland (2007) analyzed the costs and returns to cage and float oyster aquaculture in the Chesapeake Bay. Information was collected from representative contained oyster cage and float aquaculturists working in the Rappahannock River in Virginia. An enterprise budget financial model was used. Both float and cage enterprises were profitable. Wieland notes, however, other financial costs, such as maintenance, a boat, and facilities to dock a boat were not subtracted from the net returns described. These additional costs could potentially make the representative oyster firm unprofitable and unable to meet a targeted financial objective.

Bio-economic modeling simulation software programs have also been developed as tools to analyze the economics of oyster aquaculture. The Sea Fish Industry Authority (Seafish) in the United Kingdom developed a ten-year firm level oyster cultivation economic model called *The Oyster Hyperbook*® to assist enterprises with business decisions (Sea Fish Industry Authority 2001). Lipton (2007) used similar data from the Paynter, Mallonee, and Shriver (1992) study to examine the economic feasibility of using private aquaculture of *C. virginica* with a stochastic financial simulation modeling software called AQUASIM. This risk analysis used a triangular probability distribution to evaluate the responses to different oyster survival rates. Lipton found that 94% of the 300 iterations that were run using AQUASIM were solvent for each of the 10 years of the analysis. Management time, however, was not included in the analysis. Lipton states that even with a small payment to management, the enterprise would be unprofitable.

2.3.1 Nutrient Assimilation Oyster Aquaculture Bio-economic Model

The existing research highlights the limited financial incentives to investing in oyster aquaculture throughout the Chesapeake Bay region. A firm level financial simulation model was developed to analyze the monetary payment for water quality services necessary to make new investments in oyster aquaculture. The financial simulation, which was created and operated using Microsoft Excel 2004 (see Appendix A.1. and A.2.), calculated the annual net cash flow from an aquaculture operation over a hypothetical 10-year investment period. Using annual net cash flow, the model calculates an internal rate of return (IRR) for a defined oyster aquaculture operation specified by the user. The model uses annual costs based on input quantities and prices of inputs. Costs include capital investment costs, administrative and permitting costs, and operation and maintenance costs. Annual oyster production is estimated through the specification of oyster production parameters such as the oyster stocking density, growout rate (time to market), and mortality rate. Cash flow is initially derived from oyster production. To calculate net cash flow, annual costs are subtracted from annual total cash flow from oysters. The IRR was then calculated for 10 years of annual net cash flow. Nutrient removal per year was subsequently calculated through the estimation of oyster biomass removal and denitrification. With the addition of potential cash flow from the sales and payments from nutrient credits, the simulation model was subsequently used to calculate the nutrient credit price or cash flow needed to make the firm able to meet a specified targeted rate of return (TRR) (see discussion below).

2.3.1.1 Capital Investment Costs

Capital investment costs represent the first set of costs for the model. Capital investment costs are costs for fixed assets to the oyster aquaculture enterprise. Table 2.1 presents fixed capital investments used in the model for an oyster aquaculture facility with cage or float production technology. While all conceivable capital costs are not listed, these inputs represent the primary capital inputs for a contained oyster aquaculture enterprise in the Chesapeake Bay. Capital inputs included in this model are investments within the following categories: nursery, growout and harvest, and other. The simulation model does not include hatchery capital costs, as it is assumed that firms purchase seed from a hatchery.

General simulation values needed to calculate capital input costs are listed in Table 2.2. The model calculates the capital investment costs for a particular year, given a specified cost of the investment, the anticipated life of the investment and the percentage of use a specific investment is allocated to oyster aquaculture production. The percentage to oyster aquaculture is the percentage of the capital asset that a shellfish aquaculture enterprise allocates to oyster aquaculture. For example, a shellfish enterprise may produce clams and oysters and therefore use the facility equipment for an average of 25% for clam culture and 75% for oyster culture. Life expectancy and salvage values for capital investment items are used in order to calculate disposal costs and payments from these capital investments. Salvage values are accounted for given the entered life expectancy.

The cost of cages and floats (production units) is a significant component of overall costs. The number of production units used by the enterprise is calculated by the simulation program based on the number of oysters in growout and the capacity of each type of production unit (oysters per cage or float). Subsequently, the model increases the total number of units owned by the enterprise by five percent over the full capacity estimate. However, actual enterprises cannot fully utilize all available production units due to down times when units are out of production for repair, cleaning, variation in seed availability, and the seasonality of oyster deployment.

Table 2.1

Capital Inputs for a Contained Aquaculture Enterprise

Item
Boat or Barge w/ Engine & Boom/Crane
Oyster Cage (Nursery/Growout)
Oyster Float (Nursery/Growout)
Plastic Mesh Oyster Bags & Barriers
Nursery (Upweller)
Shaker Table
Sorter / Cleaner
Anchors, Floats/Buoys
Post Harvest Treatment Equipment
Regulatory Start-up Survey
Truck and/or Vehicle
Office Equipment (Computer, Etc.)
Facility Equipment (Pressure Washer, Etc.)
Dock

Table 2.2

Model Variables used to Calculate Input Costs

Item
Cost Per Item
Quantity
Expected Life
Salvage Value (If investment needs to be disposed)
Percent to Oyster Aquaculture

2.3.1.2 Operational and Management Costs

Operational and management costs are the second set of costs used by the simulation model. Table 2.3 presents the operation and maintenance costs for an oyster aquaculture facility using cage or float production technology and the information needed by the model to calculate costs. Oyster operating costs include seed to stock the nursery or growout stage as well as other materials needed for production process, such as shipping boxes. Labor costs are divided into five different stages depending on the tasks completed (see Figure 2.2). Utilities incorporate the electricity cost for a nursery system, if needed, and general operation of the facility. Nursery electricity costs are calculated using the number of watts used per pump, the number of pumps, the cost per kilowatt hour (kWh), and the number of hours the nursery operates per season. The average number of kWh used per year to operate the general facility, such as refrigerators, sorters, etc, is used to calculate general electricity costs.

Costs also include operational costs for a boat, shipping oysters to market, other transportation, and equipment maintenance. The number of miles to the growout location is entered into the model and used to calculate an estimate of the number of gallons of marine diesel used per year. The calculation assumes that a barge or boat uses a 50 horsepower (HP) marine diesel engine that consumes an average of two and one-half gallons an hour, travels, on average, at 8 knots, and makes five round trips per year. Using an entered cost per gallon of marine diesel and the calculated number of gallons used per year, the total cost for operating a marine vessel per year was calculated. To determine shipping costs for market sized oysters, the total number of oysters ready for market each year is divided by the capacity of the shipping box and multiplied by the shipping cost per box. The model assumes that oysters are shipped via a 100 count box with a per unit cost which is entered by the user for the intended market destination. Direct local marketing delivery costs and additional transportation costs are determined by the user entering the average number of miles driven in a year, the average miles per gallon for a truck, and the average cost per gallon of fuel used. Equipment maintenance for nursery pumps, cages or floats, and general facility needs, as well as office overhead expenses, are also entered on an annual basis.

Table 2.3

Operational and Management Costs for a Contained Aquaculture Enterprise Model

Item	Simulation Model Units
Oyster Seed: Nursery or Growout	Cost per 1000 Seed Oysters
Packaging and Shipping Supplies	Cost per Year
Miscellaneous (Marketing, Etc.)	Cost per Year
Shipping	Cost per 100 Market Oysters
Nursery Labor	Hours Per Production Unit; Cost per Hour
Sorting and Growout Preparation Labor	Hours Per Production Unit; Cost per Hour
Growout Labor	Hours Per Production Unit; Cost per Hour
Harvest and Market Preparation Labor	Hours Per Production Unit; Cost per Hour
Relaying Labor	Hours Per Production Unit; Cost per Hour
Regulatory and Permitting Labor	Hours Per Production Unit; Cost per Hour
Utilities: Nursery and General Electricity	Cost / kWh and Quantity Used per Year
Boat and Vehicle Fuel	Cost / Gallon and Quantity Used per Year
Equipment Maintenance	Cost per Year
Office Overhead	Cost per Year

2.3.1.3 Permitting and Administrative Costs

Permitting and Administrative costs are the third set of costs. Table 2.4 presents these costs for an oyster aquaculture facility using cage or float production technology and the information needed to calculate these costs. Liability insurance for oyster aquaculture facilities is typically used to hedge against the risks from any third party claims, such as a consumer becoming ill from the consumption of oysters from the firm. Capital investment insurance covers potential risks and loss associated with investments of the firm. Legal needs include annual fees for maintenance and needs for any legal form of the business per year, such as a Limited Liability Corporation. Taxes for the oyster aquaculture facility include taxes on annual net cash flow. The tax rate is based on an average percentage rate for a representative oyster aquaculture firm in the Chesapeake Bay. The tax rate is assumed to be a cost and does not include deductions that an aquaculturist might file with the Internal Revenue Service.

Table 2.4

Permitting and Administrative Costs for a Contained Aquaculture Enterprise Model

Item	Simulation Model Units
Liability Insurance	Cost Per Year
Capital Investment Insurance	Insurance Rate (%) on Capital Inputs
Legal Maintenance Fees	Cost Per Year
Taxes	Tax Rate (%) on Net Cash Flow
Bottom Lease or Habitat Fees for Growout Area	Cost Per Year Per Acre (cage) or sq ft (float)
Permits & Licenses Fees For Aquaculture Operation	Cost Per Year Per Operation

In order to operate a commercial oyster aquaculture enterprise, aquaculturists must adhere to a number of state laws and regulations. These regulations and requirements can impose time and administrative costs to an oyster aquaculture enterprise. In Virginia, a commercial oyster aquaculturist is required to lease oyster bottom from the State of Virginia as pursuant to § 28.2-603 of the Code of Virginia. Oyster bottom in Virginia has been delineated as either public oyster ground; know as “Baylor grounds,” or “barren bottom.” Barren bottom grounds, where oysters were not found at the time of delineation or surveying, can be leased by private leaseholders from the state. Oyster aquaculturists may rent available oyster ground from the state for a small annual rental charge of $1.50 per acre, if the lease ground is available, or sublease the ground from a current lessee if the current lease is currently occupied. Approximately 100,000 acres are currently held in private leases throughout the Chesapeake Bay (Mason 2008).

If new private oyster ground not delineated by the state is sought, the oyster aquaculturist must insure that the ground is not a Baylor ground, not within navigational jurisdiction, and not claimed by riparian landlords (pursuant to § 28.2-603 and § 28.2-1205 of the Code of Virginia). If applicable, an Application for Oyster Planting Ground, which includes an Oyster Ground Application Use Plan, must be made with the Virginia

Marine Resource Commission (VMRC) with an accompanying $25.00 application fee. At such time, the application is published in a newspaper for four continuous weeks, which allows for a comment period to proceed. The advertising cost in the newspaper varies and must be covered by the applicant. After comments are received, a decision is made by VMRC as to the status of the future of the application. If it is accepted, the grounds of interest are surveyed and a lessee is awarded private oyster grounds for a period of ten years. The surveying fee through VMRC is $510.00 with an additional $75.00 for each additional plat of bottom. Additional plats also cost a $12.00 recording fee and $1.50 assignment fee for each one (Mason 2008).

Once a lease is acquired, an oyster aquaculturist must apply for a General Permit for the use of temporary enclosures (e.g. cages) on leased oyster ground as pursuant to § 28.2-201 and § 28.2-603.1 of the Code of Virginia. In summary, the General Permit mandates that temporary shellfish growing enclosures (cages) may not be constructed of toxic materials, be placed on submerged aquatic vegetation (SAV), be placed within 100 feet (30m) of any shoreline or pier without the permission of the riparian landlord, exceed 250 structures per acre, or conflict with navigation interests (4 VAC 20-1130-50). Upon approval of the General Permit, the oyster aquaculturist will be charged a minimum of $125.00 for 500 structures and a maximum of $1,000.00 for 2,500 or more structures annually (4 VAC 20-1130-60).

If the oyster aquaculturist seeks to use floating structures, a Habitat Permit, which includes an application fee, must be filed with VMRC as pursuant to § 28.2-1204 and § 28.2-1205 of the Code of Virginia. When considering awarding a permit, VMRC is charged with determining how the potential floating aquaculture structures might affect marine fisheries resources, tidal wetlands, adjacent properties, water quality, and SAV. Once the permit is awarded, an annual $0.005 fee per square foot of impacted habitat is charged to the applicant.

After obtaining a General Permit for temporary shellfish aquaculture structures or a Habitat Permit for floating structures, aquaculturists must acquire licenses for the commercial harvesting oysters through oyster aquaculture as pursuant to § 28.2-201 of the Code of Virginia annually. These licenses include an Oyster Aquaculture Product Owner's Permit ($10.00) and an Oyster Aquaculture Harvester's Permit ($5.00) (4 VAC 20-1090-10). As pursuant to § 28.2-204 of the Code of Virginia, all Oyster Aquaculture Product Permit holders shall report the harvest of their oysters. If an oyster aquaculture lease falls within condemned shellfish waters, a permit from the Virginia Department of Health must be obtained in order for aquaculturists to relay their oysters before they can be sold or consumed (4 VAC 20-310-50).

Whether aquaculturists are using cages or floats, these regulations represent a possible time delay or opportunity cost to the oyster meat and nutrient production function. The time delay is a period that may elapse as a result of the time needed to acquire permits and licenses for an oyster aquaculture facility. If appropriate, the model has the ability to delay the time until production starts based on regulatory, administrative, and licensing time delays. The time delay, in years, is entered into the simulation program so that the total time allocated to regulatory issues can be calculated. The delay, therefore, creates an opportunity cost for the business or a time period where the firm is unprofitable or unable to receive cash flows from oysters and nutrient credits.

In some situations, it may take years to receive the necessary permits and licenses needed to conduct oyster aquaculture in Virginia.

2.3.1.4 Oyster Growth and Sales from Oysters

The financial simulation model assumes that oyster seed is purchased for either a nursery or growout starting stage. The total number of oysters produced for market is determined through an oyster aquaculture production function by user identified parameters through an input deck (see Appendix A.1 and A.2). Table 2.5 presents the oyster production function parameters required by the model. The oyster production function uses initial parameters such as the quantity of oysters stocked and the entering size. Oyster growth rates are critical elements to oyster production and are also identified parameters by the user as the number of months in the nursery and growout stages. The model tracks monthly oyster production. The sum of monthly harvest in a given year is summed to an annual harvest total.

Table 2.5

Oyster Growth Production Function Parameters for the Oyster Aquaculture Enterprise Model

Simulation Model Parameters	Simulation Model Parameters
Starting Stage: Nursery or Growout	Nursery and Growout Mortality
Nursery and Growout Starting Month	Oyster Size at Growout Stocking
Number of Months in Nursery and Growout Stage	Oyster Size at Harvest
Number of Times Nursery is Stocked	Growout Length at Market
Number of Oysters Stocked into Nursery or Growout	Price ($) per Oyster Type
% Ready for Market at time (*t*) 1,2,3	Permit and License Time Delay
% of Oysters to Each Market	

Specifying the month the enterprise stocks oysters into the nursery system, if applicable, initializes oyster production by the simulation model. The total number of oysters reared in the nursery is calculated in the model using user specified values of the duration of time oysters are held within the nursery, the quantity stocked into the nursery, and the nursery mortality rate. The growout mortality for the calculated number of oysters entering the growout stage from the nursery is a user identified model parameter if the aquaculturist is starting from the nursery stage. Growout mortality can represent total (i.e. cumulative) average oyster mortality from both natural causes and consistent disease mortality. If the production cycle begins at the growout stage, the starting month, quantity, entering size, and the mortality rate are entered into the model.

Oyster growth rates in the growout stage are estimated based on user supplied information on the number of months oysters spend in growout before reaching market size. Since oysters grow at different rates, the time of a given batch of oyster seed to reach market can be separated into three subgroups. The total percentage of harvestable oysters and the time for that subgroup to reach market size is entered for each subgroup. The percentage of oysters ready for market at a specific number of months is entered in order for the user to try to capture the variation in the time to market for one batch of oysters. For example, 25% of the number of oysters entering growout for one batch may be ready for market in 12 months, while 50% may be ready in 14 months, and the remaining 25% ready in 18 months. These values can be changed to reflect different influences of salinity, temperature, and production methods on oyster growth. Therefore, appropriate oyster growth is entered based on knowledge of a particular site and of different 'eco-zones' and genetic strains. Discretion to directly change growth allows a user to conduct sensitivity analysis in order to better understand how changing the time to market influences a return on an investment.

When the growout time is reached, oysters are assumed to be harvested during that month. The simulation program subsequently restocks the appropriate number of oysters back into the growout stage during the next month. However, due to poor algal (seston) densities in the ambient water column and the lack of oyster seed availability, the ability to restock during colder months[4] of the year is not allowed by the model. If oysters are harvested during winter months, the simulation program assumes that restocking occurs the following April.

The financial simulation model also has the ability to take risk into consideration when the financial returns to oyster aquaculture are determined. Annual percentage losses due to risk include oyster seed availability, weather events, and additional mortality from epizootic outbreaks. Disease, for the risk component of the simulation, is assumed to be additional epizootic outbreaks past the natural and consistent disease mortality captured within the entered cumulative growout mortality. This mortality percentage is applied only to oysters surviving the growout stage. Representative percentages of availability and loss can be entered for each year of the model simulation. The risk component allows for a potential investor or expanding oyster aquaculture facility to understand how risk variables influence their ability to meet a targeted rate of return.

Based on mortality and growth inputs described above, the model calculates the number of animals harvested per month, which are then summed to an annual value. The user inputs the oyster prices received in the halfshell and shucked market. The percentage of total harvest sold to the halfshell and shucked market is also identified by the user.

[4] November, December, January, February, March

Equation 2.1, therefore, calculates the total annual sales (*TS)* from the sale of oyster meat as:

$$TS_{Oysters_t} = \left(\left(\left(O_{Harvested(t)} \right) \left(\%_{Shucked} \right) \right) \left(P_{Shucked} \right) \right) + \left(\left(\left(O_{Harvested(t)} \right) \left(\%_{Halfshell} \right) \right) \left(P_{Halfshell} \right) \right) \quad (2.1)$$

where $O_{Harvested(t)}$ is the number of oysters harvested at year (*t),* $\%_{Shucked}$ is the percentage of oysters sold to the shucked oyster market, $P_{Shucked}$ is the price per oyster for the shucked market, $\%_{Halfshell}$ is the percentage of oysters sold to the halfshell market, and $P_{Halfshell}$ is the price per oyster for the halfshell market.

2.3.1.5 The Production of Nutrient Assimilation Credits from Oyster Aquaculture

Within the simulation model, oysters reaching harvest are assumed to remove nutrients from Chesapeake Bay waters by two processes: biomass sequestration and the nutrient denitrification process from oyster biodeposits. Nutrients from biodeposits that are buried on anaerobic sediment (~10% of biodeposits) are considered, in this model, not to leave ambient waters and are not used in nutrient removal credit calculations. These water quality services are expressed and quantified as a nutrient assimilation credit. A nutrient assimilation credit is defined as the total pounds (*lbs*) of total nitrogen (TN) and total phosphorus (TP) removed from Chesapeake Bay waters in a given year. Nutrient assimilation credits are a potential second source of revenue for the oyster enterprise. Total nutrient removal comes from estimates of *TN* and *TP* in oyster biomass and *TN* from the nitrification and denitrification processes.

The total quantity of nitrogen assimilation credits produced by an oyster aquaculture enterprise is calculated by equation 2.2.

$$TNC = (TN_B + TN_D) \tag{2.2}$$

where TNC is the nitrogen assimilation credit or the total amount (*lbs*) of N removed from harvested oyster biomass and biodeposit processes in a given year, TN_B is the total pounds of nutrients removed annually from harvested oyster tissue or biomass, and TN_D is the total amount of nutrients removed from the biodeposits processes of nitrification and denitrification in the form of N_2 gas. The P assimilation credit or the estimate of the total number of P pounds removed from an oyster aquaculture facility via oysters for a given year is defined as:

$$TPC = (TP_B) \tag{2.3}$$

Where, TPC is the P assimilation credit or the total amount (*lbs*) of P removed from Chesapeake Bay waters in a given year and TP_B is the total amount (*lbs)* of P removed from harvested oyster biomass.

2.3.1.5.1 Nutrients (TN and TP) Removed in Oyster Biomass

The model estimates the amount of dry weight for a single oyster based on the oyster's growout entry size and harvest size (a user identified parameter) in order to determine the amount of N and P (*lbs*) sequestered within the oyster's biomass. Total N and P (*lbs)* removed for all harvested oysters are subsequently calculated as follows:

$$TN_B = \left((Tn_B)\left(O_{Harvested(t)}\right)\right) \tag{2.4}$$

$$TP_B = \left((Tp_B)\left(O_{Harvested(t)}\right)\right) \tag{2.5}$$

where TN_B and TP_B are the total amount (*lbs)* of N and P, respectively, from all harvested oyster biomass, Tn_B is the amount of (*lbs*) of N from a single oyster of a specific size,

Tp_B is the amount of P from a single oyster of a specific size, and $O_{Harvested(t)}$ is the total number of oysters harvested per year (t).

The total mass load of TN and TP sequestered in a single oyster, denoted as (Tn) and (Tp), respectively, is the total dry weight of biomass harvested per oyster multiplied by the percentage (%) of TN and TP in the biomass. Equation 2.6 expresses the total N removed via oyster biomass.

$$Tn_B = ((Tn_m\%)(Dw_m)) + ((Tn_s\%)(Dw_s)) \tag{2.6}$$

In this equation, Tn_B is the total amount of N within a single oyster's biomass (meat and shell), $Tn_m\%$ represents the percent of total N in single oyster's meat, Dw_m represents the dry weight of a single oyster's meat, $Tn_s\%$ represents the percent of total N in single oyster's shell, and Dw_s represents the dry weight of a single oyster's shell. Equation 2.7 expresses the TP removed in a single oyster's biomass:

$$Tp_B = ((Tp_m\%)(Dw_m)) + ((Tp_s\%)(Dw_s)) \tag{2.7}$$

Here, Tp_B is the total amount of P within a single oyster's biomass (meat and shell), $Tp_m\%$ is the percent of TP in a single oyster's meat, Dw_m represents the dry weight of a single oyster's meat, $Tp_s\%$ represents the percent of TP in single oyster's shell, and Dw_s represents the dry weight of a single oyster's shell.

Model values of $Tn_m\%$, $Tn_s\%$, $Tp_m\%$, and $Tp_s\%$ are based on results from a field trial conducted by biologists from Virginia Commonwealth University's Department of Biology (Higgins, Brown, and Stephenson 2009). Oysters from a pilot oyster float aquaculture operation located on Spencer's Creek, off the Little Wicomico River in Northumberland County, Virginia, were used for the analysis. The float operation contained approximately 60,000 oysters. During the spring of 2008, 62 oysters were randomly sampled for analysis. Table 2.6 presents the descriptive statistics for the sample of oysters from the pilot oyster aquaculture operation.

Table 2.6

Summary Statistics for Spencer's Creek Oyster Float Aquaculture Field Trial

Item	Mean*	Std.Dev.*	Range*
Meat Dry Weight (g/oyster)	0.4g	.44g	.05-2.33g
Shell Dry Weight (g/oyster)	11.53g	11.04g	1.68-46.24g
Shell Total Length (mm)	55.4mm	14.9mm	29.1-88.5mm
Shell Total Height (mm)	18.5mm	6.6mm	10.4-38mm

*For 62 sampled oysters Source: (Higgins, Brown, and Stephenson 2009)

Oysters were dried to determine the percent amount of TN ($\%Tn$) and TP ($\%Tp$) in a single oyster's tissue and shell. Mean oyster tissue contained 8.15% N (Std.Dev.=0.80) and 0.82% P (Std.Dev.=0.07) in the tissue, while the shell contained 0.22% N (Std.Dev.=0.10) and 0.05% P (Std.Dev.=0.01) (Higgins, Brown, and Stephenson 2009). These findings are similar to those reported by Newell et al. (2005), who found that an average oyster in the Choptank River, Maryland contained 7% N and 0.80% P in the tissue, with 0.3% N and 0.10% P in the shell. The results from Higgins, Brown, and Stephenson (2009) were used as the model parameters for ($\%Tn$) and ($\%Tp$).

Single oyster dry weight (Dw_m and Dw_s, from equations 2.8 and 2.9) is dependent on the size of the oyster at harvest. Since the model reports the total number of oysters harvested at a particular size, observable oyster measurements at harvest are used to estimate dry weight. Previous research suggests that oyster biomass dry weight is correlated with oyster shell length (Livingston 2006; Livingston 2003). Using wild oysters from Apalachicola Bay, Florida Livingston determined that a 3-inch (76.2 mm) market sized oyster returns about .72 grams of dry tissue. Additionally, Newell et al.

(2005) found that a 3 inch or 76 mm oyster yields approximately one gram of dry tissue weight for wild Choptank River, Maryland oysters.

The relationship between dry weight of the meat (Dw_m) and shell (Dw_s) to shell length was determined using data from (Higgins, Brown, and Stephenson 2009). The statistical relationship between shell length and dry weight for oyster meat and oyster shell was estimated for sampled oysters from the Spencer's Creek float oyster aquaculture operation described above. For the 62 sampled oysters (shell and meat (g)), dry weight was regressed against shell length (mm). Following Livingston, a log-log specification was used. The data plots and the estimated statistical relationship are shown in Figure 2.6 and Figure 2.7.

The resulting equation, using shell length, for grams of dry weight for oyster meat was the following:

$$Dw_m = e^{((3.0544 \bullet \ln(SL)) - 13.394)} \tag{2.8}$$

where Dw_m is the dry weight of oyster meat (g) and SL is the total oyster shell length (mm). The R^2 value for this regression equals 0.7459. The independent variable (SL) therefore predicted ~75% of the variation in the dependent variable (Dw_m). The resulting equation for grams of dry weight for oyster shell was the following:

$$Dw_s = e^{((2.825 \bullet \ln(SL)) - 9.1673)} \tag{2.9}$$

where Dw_s is the dry weight of oyster shell and SL is the total oyster shell length. The R^2 value for this regression equals 0.8304. Therefore the independent variable (SL) predicted ~83% of the variation in the dependent variable (Dw_s).

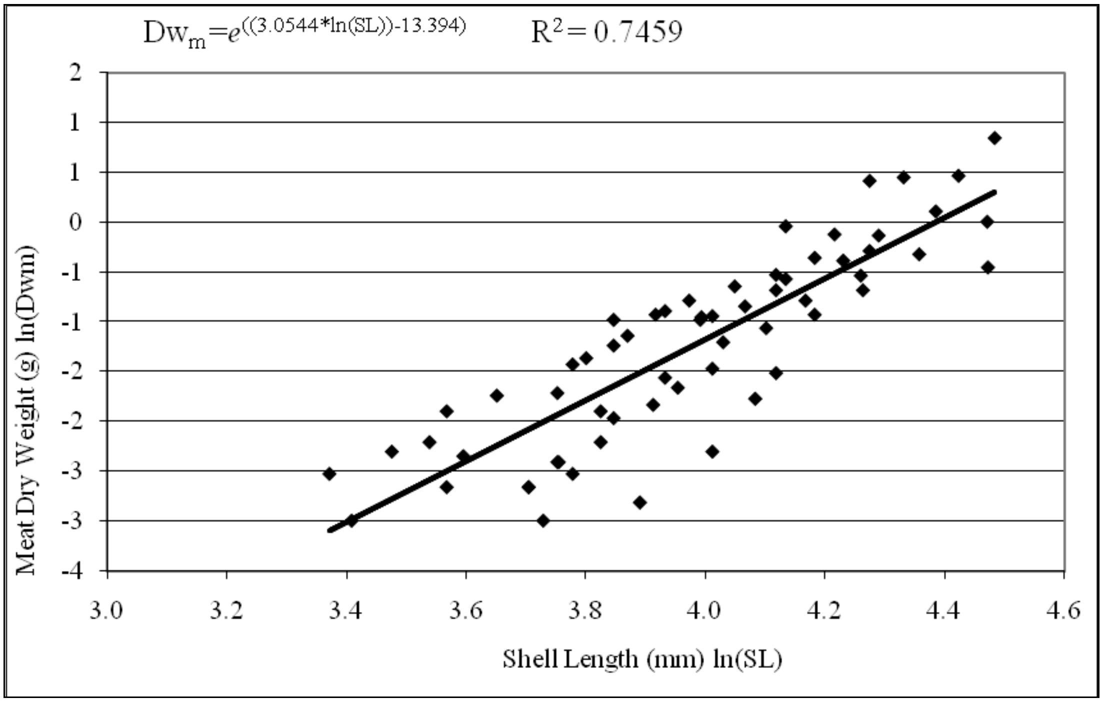

Figure 2.6. The Relationship between Spencer's Creek, VA Float Oyster Aquaculture Shell Length (SL) and Oyster Meat Dry Weight (Dw_m).

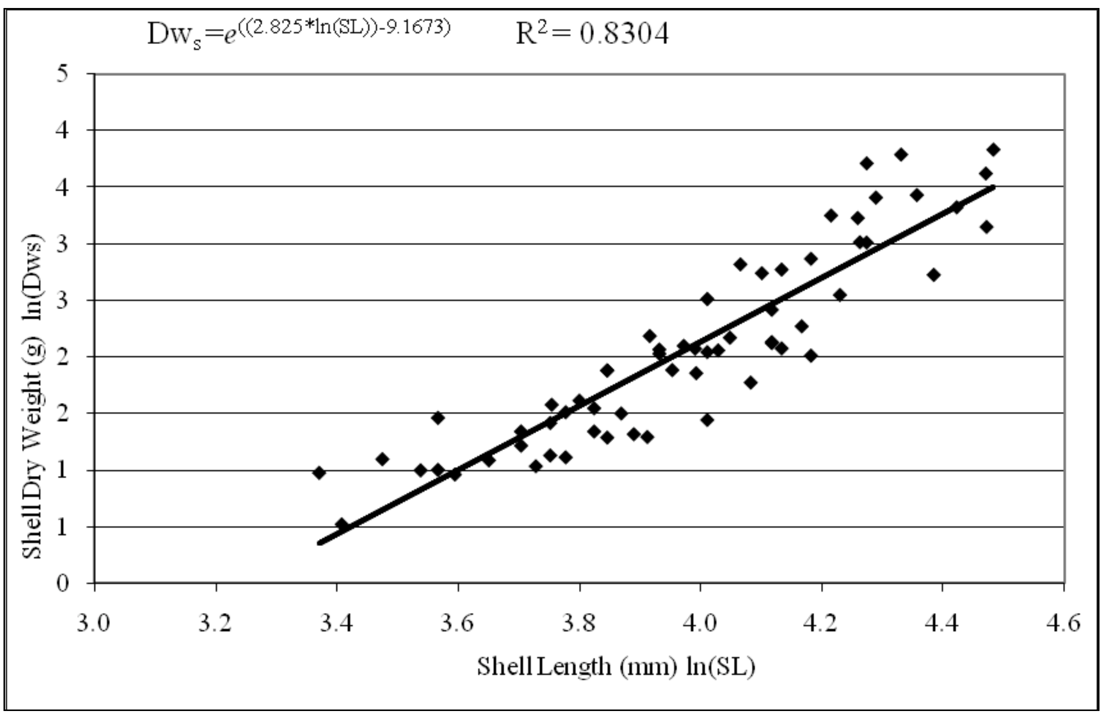

Figure 2.7. The Relationship between Spencer's Creek, VA Float Oyster Aquaculture Shell Length (SL) and Oyster Shell Dry Weight (Dw_s).

Using the determined equations above, the amount of shell and meat dry weight for an oyster of a specified size (mm) oyster can be determined. Substituting equation 2.8 and 2.9 for equation 2.6 and 2.7 yields the following equations for Tn_B and Tp_B, respectively:

$$Tn_B = ((Tn_m\%)(e^{((3.0544 \bullet \ln(SL)) - 13.394)})) + ((Tn_s\%)(e^{((2.825 \bullet \ln(SL)) - 9.1673)})) \quad (2.10)$$
$$Tp_B = ((Tp_m\%)(e^{((3.0544 \bullet \ln(SL)) - 13.394)})) + ((Tp_s\%)(e^{((2.825 \bullet \ln(SL)) - 9.1673)})) \quad (2.11)$$

Model users specify shell length (SL) at the time of harvest. Table 2.7 illustrates mass load estimates for N and P in oyster meat and shell for a 76.2 mm or 3-inch oyster and a 101.6 mm or 4-inch oyster using the procedure explained above.

Table 2.7

Estimated Dry Weight and N and P in 3 and 4-Inch (76-102mm) Oysters

Simulation Item	**3 inch oyster (76.2 mm)**	**4 inch oyster (101.6 mm)**
Dry Weight of Meat (g) (Dw_m)	0.854g	2.055g
Dry Weight of Shell (g) (Dw_s)	21.64g	48.77g
N in Meat (g) (Tn_m)	0.070g	0.168g
N in Shell (g) (Tn_s)	0.048g	0.109g
TN per Oyster Biomass (g) (Tn_B)	0.118g	0.277g
P in Meat (g) (Tp_m)	0.007g	0.017g
P in Shell (g) (Tp_s)	0.012g	0.026g
TP per Oyster Biomass (g) (Tp_B)	0.019g	0.043g

2.3.1.5.2 Nutrients (TN and TP) Removed by Oyster Biodeposit Denitrification (N^2)

The second source of nutrient removal occurs when organic N from oyster biodeposits is converted into N_2 gas through denitrification. Total N removed from denitrification is estimated in the model as a two-stage process. During the first stage, the total mass load of TN in biodeposit dry weight processed by an oyster is estimated. In the second stage, the total mass load of TN removed through denitrification is estimated as a percent of the total organic N multiplied by the dry weight processed.

Jordan (1987) found that the total dry weight of feces and pseudofeces (biodeposits) produced by *C. virginica* in a given time is related to the biodeposition rate at which oysters process organic material. Jordan (1987) defined the biodeposition rate—milligrams per grams of dry weight per hour (*mg/gdw/hr*)—as the amount of dry weight in milligrams of oyster biodeposits produced per gram of dry weight of oyster meat in one hour. Based on data from the Choptank River, MD, Jordan (1987) found that this rate is largely dependent on the seston density (*mg/l*) in the water column and ambient temperature (°*C*). To determine the biodeposition rate for a single oyster (B_r) for one hour, the following constant transformation function estimated by Jordan (1987) was used:

$$B_r = 10^{\left(-0.7459+(0.1478\bullet{}^{\circ}C)+\left(-0.00421\bullet{}^{\circ}C^2\right)+\left(0.000255\bullet\left(\left({}^{\circ}C^2\right)\bullet(S)\right)\right)+\left(-0.00000521\bullet\left(\left({}^{\circ}C^2\right)\bullet\left(S^2\right)\right)\right)\right)} \quad (2.12)$$

In this equation, B_r is the biodeposition rate (*mg/gdw/hr*), $^{\circ}C$ is degrees Celsius of the ambient water, and S is the seston density of ambient water in mg/l.

Ambient conditions—temperature (°C) and seston density (S)—are used within the biodeposition rate equation (2.12) on an average monthly basis for each month of the year. Temperature (°C) is represented as monthly averages for Spencer's Creek, VA, while seston density, *S* (*mg/l*), is represented as monthly averages for the Choptank River, Maryland throughout the year as recorded by Newell et al. (2005). These monthly averages for seston density and temperature were used in the simulation model and are presented in Table 2.8.

Table 2.8

Monthly Average Water Temperature °C and Seston Concentrations (*mg/l*) Used within the Simulation Model.

Month	Water Temp °C	Seston (*mg/l*)
Jan	5	11.4
Feb	5	14.3
Mar	8	13.2
Apr	13	16.7
May	19	14.5
Jun	25	10.7
Jul	29	13.0
Aug	29	13.0
Sept	27	13.4
Oct	21	12.8
Nov	13	9.4
Dec	8	11.4

Total mass load estimates of the dry weight of biodeposits produced and available for possible nitrogen processing per month were calculated. Biodeposition rates depend on oyster size, where the rate is the number of *mg* of biodeposit dry weight produced each *hour* for each *gram* of oyster meat dry weight. The size of an oyster at any given month was calculated using an oyster's growout entry and harvest size and a linear growth function. In order for the total dry weight of biodeposits produced in any given month by a single oyster to be determined, the calculated amount of oyster tissue dry weight (*gdw)*, given the size of the oyster for that month, was multiplied by the biodeposition rate (*mg/hr)* for that month using the following equation:

$$TD_w = ((B_r)(Dw_m)) \tag{2.13}$$

where TD_w is the total estimated amount of biodeposit dry weight for a single oyster on a monthly basis, B_r is the biodeposition rate in *mg/gdw/hr*, and Dw_m is the estimated amount of meat dry weight determined from equation 2.8 for a single oyster. The simulation model subsequently converted the biodeposition rate into grams per gram of dry weight of biodeposits per month (*g/gdw/month*) and summed the dry weight of biodeposits produced based on the number of months the oyster spent in the water. A resulting dry weight amount of biodeposits produced per oyster for a single oysters time in the water was therefore determined.

Using the total estimated amount of dry weight of biodeposits for a single oyster's time in the water and the proportion of TN in one gram of oyster biodeposit dry weight, one can calculate the amount of N within an oysters' biodeposits' dry weight. The mass load of N (.0048 *g* of N) per *g* of dry weight of oyster biodeposits, derived from Jordan (1987), was used in determining the total amount of N within the mass load of oyster biodeposits (Tn_{BD}) through the use of the following equation:

$$Tn_{BD} = ((TDw_t)(B_n)) \tag{2.14}$$

where Tn_{BD} is the total amount of N within the estimated amount of dry weight of biodeposits for a single oyster's time in the water, TDw_t is the total dry weight amount of estimated biodeposits for a single oyster in time in the water, and B_n is the percent of TN in oyster biodeposits.

A denitrification percentage was then used to determine the total amount of N processed into N_2 gas through nitrification and denitrification. Newell et al. (2005) references literature that states that 20% to 70% of N in marine ecosystems is released in the form of N_2 gas through the denitrification process. The percentage of TN denitrified, therefore, can be changed within the simulation model in order for users to evaluate how denitrification rates influence the amount of N removed from Bay waters. Thus, this percentage is not a fixed constant in the simulation model, but, rather, is entered directly by the user. Equation 2.15 was used for the determination of the total amount of N removed from the denitrification process.

$$Tn_D = ((Tn_{BD})(D_{\%})) \tag{2.15}$$

In this equation, Tn_D is the total N removed (*g*) from biodeposit denitrification for a single oyster, Tn_{BD} is the total amount of N within a single oysters' biodeposits, and $D_{\%}$ is the percentage of total TN in the biodeposists that was denitrified. Total calculated grams of N removed from oyster biodeposit denitrification per oyster were converted to a per pound basis so that the total number of pounds removed per year based on the total number of oysters harvested per year could be determined.

The total number of pounds (*lbs*) of N removed via nitrification and denitrification for all harvested oysters in a particular year was determined through the multiplication of Tn_D per oyster by the total number of oysters harvested that year. Equation 2.16 was used for this calculation.

$$TN_{D_t} = \left((Tn_D)\left(O_{Harvested(t)}\right)\right) \tag{2.16}$$

In this equation, TN_{D_t} is the total amount of N removed (*lbs*) for all harvested oysters per year (*t*), Tn_D is the total amount of N removed from denitrification from a single oyster's biodeposits, and $O_{Harvested(t)}$ is the total amount of oysters harvested per year (*t*). Any filtering capacity done by oysters that die prior to harvest is not included in the simulation model estimates of the denitrified TN load.

2.3.1.5.3 The Oyster Aquaculture Bio-economic Model Estimation of Cash Flows and the N Credit Price.

Cash flow from oyster aquaculture enterprises in time period t, in the absence of nutrient credits, is calculated using equation 2.17.

$$CF_t = \left(TS_{Oysters_t} + TS_{Salvage_t}\right) - \left(TC_{AP\,t} + TC_{OM\,t} + I_t\right) \qquad (2.17)$$

Where, in time period t, CF is net cash flow from oyster operations, $TS_{Oysters_t}$ is total annual sales from halfshell and shucked oysters, $TS_{Salvage_t}$ is total annual salvage sales, TC_{AP_t} is total annual costs from administrative and permitting, $TC_{OM\,t}$ is total annual costs from operation and maintenance, and I_t is capital investments.

Assuming the facility uses equity or retained earnings to finance the capital items necessary for operations, the internal rate of return (IRR) on the investment is calculated using equation 2.18.

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1 + IRR)^t} = 0 \qquad (2.18)$$

Where, CF_t is cash flow from equation 2.17. The IRR or discount rate is the rate where net present value (NPV) for the ten-year cash flow equals zero. An IRR for the oyster aquaculture facility is subsequently reported.

An oyster aquaculturist can conceptually, however, also receive sales or payments from nutrient credits. Total nutrient sales or payments for time period t are calculated using equation 2.19.

$$NC_t = \left(\left(P_{PAC}\right)\left(TP\right)\right) + \left(\left(P_{NAC}\right)\left(TN\right)\right) \qquad (2.19)$$

Where, in time period t, NC is total sales or payments from nutrient credits, P_{PAC} is the price per phosphorus (P) credit, TP is the total amount of P removed (*lbs)*, P_{NAC} is the price per nitrogen (N) credit, and TN is the total amount of N removed (*lbs*).

To determine what the N credit price would need to be to meet a user entered targeted rate of return (TRR) equation 2.20 is used.

$$NPV = \sum_{t=0}^{n} \frac{CF_t + NC_t}{(1+TRR)^t} = 0 \qquad (2.20)$$

Where, CF_t is cash flow from equation 2.17, NC_t is nutrient credit sales from equation 2.19 and TRR is the user specified targeted rate of return. In order to find what the N credit price per unit (P_{NAC}) would need to be, the simulation model searches for a price where the total sales from nitrogen assimilation credits in addition to the fixed total sales from phosphorus assimilation credits and cash flows (CF_t) from the oyster aquaculture enterprise equals the user specified financial objective or TRR. The model subsequently reports the number of N and P pounds removed and the N credit price needed to allow the firm to achieve the entered financial goal (i.e. TRR).

Chapter 3

The Nutrient Assimilation Baseline Credit Price and Sensitivity Analysis for Oyster Aquaculture Enterprises in the Chesapeake Bay

3.1 Introduction

Given a range of assumptions, this chapter delineates what the required nutrient removal credit payment would need to be to reach a target rate of return for aquaculture oyster operations. The financial simulation program described in chapter two is used to estimate this required nitrogen (N) assimilative credit payment.

The required payments for both cage and float enterprises are analyzed. For each of the two hypothetical enterprises evaluated, inputs, input prices, and oyster selling prices are defined. The assumptions used within the model represent mid-point or average parameters and values for a representative cage and float oyster aquaculture enterprise in Virginia's Chesapeake Bay. These two oyster aquaculture investments were used as the baseline for all subsequent analysis. If the sale of oysters alone was insufficient to achieve a targeted rate of return, an N credit price was determined in order to achieve a targeted rate of return (TRR) for an oyster aquaculture enterprise.

Next, sensitivity analysis was conducted on key determinants to the financial viability of the oyster enterprises to determine how N credit prices may change given different assumptions about mortality, the denitrification removal percentage, halfshell oyster prices in combination with the percentage sold to halfshell market, and the average total number of months an oyster grows within the combined nursery and growout stages. The payment (N credit price) for N removal, under these scenarios, is compared to current estimated costs of N removal from point and nonpoint source reductions.

3.2 The Baseline Oyster Aquaculture Enterprise Scenario

3.2.1 The Baseline Cage Oyster Aquaculture Enterprise Scenario

The representative oyster off-bottom cage investment, while hypothetical, is broadly characteristic of the commercial cage operations currently operating in the Virginia Chesapeake Bay region (Erskine 2008; Gallivan 2008; Kallen et al. 2001; Leggett 2008; Lipton 2007; Pelz 2008; Vigliotta 2008; Wieland 2007). The enterprise is geographically situated within the middle-Bay region with an intermediate to high salinity that ranges between 11-30‰. The cage oyster aquaculture enterprise is assumed to have a lease and a General Permit from the State of Virginia for 100 acres (40 hectares) of shellfish bottom, which is located approximately three miles (5km or~2.6 nautical miles) from the 200-foot (61 meters) dock of the enterprise (Table 3.1).

The cage operation is assumed to purchase seed from a hatchery at a total shell length of 1-2mm (.04-.07 inches) and stock the seed in a nursery upweller system three times each production year. The upweller has a capacity of approximately two million oysters. A total of four million oysters are assumed to be stocked each season into the nursery upweller. Moreover, approximately 1.33 million oysters are stocked into the upweller three different times during the production season. With the season starting in April, oysters stay in the upweller for two months during each stocking and experience a 10% mortality loss. Oysters are assumed to be moved from the nursery to the growout stage at 13mm (0.5 inches) (Table 3.1).

Oysters are initially placed into the growout stage using nursery sized small mesh cages, which hold an average of 5,000 oysters per cage at the end of the stage. Oysters are later transferred to standard growout cages to undergo final growout. The standard growout cage holds approximately 1,500 oysters at harvest. Based on beginning initial seed purchases, mortality, cage stocking densities, expanded cage buffer, the model estimates the oyster aquaculture cage enterprise owns 2,526 cages. Transportation of oysters to and from growout leased oyster grounds takes place using a barge and boom/crane arrangement. The cumulative mortality rate for the growout stage is assumed to be 30%. Oysters spend an average of 16 months with a minimum of 14 months and a maximum of 18 months in the growout stage in order to reach a market size of 76mm (3inches) in total shell length (Table 3.1). With the two months in the nursery stage, total time from nursery entry to market ranges 16 to 20 months, or an average of 18 total months in the production process.

Only harvested oysters are assumed to produce nutrient assimilation credits. The amount of N and phosphorus (P) in harvested oyster biomass and the amount of N removed through denitrification is calculated assuming a 3-inch (76mm) oyster and the equations and procedures described in Chapter 2. Since the filtration rate of seed oysters is trivial, the N removed from denitrification is calculated beginning when oysters enter the growout stage. To prevent partial submersion of cages in the bottom sediments, a fairly solid (sandy) bottom is necessary for cage bottom aquaculture. For the cage scenario, it was assumed that the bottom conditions of the oyster aquaculture enterprise were partially sandy and 20% of the total amount of N within oyster biodeposits was denitrified and released into the atmosphere as N_2 gas (Table 3.1).

For purposes of this analysis, if the oyster aquaculture facility receives credit for nutrient assimilation services, a credit price of $5.04 per pound of P was assumed. The Virginia State Water Quality Control Board outlines this credit price within state regulation number 9 VAC 25-820-10. The simulation program calculates the price of an N assimilation credit needed to achieve the target rate of return. Under some situations within the *Chesapeake Bay Watershed Nutrient Credit Exchange Program* point sources are allowed to offset their nutrient loads buy purchasing nonpoint source credits (Virginia Code § 62.1-44.19:12-19).

It is assumed that the cage oyster aquaculture enterprise grows oysters within non-condemned waters as determined by the Virginia Department of Health (VDH). Consequently, oysters that reach market size go directly to market without the need for post-harvest treatment. All oysters harvested at 76mm (3inches) in total shell length are assumed to be sold to the halfshell (90%) or shucked fresh market (10%). Where appropriate, market prices per oyster were held constant at $0.14 per shucked oyster. Halfshell oyster prices were held constant at $0.28 per oyster due to the large scale of cage oyster aquaculture enterprises and the fact that these operations market their oysters to larger seafood distribution markets (Table 3.1). The targeted rate of return (TRR) for the cage oyster aquaculture enterprise is assumed to be 12%, as this rate of return needed to be sufficiently high to compensate for returns for the level of risk. Oysters are transported to market via a seafood trucking service.

Table 3.1

Summary of Baseline Simulation Parameters for a Representative Cage Oyster Aquaculture Enterprise in Virginia's Chesapeake Bay

Item	Range	Simulation Value
Acres (ac) / Hectare (ha) of Leased Shellfish Bottom	25-300ac (10-121ha)	100ac (40 ha)
Length of Dock	100-500ft (30-152m)	200ft (61m)
Distance to Growout Location	0-10mi (0-16km)	3mi (5km)
Starting Stage	Nursery or Growout	Nursery
Nursery Starting Month	February to May	April
Number of Months in Nursery	1-3 Months	2 Months
Number of Times Nursery is Stocked Per Season	2-4 Times	3 Times
Size (inches) entering Growout Production Stage	.39-1in (10mm–25mm)	.5in (13mm)
Nursery Mortality Rate	10-30%	10%
Number of Oysters Stocked in Nursery Per Season	1-8 Million	4 Million
Number of Cages	0-4,000	2,526
Number of Different Types of Cages	1 or 2 Types	2 Types
Grow-out Stocking Density Per Nursery Cage at End of Stage	1,000-10,000	5,000
Grow-out Stocking Density Per Standard Cage at End of Stage	1,000-5,000	1,500
Cumulative Growout Mortality Rate	10-60%	30%
Total Number of Months to Market for First 25% of Oysters	10-16	16
Total Number of Months to Market for Middle 50% of Oysters	14-20	18
Total Number of Months to Market for Final 25% of Oysters	18-26	20
Size (inches) leaving Growout Production Stage	3-4in (76mm-102mm)	3in (76mm)
Oyster Relaying	Yes or No	No
Post Harvest Treatment	Yes or No	No
Denitrification % Removal Rate	0-70%	20%
% of Oysters to Halfshell Market	0-100%	90%
% of Oysters to Shucked Market	0-100%	10%
Halfshell Oyster Market Prices Per Oyster	$.18-$.38	$.28
Shucked Oyster Market Prices Per Oyster	$.08-$.21	$.14
Price Per *lbs* of P	$0.00-$50.00	$5.04

Costs for the representative cage culture operation in the Bay include capital investment costs, administrative and permitting costs, and operational and management costs. The firm is assumed to own land and a building for the operation of the enterprise, while a small truck, dock, sorters, boat/barge, power tools, cages, and nursery upweller are needed to be purchased for the oyster enterprise. Capital investment costs for cage oyster aquaculture are presented in Table 3.2. The items are listed with a range of the cost, subsequent model parameter value, and salvage value. The corresponding life, in years of the capital investment cost, is listed in addition to the percent in which the aquaculture facility uses a certain item strictly for cage oyster aquaculture production. Salvage cost and payments are also listed. See section 2.3.1.1. for further details on how costs were determined and calculated for use within the simulation model.

Table 3.2

Summary of Baseline Capital Investment Costs for a Representative Cage Oyster Aquaculture Production Enterprise in Virginia's Chesapeake Bay

Capital Investment Cost Items	Cost Range	Cost	Salvage Value [c]	Life	% to Oyster Aquaculture
Nursery System	$5k - $20k	$15k	$-500	10	75%
Nursery Sorter	$500 - $15k	$9k	$100	10	75%
Nursery Growout Cage	$85 - $300	$250	$-.50	10	100%
Standard Growout Cage	$85 - $300	$225	$-.50	10	100%
Misc Per Cage [a]	$5 - $25	$10	$-.10	5	100%
Growout Sorter	$500 - $15k	$8k	$100	10	100%
Office Equipment	$500 - $10k	$5k	$100	5	75%
Facility Equipment [b]	$0 - $20k	$10k	$250	10	75%
Dock	$10k - $50k	$22k	$-500	30	75%
Truck / Vehicle	$10k - $50k	$10k	$5k	10	75%
Boat / Barge	$1k - $50k	$35k	$5k	10	75%

[a] Anchors, lines, bags, barriers, buoys.
[b] Tools, power washer, etc.
[c] Negative salvage values represent the per unit cost of disposal while positive values are payments per unit.

Annual permitting and administrative, and annual operational and management costs for the representative cage oyster aquaculture production facility in the Chesapeake Bay are listed in Table 3.3. The table includes a range of the costs, the simulation values used, as well as the respective units and quantity for each cost. Labor values were calculated based on estimates for the number of man-hours per cage for each stage of production. A 7.65% FICA payroll employment tax was incorporated into the total labor costs. Halfshell oysters are shipped to market on common carrier seafood trucks at a cost of $2.50 per box of 100 market-sized oysters. Oysters sold to the shucked market travel to shucking houses using a small truck owned by the oyster aquaculture enterprise.

Table 3.3

Summary of Baseline Annual Permitting and Administrative and Annual Operational and Management Costs for a Representative Cage Oyster Aquaculture Production Enterprise in Virginia's Chesapeake Bay

Annual Permitting and Administrative Cost Items	Cost Range	Sim. Value	Unit	Quantity	Cost
Lease Fee / Acre (.4ha)	$1.50	$1.50	/Acre	100	$150
Permit Fee Per # of Cages Used[a]	$125-$1,000	$1,000	/Year	1	$1,000
License	$15	$15.00	/Year	1	$15
Insurance (Liability & Additional)	$500 - $2,000	$1,000	/Year	1	$1,000
Insurance Rate (%) on Capital	1% - 5%	3%	$726,632 [b]	1	$21,799
Legal Maintenance for Business	$500 - $1,500	$1,000	/Year	1	$1,000
Income Tax Percentage (%)	10% -35%	28%	$110,088 [c]	1	$30,825 [d]
Annual Operational and Management Cost Items	**Cost Range**	**Sim. Value**	**Unit**	**Quantity**	**Cost**
Nursery Oyster Seed	$7.00 - $8.00	$7.5	Oysters	1000	$7.50
Packing & Shipping Supplies	$1.00 - $5.00	$2.50	Oysters	100	$2.50
Oyster Shipping	$2.00-$5.00	$2.50	Oysters	100	$2.50
Miscellaneous (Marketing)	$200-$3,500	$1,500	/Year	1	$1,500
Nursery Labor [e]	$7 - $15	$12	Hrs/Batch	70	$904
Sorting and Growout Preparation Labor [e]	$7 - $15	$12	Hrs/Cage	.75	$10
Growout Labor [e]	$7 - $15	$12	Hrs/Cage	1.5	$19
Harvest and Market Preparation Labor [e]	$7 - $15	$12	Hrs/Cage	2.	$26
Nursery and General Electricity (kWh)	$.05 - $.25	$.10	kWh	1	$.10
Boat/Barge Diesel Fuel ($/Gal. (3.4L))	$1.50 - $5.00	$4.00	Gal. (3.4L)	1	$4.00
Vehicle/Truck Fuel	$1.00 - $4.00	$3.00	Gal. (3.4L)	1	$3.00
Repair & Equipment Maintenance	$250 - $2,500	$1,500	/Year	1	$1,500
Office Overhead	$150 - $1,500	$1,000	/Year	1	$1,000

[a] The oyster aquaculturist is charged a minimum of $125.00 for 500 structures and a maximum of $1,000.00 for 2,500 or more structures annually in Virginia. —(4 VAC 20-1130-50).
[b] Total capital investment.
[c] Average net cash flow per year over ten years before tax.
[d] Average tax per year over ten years.
[e] Assumes 7.65% FICA in final calculation in model.

3.2.2 The Baseline Float Oyster Aquaculture Enterprise Scenario

Similar to the baseline cage oyster aquaculture enterprise, the oyster float enterprise described here is based on a representative commercial size operation found in the Chesapeake Bay of Virginia (Erskine 2008; Gallivan 2008; Kallen et al. 2001; Leggett 2008; Lipton 2007; Pelz 2008; Vigliotta 2008; Wieland 2007). With an intermediate to high salinity range of 11-30‰ the float oyster aquaculture enterprise is located in the mid-section of the Chesapeake Bay. The waters of the location are non-condemned for the harvest of shellfish by the VDH. The float oyster aquaculture enterprise has a habitat permit from the State of Virginia for 43,560 sq.ft (1 acre or 4,047sq.m) of potentially impacted marine resources. The floating oyster production units are juxtaposed with the 300-foot (91m) dock of the enterprise (Table 3.4).

The floating oyster aquaculture operation purchases seed from a hatchery at a total shell length of approximately 2 mm (~.07 inches). Starting in April of each year oysters are stocked three times per season in a nursery upweller system that holds approximately 500,000 seed oysters per batch. Since existing float operations in the Bay tend to operate at a smaller scale than cage operations, this float production scenario assumes that a total of one million oysters are stocked into the nursery per season. Moreover, approximately 333,000 oysters are stocked into the nursery three times during one production season. Oysters stay in the nursery upweller for two months and experience a mortality loss near 10% (Table 3.4).

Oysters enter the growout stage at 25mm (1-inch) and spend a minimum of 12 months and a maximum of 16 months in the stage in order to reach a market size of 76mm (3inches) in total shell length. One type of float is used for growout production, which has a stocking density of approximately 1,000 oysters per float. Based on beginning initial seed purchases, mortality, cage stocking densities, and additional float buffer, the model estimates the oyster aquaculture float enterprise owns 711 floats (Table 3.4). Total time from nursery entry to market therefore ranges 14 to 18 months, with an average of 16 months. Cumulative mortality for the growout stage is 25%.

Because harvest size filter-feeding oysters have removed nutrients from the water, they might be eligible assimilation credit payments. With the equations defined in Chapter 2, the quantity of N and P removed via harvested biomass and through N denitrification was calculated for the duration of time a 1-inch (25mm) oyster enters the growout stage until removal for harvest at 3 inches (76mm). While a float aquaculture enterprise can be sited over any bottom condition, a float production system can more easily be sited over less firm bottoms that generally have higher organic content. A partially organic benthic community was assumed with the baseline quantity of N processed through denitrification and released as N_2 gas being 30%. Similar to the cage P credit, a potential P credit of \$5.04 was held constant when running the financial simulation model (Table 3.4).

Once reaching market size (3in or 76mm), oysters ready for market from the enterprise are marketed to the halfshell (90%) or fresh shucked (10%) market. Market prices per oyster are assumed to be \$0.14 per shucked oyster and \$0.38 per halfshell oyster. The baseline halfshell oyster price of \$0.38 was used for float oyster aquaculture enterprises as these oyster aquaculture enterprises are typically smaller in scale and focus their direct marketing efforts toward high-end local restaurants and farmers markets, which typically receive higher prices (Table 3.4). One truck is owned by the enterprise and used to transport oysters to local restaurants and farmers markets. The targeted rate of return for the float oyster aquaculture enterprise was 12%.

Table 3.4

Summary of Baseline Simulation Parameters for a Representative Float Oyster Aquaculture Enterprise in Virginia's Chesapeake Bay

Parameters	**Range**	**Simulation Value**
Potentially Impacted Square Feet (sq/ft)	21,780-87,120sq/ft	43,560sq/ft
Potentially Impacted Square Meters (sq/m)	2,023-8,093sq/m	4,047sq/m
Length of Dock	100-500ft (30-152m)	300ft (91m)
Distance to Growout Location	0-1mi (1.6km)	0.0mi (0km)
Starting Stage	Nursery or Growout	Nursery
Nursery Starting Month	February to May	April
Number of Months in Nursery	1-3 Months	2 Months
Number of Times Nursery is Stocked Per Season	2-4 Times	3 Times
Size (inches) entering Growout Production Stage	0.39-1in (10-25mm)	1in (25mm)
Nursery Mortality Rate	10-30%	10%
Number of Oysters Stocked in Nursery Per Season	1-4 Million	1 Million
Number of Floats	0-3,000	711
Number of Different Types of Floats	1 or 2 Types	1 Type
Growout Stocking Density Per Float at End of Stage	500-1,500	1,000
Cumulative Growout Mortality Rate	10-60%	25%
Total Number of Months to Market for First 25% of Oysters	8-14	14
Total Number of Months to Market for Middle 50% of Oysters	12-18	16
Total Number of Months to Market for Final 25% of Oysters	16-24	18
Size (inches) leaving Growout Production Stage	3-4in (76mm-102mm)	3in (76mm)
Oyster Relaying	Yes or No	No
Post Harvest Treatment	Yes or No	No
Denitrification % Removal Rate	20-70%	30%
% of Oysters to Halfshell Market	0-100%	90%
% of Oysters to Shucked Market	0-100%	10%
Halfshell Oyster Market Prices Per Oyster	$0.28-$0.48	$0.38
Shucked Oyster Market Prices Per Oyster	$0.08-$0.21	$0.14
Price Per *lbs* of Phosphorus (P)	$0.00-$50.00	$5.04

The representative float culture operation in the Bay incurs costs similar to the cage oyster aquaculture enterprise. Costs for the float operation include capital investment costs, administrative, permitting, and operational and management costs.

Capital investment costs and associated salvage values for capital investments for float culture are the first costs described (Table 3.5). The per-unit cost used in the model for a particular item is identified as well as the range of the cost for a particular item. The percent in which a float oyster aquaculture facility uses each of the cost items is presented, along with an anticipated life in years. Annual salvage accounting payments and disposal costs are also listed and were accounted for given the salvage payment or cost and the anticipated life of the item. Section 2.3.1.1. further explains how costs were used within the simulation model.

Table 3.5

Summary of Baseline Capital Investment Costs for a Representative Float Oyster Aquaculture Production Enterprise in Virginia's Chesapeake Bay

Capital Investment Cost Items	Cost Range	Cost	Salvage Value [c]	Life	% to Oyster Aquaculture
Nursery System	$5k - $20k	$7.5k	$-250	5	100%
Nursery Sorter	$500 - $15k	$9k	$100	10	100%
Growout Float	$50 - $200	$125	$-0.25	5	100%
MISC Per Float[a]	$5 - $25	$8	$-0.10	5	100%
Growout Sorter	$500 - $15k	$8k	$100	10	100%
Office Equipment	$500-$10k	$5k	$100	5	100%
Facility Equipment[b]	$0-$20k	$8k	$200	10	100%
Dock	$10k-$50k	$33k	$-750	30	100%
Truck / Vehicle	$10k-$50k	$10k	$5k	10	100%
Boat / Barge	$1k-$50k	$9.5k	$4.5k	10	100%

[a] Anchors, lines, bags, barriers, buoys.
[b] Tools, power washer, etc.
[c] Negative salvage values represent the per unit cost of disposal while positive values are payments per unit.

The final costs for a representative float oyster aquaculture production facility in the Chesapeake Bay are the annual permitting and administrative and annual operational and management costs. These costs are presented in Table 3.6. A range for the cost items are presented in combination with the cost value used in the simulation model. The units and quantity for each cost item are also presented. Total labor costs were calculated using the total number of man hours required for each stage of the production process, the hourly wage per man hour, and a 7.65% labor FICA payroll employment tax.

Table 3.6

Summary of Baseline Annual Permitting and Administrative and Annual Operational and Management Costs for a Representative Float Oyster Aquaculture Production Enterprise in Virginia's Chesapeake Bay

Annual Permitting and Administrative Cost Items	Cost Range	Sim. Value	Unit	Quantity	Cost
Habitat Fee (sq/ft)	$0.005	$.005	/sq/ft	43,560	$218
Habitat Fee (sq/m)	$0.005	$.005	/.093 sq/m	4,047	$218
License	$15	$15	/Year	1	$15
Insurance (Liability & Additional)	$500 - $2,000	$1,000	/Year	1	$1,000
Insurance Rate (%) on Capital	1% - 5%	3%	$184,500[a]	1	$5,535
Legal Maintenance for Business	$500 - $1,500	$1,000	/Year	1	$1,000
Income Tax Percentage (%)	10% – 35%	28%	$32,245[b]	1	$9,029 [c]
Annual Operational and Management Cost Items	**Cost Range**	**Sim. Value**	**Unit**	**Quantity**	**Cost**
Nursery Oyster Seed	$7.00 - $8.00	$7.50	Oysters	1000	$7.50
Packing & Shipping Supplies	$1.00 - $5.00	$2.50	Oysters	100	$2.50
Miscellaneous (Marketing)	$200-$3,500	$1,500	/Year	1	$1,500
Nursery Labor[d]	$7 - $15	$12	Hrs/Batch	60	$775
Sorting and Growout Preparation Labor[d]	$7 - $15	$12	Hrs/Float	1.75	$23
Growout Labor [d]	$7 - $15	$12	Hrs/Float	2.50	$32
Harvest and Market Preparation Labor [d]	$7 - $15	$12	Hrs/Float	3.00	$39
Nursery and General Electricity (kWh)	$0.05 - $0.25	$0.10	kWh	1	$0.10
Boat/Barge Diesel Fuel ($/Gal. (3.4L)	$1.50 - $5.00	$4.00	Gal. (3.4L)	1	$4.00
Vehicle/Truck Fuel	$1.00 - $4.00	$3.00	Gal. (3.4L)	1	$3.00
Repair & Equipment Maintenance	$250 - $2,500	$1,500	/Year	1	$1,500
Office Overhead	$150 - $1,500	$1,000	/Year	1	$1,000

[a] Total capital investment.
[b] Average net cash flow per year over ten years before tax.
[c] Average tax per year over ten years.
[d] Assumes 7.65% FICA in final calculation in model.

3.3 Baseline Results

The simulation results for the representative cage and float operation are summarized in Table 3.7. Results include the average number of oysters produced per year over ten years, the average number of pounds of N removed via harvest biomass and denitrification per year over ten years, the average number of pounds of P removed per year over ten years, and the IRR over ten years. The internal rate of return was initially calculated and reported in the absence of any additional cash flow from N or P nutrient credits.

Table 3.7.

Results from the Baseline Simulation for a Representative Cage and Float Oyster Aquaculture Production Enterprise in Virginia's Chesapeake Bay in the Absence of a Nutrient Credit

Item	Cage Simulation Result	Float Simulation Result
Average Number of Oysters to Market Per Year over Ten Years	1,449,000	438,750
Average Number of *lbs* of N removed Per Year over Ten Years	913	332
Average Number of *lbs* of P removed Per Year over Ten Years	60	18
Average Cost to Produce One Oyster Per Year over Ten Years	$0.20	$0.29
Ten Year IRR over Ten Years	11.6%	10.0%

In the absence of N and P nutrient assimilation credits, a representative cage oyster aquaculture enterprise harvested an average of 1,449,000 oysters per year over ten years and had an 11.6% IRR. Due to the variable growth and cyclical nature of production over the ten year simulation, oyster harvest varied from year to year from an average of 1,260,000 oysters to 2,520,000 oysters sold to the market.

Significant costs for the representative cage enterprise originated from the cage production unit capital investments and annual labor costs. Capital investment costs for cages constituted 84% of the total upfront capital investment costs for the enterprise while annual average labor costs were 32% of the annual average variable costs. Production costs were found to be $0.20 per oyster[5] (Table 3.7).

[5] The cost per oyster was calculated as the annualized value of all costs discounted at .05% and divided by the average annual harvest.

Assuming a denitrification rate of 20%, the facility removes an average of 913 pounds of nitrogen per year over ten years and an average of 60 pounds of phosphorus per year over ten years. The procedure described in Chapter 2 to calculate the average number of pounds of N removed through the nitrification and denitrification appears to yield a conservative estimate of the amount of denitrification that occurs when compared to the procedures used by other studies (Newell, 2005). On average, 377 pounds of N were removed through oyster biomass harvest per year, while 536 pounds of N were removed as a function of the denitrification processes.

Without nutrient credits, the representative float oyster aquaculture facility produces an average of approximately 438,750 oysters per year over 10 years and returned a 10.0% internal rate of return. Production of oysters averaged 337,500 oysters to 675,000 oysters per year over the ten year simulated financial analysis.

Costs per oyster were estimated at $0.29 per oyster for the float operation (See Table 3.7). Paynter, Mallonee, and Shriver (1992) found that the cost of raising oysters in the Bay, using floats, was estimated at about $.20-$.29 per oyster (2008 dollars). Paynter, Mallonee, and Shriver (1992) also note that production costs could be as high as $0.43 per oyster in 2008 dollars if mortality rates increased. Through a modified model of the Paynter, Mallonee, and Shriver (1992) study, Lipton (2007) found that production costs for a float oyster aquaculture enterprise were $0.17 per oyster in 2008 dollars. It is important to note that total production costs used in the bio-economic simulation developed here include more costs than Lipton and Paynter used in their estimates. Capital investments other than floats, shipping costs, boat/barge operation expenses, taxes, and other costs were included in the bio-economic model developed here that were not accounted for by Lipton or Paynter.

Significance costs, for the float enterprise, included the upfront capital investment costs for float production units and annual labor costs. Total upfront capital investment float costs were 48% of the upfront total costs for the enterprise, while average annual labor costs were 59% of the average annual variable costs for the facility. Paynter, Mallonee, and Shriver (1992) estimated that more than 85% of the total upfront capital investment costs of the research float cost analysis project were associated with float costs, while total annual labor costs for the project constituted approximately 63% of the annual variable costs for the project.

The representative float operation removed an average of 332 pounds of N and 18 pounds of P from the facility location per year over ten years. Averages of 114 pounds of N were calculated to be removed through the harvest of oyster biomass, while 218 pounds of N were removed through the nitrification and denitrification process.

The rate of return estimates are broadly consistent with previous oyster aquaculture studies and anecdotal evidence for the Chesapeake Bay (Kallen et al. 2001; Lipton 2007; Wieland 2007). Given the input costs and oyster prices specified above, both representative operations achieved modest returns on a relatively risky investment. These positive returns conform with the fact that oyster aquaculturists throughout the Bay are currently investing, to some degree, in this form of aquaculture. At specified input and output prices, target rates of 10% or less would not require additional revenue from nutrient assimilation credit sales. However, addition revenue and thus higher returns may be necessary for further expansions in production.

Using baseline parameters, a positive N credit price was needed to achieve a 12% and 15% targeted rate of return (TRR) for each of the representative cage and float enterprises. The price per pound of phosphorus was held constant at $5.04 for the analysis (9 VAC 25-820-10). For the baseline cage oyster aquaculture enterprise simulation, a $2.46 per pound and $25.49 per pound nitrogen assimilation credit price would be required to achieve a 12% and 15% targeted rate of return (TRR), respectively. The float enterprise would need to receive $11.57 and $29.48 per credit, respectively, in order to meet a 12% and 15% target rate of return.

3.4 Nutrient Assimilation Credit Price Sensitivity Analysis

For each of the representative oyster aquaculture facilities described above, sensitivity analysis was used to estimate the influence of selected financial parameters on the price of an N assimilation credit, holding other values and parameters constant. Specific prices, costs, and production values selected for the sensitivity analysis were based on their potential influence on the IRR. Table 3.8 presents the parameters and parameter ranges subject to the sensitivity analysis. The parameters included halfshell market prices, percentage of oysters sold to the halfshell market, growout mortality rates, denitrification percentage rates and average total time to market. Nitrogen credit prices needed to achieve a 12% target rate of return (TRR) were calculated across the range of values identified in Table 3.8. The 12% TRR was used as an arbitrary targeted financial goal. It should be noted that Weston and Brigham (1985) stated that a return of at least 10% is a good starting point when conducting project analysis.

Table 3.8

Simulation Parameter Values Used for Sensitivity Analysis of Nutrient Credit Prices

Simulation Parameter	Range
Growout Mortality	10-60%
Denitrification % Removal	0-70%
% of Oysters Sold to Halfshell Market	60-90%
Halfshell Oyster Market Prices	$.18 - $.48
Average Total Time from Nursery Entry to Harvest Entry	12-24 months

Mortality in oyster aquaculture occurs within both the nursery and growout stages. While there are two types of mortality that influence oyster aquaculture enterprises, natural and consistent disease mortality and additional mortality from epizootic disease outbreaks, the sensitivity analysis here focuses on the cumulative natural and consistent disease mortality in the growout stage. Cumulative growout stage mortality, as compared to the nursery stage mortality, typically exhibits more variation within and across operations. Mortality, ranging from as high as 50 percent, is not uncommon and can significantly influence the financial viability of an oyster aquaculture enterprise. A cumulative growout mortality range of 10-60% was investigated in the sensitivity analysis (Table 3.8).

Denitrification rates also play a key role in the amount of nitrogen removed from the water (see section 2.2.2). The percentage rate of denitrification is largely variable, uncertain, and can potentially range from 20% to 70% (Newell et al. 2005). Through the analysis conducted here, a range of 0% to 70% was used to investigate the influence denitrification rates have on nutrient credit prices and the total amount of N removed from ambient waters.

Halfshell prices have been documented to be critical to the financial success of an oyster aquaculture facility (Kallen et al. 2001). Murray and Oesterling (2008) reported modal and mean oyster market prices for Virginia aquacultured oysters in 2007 at $0.35 and $0.28, respectively. Maximum prices from 2005 to 2007 were $0.58 per oyster, while minimum prices where $0.15. A range of $0.18-$0.38 per oyster was used for the cage sensitivity analysis while halfshell oyster prices ranging $0.28-$0.48 were used for float oyster aquaculture enterprises.

The percentage to which oysters are marketed to the halfshell market is also variable and has been documented to be a contributing factor to the success of an oyster aquaculture firm (Kallen et al. 2001). A range of 60-90% of oysters marketed to the halfshell market was used to evaluate the influences to nutrient credit prices in combination with changes in halfshell oyster prices. Shucked oyster market prices were held constant at $0.14 per wholesale oyster during the analysis, as shucked oyster prices have been documented to be relatively stable and represent only a marginal influence on the potential financial success of oyster aquaculture enterprises (Aprill and Maurer 1976).

Scale-up in the industry will put downward pressure on halfshell oyster prices. The excess demand in the halfshell market may also shift production into the shucked market. Either development would reduce firm returns and require higher nutrient assimilation credit prices to achieve the same target rate of return.

The time that an oyster spends within the water (e.g. nursery to harvest) has significant consequences on the financial returns for cage and float oyster enterprises. As oyster growth rates increase, the total number of oysters that are harvested in a year also increases. Consequently, as the quantity of oysters supplied to the market over a season increases, the IRR improves. Moreover, as time to market decreases, IRR, of course, increases. The nutrient assimilation potential of oysters also increases with oyster size.

Thus, the longer an adult oyster stays in the water, the filtration and N processing capacity increases. Seven mutually exclusive average numbers of months, ranging between 12 to 24 months, were used to better understand the influence that average total time within the production process had on the N credit price needed to meet a 12% TRR financial objective.

For each of the parameters selected for sensitivity analysis, a duplicate procedure was followed. The selected ranges for each of the variables listed in Table 3.8 were entered into the simulation model individually, as were the corresponding ranges of oyster halfshell prices, and, where appropriate, the percentage which was sold to the halfshell market. Variable values, which were not investigated through the sensitivity analysis, such as the cost of a float or cage, were held constant. For each parameter value investigated, the simulation model subsequently searched for the N credit price per pound of N needed to meet a targeted rate of return (TRR) of 12% for the cage and float oyster aquaculture enterprise.

3.4.1 Nutrient Credit Price Sensitivity Analysis Results for the Cage Oyster Aquaculture Enterprise Scenario

For the representative cage oyster aquaculture enterprise, the relationship between N assimilation credit prices, cumulative growout mortalities, and halfshell oyster prices are presented in Figure 3.1.

As expected, oyster mortality has a large influence on the compensation necessary for oyster aquaculturalists to meet their financial objectives. Using the baseline halfshell oyster price of $0.28 per oyster, N assimilation credit prices ranged from $0.00 to nearly $115.00 per pound of reduction for growout mortality in the 10 to 60% range (See

Appendix B.1.). The simulation results indicate that an oyster aquaculturalist could meet a 12% return on investment without receiving any additional compensation from the sale of N credits when oyster mortality is relatively low. For example, at oyster prices of $0.28, the representative oyster aquaculture facility with oyster growout mortality equal to or below 25% would meet its financial rate of return objective without receiving any additional compensation from nitrogen assimilation credits. However, if mortality exceeds 50%, simulation results indicate that the oyster enterprise would need to charge in excess of $60.00 per pound of N removed in order to reach the targeted rate of return (Figure 3.1). When the range of cumulative growout mortality is 40% or less, and oyster prices are $0.28 per halfshell oyster, an oyster aquaculturalist could potentially provide N removal services for $25 per pound or less.

Figure 3.1 also shows that relatively small changes in oyster prices have a relatively large influence on the cost to supply N assimilation credits. If the oyster aquaculture enterprise received a lower oyster price, such as $0.26 or $0.24 per halfshell oyster, N credit prices would need to be $31.00 and $60.00 per pound of N removed, respectively, given the baseline 30% growout mortality rate. Given growout mortalities equal to or less than 40%, a $0.02 increase in oyster prices ($0.28 to $0.30) would eliminate the need to receive any additional revenue for providing water quality services in order to meet the financial objectives. In other words, the N assimilation credit price would be zero.

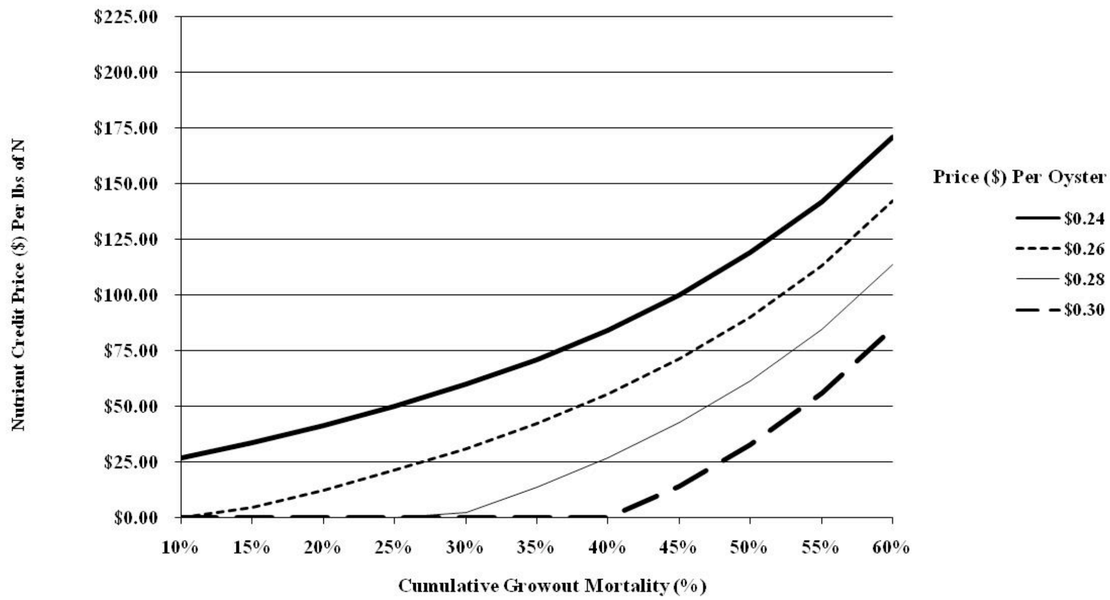

Figure 3.1. The Influence of Cumulative Growout Mortality Percentage (%) on the Nutrient Credit Price ($) per lbs of N needed to meet a 12% TRR for Cage Oyster Aquaculture, *ceteris paribus*.

Figure 3.2 illustrates the results from the cage oyster aquaculture denitrification rate sensitivity analysis. Based on this analysis, denitrification rates have a relatively small impact on N assimilation credit prices (See Appendix B.2). Given the conditions analyzed here, the influence of denitrification and the subsequent quantity of N removed represents only a small percentage of the total revenue the oyster aquaculture enterprise receives. Given the baseline price of $0.28 per halfshell oyster, a doubling of denitrification rates from 30% to 60% reduced N assimilation credit price from $1.90 to $1.13 per N credit (or about 40%). Lower oyster prices would produce the same relative change in N assimilation credit prices. For example, assuming an oyster price of $0.24, doubling denitrification rates increase from 30% to 60% would decrease N credit prices by 40% ($46.18 to $27.48, respectively).

Assuming the baseline halfshell price of $0.28, the N credit prices identified here appear to be cost effective. If the price were to decrease to $0.24 per halfshell oyster, however, the compensation needed would range from about $24.00 to $144.00 for the entire range of denitrification.

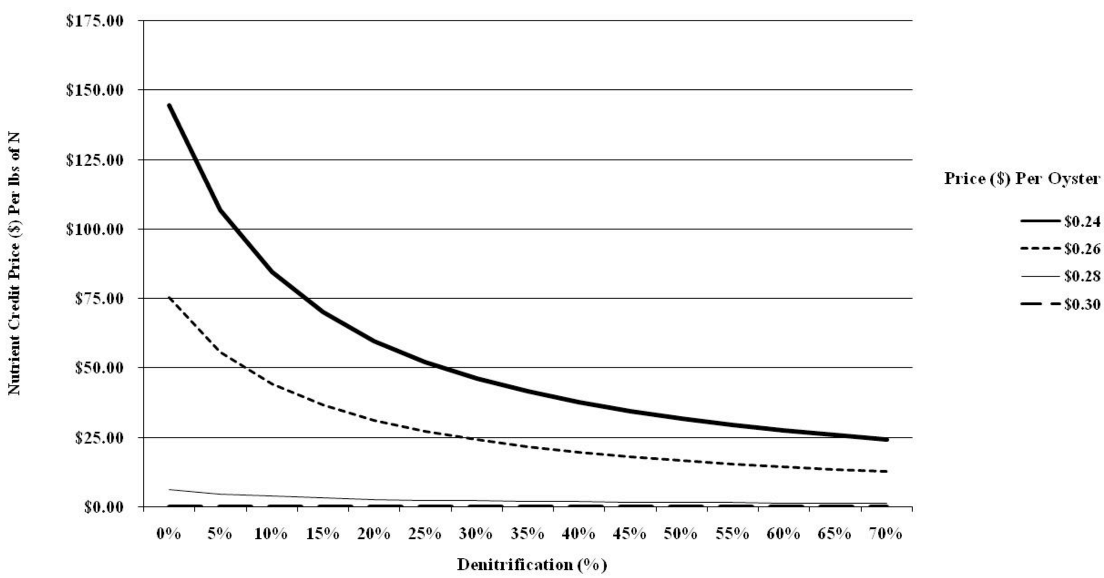

Figure 3.2. The Influence of Denitrification Percentage (%) on the Nutrient Credit Price ($) per lbs of N needed to meet a 12% TRR for Cage Oyster Aquaculture, *ceteris paribus*.

The sensitivity of nitrogen assimilation credits to changing the percentage oysters sold to the halfshell market are presented in Figure 3.3. Changes in the percentage sold the halfshell market also had a significant impact on N credit prices (See Appendix B.3.). The results show that increasing the percentage sold to the shucked, or processed market, by 20% resulted in more than a 175% increase in the price of an N credit. For example, decreasing the percentage of oysters sold in the halfshell market from 80% to 60% escalated the N credit price from $20.75 to $57.33, given a baseline of $0.28 per halfshell oyster.

Figure 3.3 also shows the fairly narrow range of oyster prices in which cost effective reductions can be achieved through the use of the representative cage oyster aquaculture enterprise. If oyster prices range from $0.28 to $0.34, and the percentage sold to the halfshell market is 90% to 60%, respectively, N credit prices will range from $0.07 to $20.75.

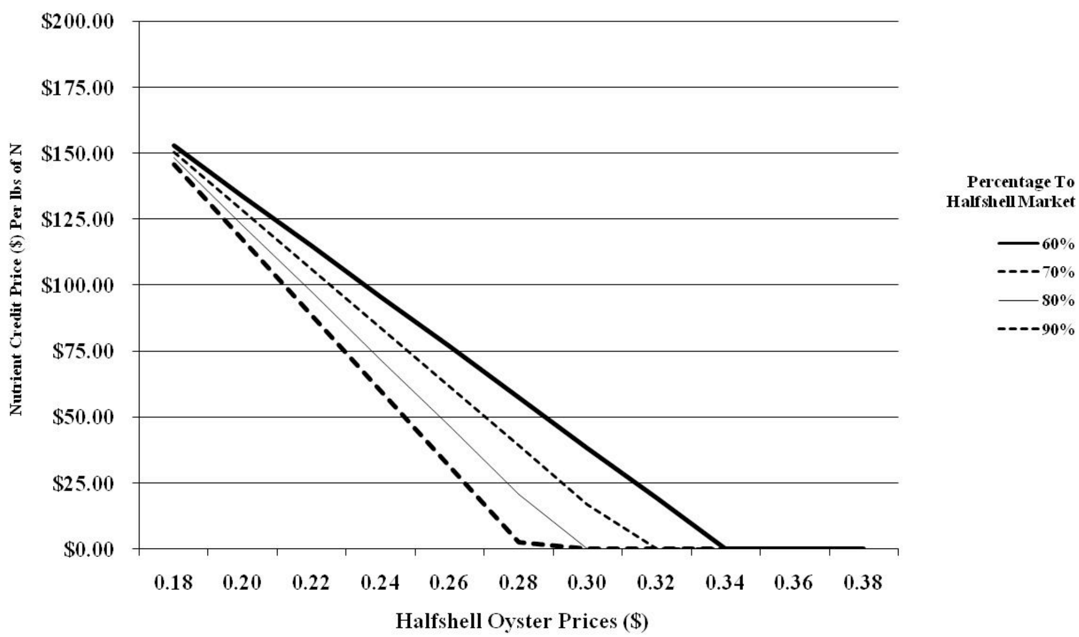

Figure 3.3. The Influence of Halfshell Oyster Prices ($) on the Nutrient Credit Price ($) per lbs of N needed to meet a 12% TRR for Cage Oyster Aquaculture, *ceteris paribus*.

Figure 3.4 shows the relationship between N assimilation credit price and average time total number of months to market for a 3-inch (76mm) oyster. Similar to the influence of changes in halfshell oyster prices, N credit prices significantly increased when the number of months in production increased (See Appendix B.4.). For example, at the $0.28 baseline price, when the average total number of months in the production process (e.g. nursery to harvest) increases from 18 to 20 months, the N credit price, or the cost to supply nutrient assimilation services, increased from $2.46 to $52.36. The sensitivity analysis demonstrates that at faster growth rates (an average of 16 months or less in the production process) additional revenue from N assimilation credits was not necessary to meet the targeted rate of return for the $0.28 baseline price. If the average number of months within the total production process is equal to or greater than 22 for the baseline $0.28 halfshell price, however, compensation from N assimilation credits becomes expensive, exceeding $100 per pound of N removed.

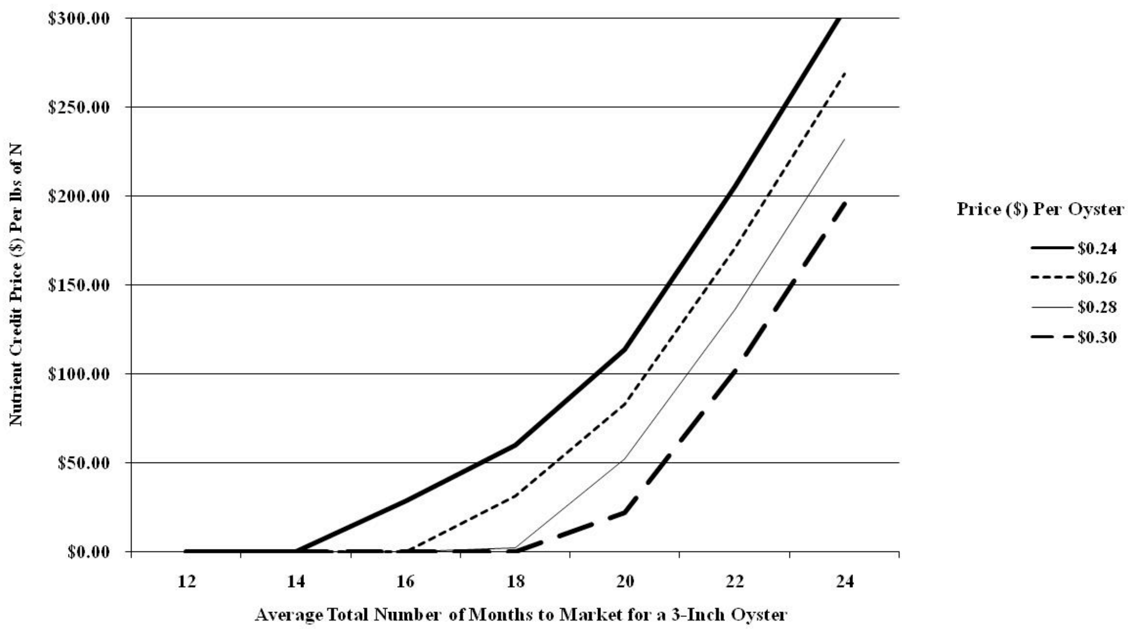

Figure 3.4. The Influence of the Average Total Number of Months to Market for a 3-Inch (76mm) Oyster on the Nutrient Credit Price ($) per lbs of N needed to meet a 12% TRR for Cage Oyster Aquaculture, *ceteris paribus*.

3.4.2 Nutrient Credit Price Sensitivity Analysis Results for the Float Oyster Aquaculture Enterprise Scenario

Similar sensitivity analysis was performed for the representative float oyster aquaculture enterprise. The parameters of growout mortality, denitrification rates, halfshell oyster prices and the percentage sold to the fresh and processed market, and the average total number of months from nursery entry to harvest entry, were used. Similar to the cage oyster aquaculture enterprise, the cost to provide nutrient assimilation services was sensitive to changes in growout mortality rates, halfshell oyster prices, and the average time oysters spent within the water. Changes in denitrification rates also had a relatively insignificant impact.

The influences of cumulative growout mortality on N assimilation credit prices for the representative float oyster aquaculture enterprise are presented in Figure 3.5. Using the baseline $0.38 price per halfshell oyster, N credit prices ranged from $0.00 to more than $145.00 (See Appendix C.1.). These simulation results are comparable to those of the cage oyster aquaculture enterprise, as marginal changes in mortality rates also increases the N credit price. For instance, the influence of a 10% increase in the cumulative mortality percentage at the baseline halfshell price, from 25% to 35%, for the float oyster aquaculture enterprise, increases the N credit price by $24.00.

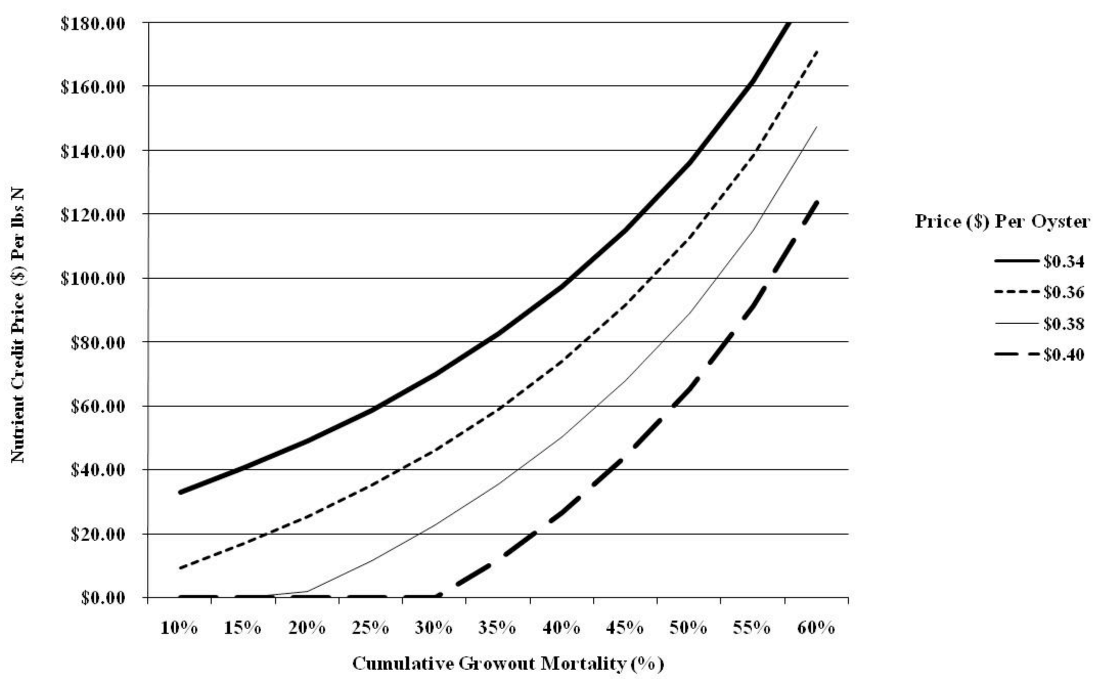

Figure 3.5. The Influence of Cumulative Growout Mortality Percentage (%) on the Nutrient Credit Price ($) per lbs of N needed to meet a 12% TRR for Float Oyster Aquaculture, *ceteris paribus*.

Results from the denitrification sensitivity analysis for the representative float enterprise are shown in Figure 3.6. For the baseline halfshell oyster price of $0.38, N credit prices ranged from $6.00 to $34.00 (See appendix C.2.). As documented by the results from the cage oyster aquaculture simulation, N credit prices were not particularly sensitive to changes in denitrification rates. For example, if the rate of denitrification increased by 30% (30% to 60%) the cost to remove each pound of N only decreased by about $5.00 (i.e. $11.57 to $6.98). Past an initial denitrification rate, near 20-30%, the decision to invest in a float oyster aquaculture enterprise is not largely driven by the rate of denitrification at a particular oyster aquaculture production location. Similar to the cage operation, the cost of generating N assimilation credits is much more sensitive to the price of oysters. A modest 5% reduction in oyster price ($0.38 to $0.36) will require compensation of at least $20.00-$35.00 per pound of nitrogen removal across most of the denitrification ranges in order for the enterprise to meet its financial objective.

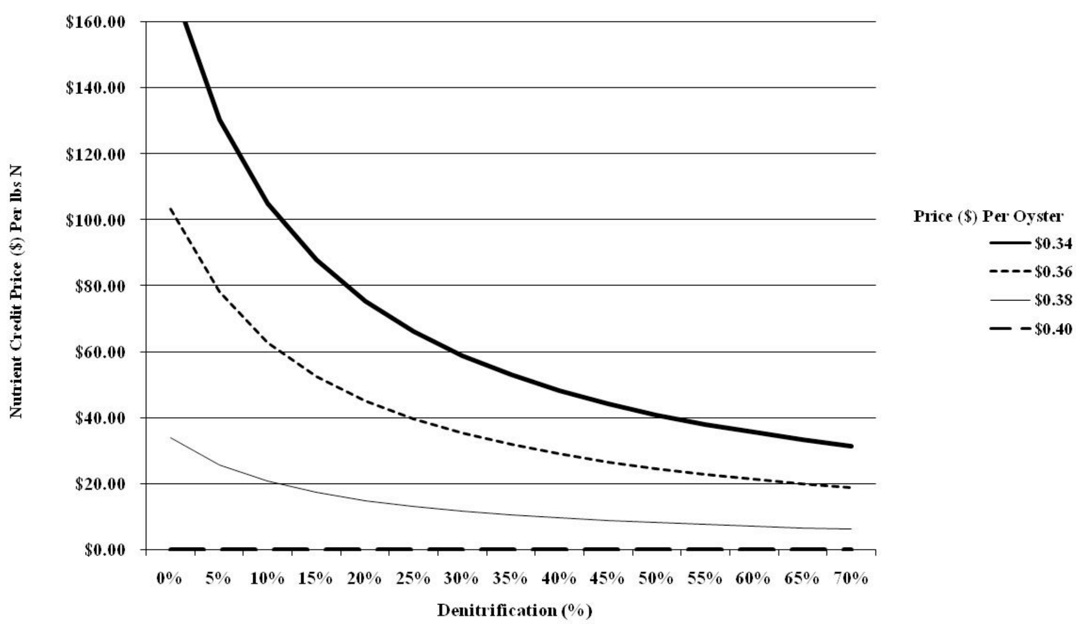

Figure 3.6. The Influence of Denitrification Percentage (%) on the Nutrient Credit Price ($) per lbs of N needed to meet a 12% TRR for Float Oyster Aquaculture, *ceteris paribus*.

Figure 3.7 shows the relationship between N credit prices, oyster prices, and the percentage sold to the halfshell market. As observed through the cage oyster aquaculture results, decreases in halfshell oyster prices and the percentage sold to the halfshell market significantly increases the compensation needed to meet a float oyster aquaculture enterprises' targeted rate of return (See Appendix C.3.). Decreasing the percentage sold the halfshell market by 20%, (i.e. 80% to 60%), for the baseline $0.38 halfshell oyster, increases the compensation needed to meet the targeted rate of return by more than 145%, or from $43.09 to $106.12. Likewise, when 90% of oysters are sold to the halfshell market a reduction in halfshell oyster prices by $0.02, $0.38 to $0.36, increases the nitrogen credit price from $11.57 to $35.21.

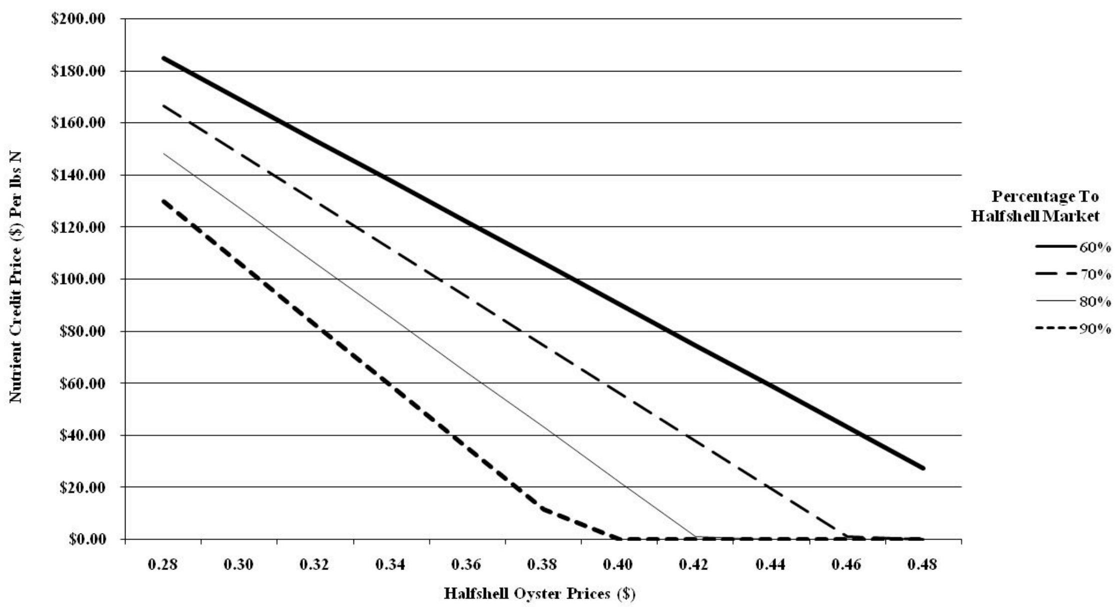

Figure 3.7. The Influence of Halfshell Oyster Prices ($) on the Nutrient Credit Price ($) per lbs of N needed to meet a 12% TRR for Float Oyster Aquaculture, *ceteris paribus*.

The relationship between the total time from nursery entry to harvest entry and subsequent estimated N credit prices are plotted in Figure 3.8. The longer oysters stay within the float oyster aquaculture production process in order to grow to a market length of 3 inches or 76mm, the returns to the enterprise decrease. Subsequently, the compensation needed to meet the float oyster aquaculture enterprises' financial objective also increases as oysters stay longer within the growout stage (See Appendix C.4.). As an example, when the baseline halfshell price is $0.38, increasing the total time within the nursery and growout stage from 16 to 18 months increases the N credit price from $11.57 to $43.78, or about $32.00.

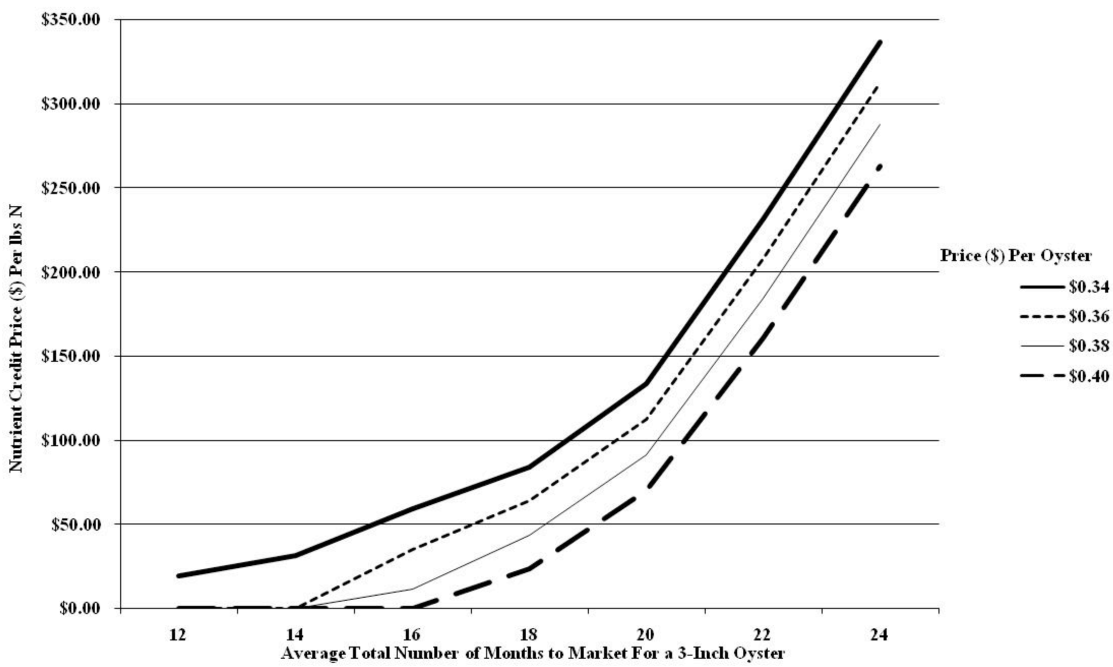

Figure 3.8. The Influence of the Average Total Number of Months to Market for a 3-Inch (76mm) Oyster on the Nutrient Credit Price ($) per lbs of N needed to meet a 12% TRR for Float Oyster Aquaculture, *ceteris paribus*.

3.5 Nitrogen Source Reduction Costs for the Chesapeake Bay

Given the conditions identified above, a potential aquaculture firm would be willing to invest in a new oyster aquaculture facility, given a targeted rate of return (TRR) of 12%-15%, if the firm received a financial payment between approximately $3.00 and $30.00 per pound. Such compensation translates into approximately $0.002 to

$0.02 per oyster for the production of N removal services. Modest drops in oyster prices could push nitrogen assimilation credit prices into the $30 to $60/lb range. This price represents the minimum additional compensation an investor would need to receive in order to provide new nutrient removal services and is interpreted as the cost to the aquaculture facility to provide that service. From the perspective of the Commonwealth of Virginia, it would therefore be important to compare the cost of N removal from oyster aquaculture to that of the cost of removing N from point and nonpoint source reduction strategies which are currently used.

Virginia has identified a variety of nutrient source reductions that can potentially be implemented in order to meet nutrient loading targets for the Chesapeake Bay (Commonwealth of Virginia 2005). These plans include technologies and various management options from regulated point source dischargers (primarily publicly owned wastewater treatment plants), urban stormwater runoff, and agricultural nonpoint sources. Table 3.9 presents an overview of frequently identified nutrient reduction options and their associated marginal costs per pound of N removed.

Table 3.9.

Point Source, Urban Stormwater, and Non-point Source Cost Estimates Per Pound of N Reduced

Point Source Reduction Measure	**Average Range of Cost Per Pound of N Removed (2008 Dollars)**
Municipal WWTP Nutrient Reduction Technology (NRT)	$9.76 - $15.79 [a,b]
Urban Stormwater Reduction Measure	**Average Range of Cost Per Pound of N Removed (2008 Dollars)**
Urban (Wet Pond, Sand Filter, Wetland, etc.)	$199.62 - $3,359.00 [b,c]
Agricultural Non-Point Source Reduction Measure	**Average Cost Per Pound of N Removed (2008 Dollars)**
Yield Reserve Program (Enhanced Nutrient Management)	$0.45 - $5.03 [a,d]
Nutrient Management	$0.64 - $1.89 [a,e]
Conservation Tillage and Low-Till Land	$1.79 - $10.17 [a,c,e]
Cover Crops and Pasture	$3.99 - $13.99 [a,c]
Animal Waste	$10.17 - $30.69 [c,e]
Animal Waste + Nutrient Management	$2.30 - $15.35 [e]

(Chesapeake Bay Commission 2004)[a]; (Aultman 2007)[b]; (Shulyer 1995)[c]; (Metcalfe et al. 2007)[d]; (Camacho 1992)[e]

Aultman (2007) and Chesapeake Bay Commission (2004) estimated the marginal cost to remove a pound of N from a wastewater municipal treatment plant (WWTP) under current N load limits. Wastewater treatment plant N removal techniques often employ a biological nitrification and denitrification process know as biological nutrient removal or a chemical based approach called chemical addition. Aultman (2007) estimated the annual marginal costs to achieve different nutrient cap levels. The study estimated that marginal costs range from $9.97 to $15.79 per pound of N removed (Table 3.9). Additionally, the Chesapeake Bay Commission (2004) estimated a marginal cost of $9.76 to remove a pound of N from a WWTP. All costs are in 2008 dollars.

Nutrient loads from urban stormwater can be reduced through variety of Best Management Practices (BMPs). In general, this group of source reduction strategies attempts to increase the uptake of nutrients and or hold nutrients in the soil. Examples of urban stormwater BMPs include wetlands, wet pounds, bioretention basins, and sand filters. Aultman (2007) constructed a cost estimating tool to determine N removal costs per pound for a variety of different types of urban BMPs. Marginal cost estimates ranged from $98.86 to $3,359.00 per pound of N removed (Table 3.9). Additionally, Shulyer (1995) estimated that the average cost of using urban BMPs to remove a pound of nitrogen was $199.62, in 2008 dollars.

Agricultural operations also use a variety of BMPs to reduce agricultural nonpoint source nutrient loading. While removal rates vary based on the location and site parameters, BMP's typically involve the use of a number of different types of N control practices that function in a similar manner as urban stormwater BMPs. Examples of agricultural BMPs include conservation tillage, nutrient management, and cover crops.

The costs per pound of N reduced have been estimated by Chesapeake Bay Commission (2004), Shulyer (1995), Metcalfe et al. (2007), and Camacho (1992). These studies found that marginal costs estimated ranged from $0.45 to $30.69 per pound of N removed, depending on the type of BMP and the range of costs included. Cost estimates for specific types of agricultural BMPs are presented in Table 3.9.

The per pound N reduction cost for agricultural BMPs reported in Table 3.9 may also represent a lower bound estimate. Most studies calculate unit costs independent from each another. If farmers implement multiple BMP's to receive increased nutrient reductions (e.g. implementing cover crops, nutrient management, conservation tillage and riparian buffers together), the nutrient removal rates for the additional practice would likely diminish. Thus, the marginal cost per pound of N removed therefore increases as additional BMPs are used by an agricultural operation.

Given the marginal costs per pound of N reduced from the source reductions presented above, the nutrient removal marginal costs associated with the practice of commercial oyster aquaculture described earlier could be, in some instances, cost effective compared to source reductions. In most all situations, oyster aquaculture can remove nutrients from Bay waters at a lower overall cost than urban nonpoint source controls. Generally, point and nonpoint source controls can be secured for less than $30.00 per pound. In order to meet a 12% target rate of return and provide nutrient assimilation credits at a cost less than $30.00, an oyster operation will generally require that mortality rates not exceed 40%, less than 20% of all production be sold to the shucked market, and growout times of 18 months or less, assuming a $0.28 halfshell market price per oyster. Only modest reductions in halfshell oyster prices can be incurred

($0.02 or less) before nutrient assimilation credit prices would rise substantially above $30.00. As a basis of comparisons, nutrient assimilation credit prices of approximately $25.00 per pound of N translates into about $0.02 cents per oyster assuming denitrification levels of 20% and less than $0.01 cents per oyster assuming zero nitrogen removed through the denitrification process.

3.6 Conclusion

Using the baseline parameters described in section 3.2, the initial ten year IRR for a representative cage and float oyster aquaculture enterprise was calculated and found to be lower than the targeted rate of return (TRR) for each firm. The corresponding compensation, the N assimilation credit price, needed for each enterprise to meet the targeted rate of return (TRR) was calculated using the simulation model. In some cases, the N removal costs were less than or largely comparable to nonpoint source and point source N removal costs for Chesapeake Bay.

Holding all else constant, sensitivity analysis was completed for the key financial and production parameters associated with each representative enterprise. While the costs per pound of N removed were slightly higher for the representative float oyster aquaculture enterprise, the influence of each of the financial production parameters on the two representative enterprises was largely homogenous. For each of the two enterprises, the influence of denitrification rates, *ceteris paribus,* did not exert a substantial influence on the cost of providing nutrient assimilation credits. Marginal changes within the mortality rates, halfshell oyster prices, and the average total number of months within the nursery and growout stage, however, had a major influence on the N credit price needed to meet the targeted rate of return.

From the standpoint of a policy making body such as the Commonwealth of Virginia, using oyster aquaculture enterprises as a method to improve water quality within the Chesapeake Bay is cost competitive when compared to other options under some financial and environmental conditions. While N credits make up only a relatively small share of revenue per oyster, under certain circumstances this additional revenue may add enough financial support to sufficiently meet a targeted rate of return for an oyster aquaculture enterprise. The conclusions found here, however, are sensitive to variations in a few key factors, such as mortality. In many instances, however, the conditions confronting the oyster industry (e.g. high mortality) will be difficult to overcome with the additional revenue from N credits.

Chapter 4

Policy Options for Creating Demand for Nutrient Assimilative Services

4.1 Introduction

Using the nutrient assimilation services derived from oyster aquaculture is a possible option for helping meet the nutrient reduction goals for the Chesapeake Bay. In Chapter 3, the results from the oyster aquaculture nutrient removal simulation model suggest that in some scenarios oyster aquaculture has the ability to remove nitrogen (N) from the waters of the Chesapeake Bay at a cost comparable to and less than other contemporary nutrient removal technologies. However, Chesapeake Bay states do not currently have well defined financial mechanisms in place that could pay people to make new investments in nutrient assimilation services.

The objective of this chapter is to assess the possible mechanisms needed to financially compensate oyster aquaculture enterprises for the water quality services they provide. First, policy approaches to create financial incentives to enhance water quality services are presented. The second half of the chapter describes the existing water quality incentive programs in the Chesapeake Bay. Incentive programs in the Chesapeake Bay are evaluated based on the opportunity to use funds to purchase and create demand for nutrient assimilation credits.

4.2 Incentive-Based Approaches for Water Quality Enhancement

The demand for nutrient assimilation credits is generated when individuals and or public and private organizations are willing and able to pay for these environmental services. Conceptually, the demand for credits can be generated through the following ways: administered markets, public financing programs, and voluntary private contributions.

First, demand for nutrient assimilation credits can come from the formation of administered markets. The use of administered markets to achieve public water quality objectives has been acknowledged for 40 years (Dales 1968). Administered markets begin when the government limits the total use of the environment for waste disposal for an identified group of dischargers. In the context of water quality policy, the government limits the mass load of effluent discharged by an identified group of dischargers. The mass load is set to achieve a water quality objective. The public agency defines a commodity or discharge rights. Discharge rights, sometime called allowances, are expressed as the total mass load of a pollutant (ex. a pound of N or phosphorus (P) that can be discharged during a given time period. The amount of discharge rights created by the public agency is equal to the discharger's mass load cap. Dischargers are then granted the authority to exchange these rights through trading. Although trading occurs, the total amount of discharge rights remain fixed in order to reach a socially determined water quality objective. By allowing exchange, dischargers have an incentive and opportunity to seek and implement nutrient controls at the least costly sources.

In a closed trading system, exchanges of discharge rights are limited to only those dischargers under the mass load cap (Shabman and Stephenson 2007). Thus, a discharger may buy rights only from other dischargers also required to limit loads under a mass load cap. In other types of trading programs, dischargers may purchase certified nutrient reductions from other entities outside the cap. Through open trading programs, a non-capped entity can be credited for additional nutrient reductions. The certified reductions are called a credit or offset. Dischargers under a cap (regulated dischargers) are allowed to increase their discharges if an equivalent amount of credits are purchased. The credit generating entity can potentially be a discharge source or an entity that removes pollutants already in the ambient environment (e.g. assimilative services). Examples of the latter type of trade occur in emerging air emission markets for carbon when projects are created to increase carbon sequestration. The demand for nutrient assimilation credits could thus be created if the rules of an administered market allowed dischargers to purchase nutrient assimilation credits. In such a situation, a capped discharge source could increase the discharge of nutrients if an offsetting amount of nutrients were removed (quantified as nutrient assimilation credits) by a new or expanding oyster aquaculture operation.

Second, government agencies could create a demand for nutrient removal services through publicly financed payments. A financial payment or inducement may be in the form of a grant, subsidy (cost-sharing), or tax incentive to adopt a particular technology/practice or purchase a piece of pollution prevention equipment, in exchange for providing water quality services. Similar approaches are currently used as a means to provide a financial incentive for implementing a BMP on agricultural land. Similarly, public programs could potentially directly compensate oyster aquaculture enterprises for the total pounds of nutrients removed during a given time period from oyster biomass sequestration and filtering capacities (denitrification).

Public funds to pay for nutrient assimilation credits could be generated through government taxing authority. Multiple sources of revenue to sponsor nutrient assimilation credits exist, including general tax revenues (income, sales, and property taxes). Funding could also come from special taxes or surcharges levied specifically to finance water quality improvement. For example, the State of Maryland initiated ‘the flush tax’ in 2004 in order to develop a fund aimed at nutrient reductions programs throughout the state (Blankenship 2004).

Third, payments for nutrient assimilative credits could come from voluntary contributions from the private sector. Within the private sector, funding could potentially originate through voluntary private donations made by people who would like to improve water quality. Under such an approach, some organizational structure would exist that would solicit and collect private donations and then use the funds to sponsor water quality improvements. An example of this approach is voluntary carbon offsets, where private citizens or firms voluntarily offset increases in carbon emissions. Here private donations are made to an organization or private business that later uses the funding to invest in activities that reduce carbon emissions or increase carbon sequestration (e.g. forest restoration projects). In a similar sense, private donations throughout the Chesapeake Bay for water quality offsets could be collected and managed by an association or fund in order to pay for nutrient removal services.

Administrated markets, public financing, or voluntary contributions could provide a source of financial compensation to oyster aquaculturists to make investments to provide nutrient assimilation credits. Regardless of the source of demand, there are two general approaches for how this compensation is made. These include direct and indirect compensation for providing nutrient assimilation credits. A direct payment is made based on the number of pounds removed from, or prevented from entering, ambient waters. Direct payments are also called performance-based payments and pay directly for the number of nutrient credits provided. For example, within a nutrient credit trading program a direct payment might be made to an oyster aquaculturist in exchange for a nutrient assimilation credit. Indirect payments are those payments made towards inputs *related* to the nutrient removal. An example might be a payment that would offset the cost of oyster cages. The compensation is indirect because the compensation is paid for an input that contributes to the production of nutrient removal services, but not the service (nutrient removal) itself.

Either direct or indirect compensation can be implemented with a fixed price or variable price system. A fixed price occurs when the unit price of compensation is set as opposed to a variable price, which is set by a competitive process. For example, a fixed price performance-based payment would identify a specific price that would be paid for a pound of nutrients removed (e.g. fixed price per credit) and not subject to negotiation. A variable price system creates competitive systems to allow the unit price of nutrient removal services to vary between buyers and sellers. Similarly, indirect compensation can be administered through either a fixed or variable price system.

This chapter assesses possible sources of demand for nutrient assimilative credits. Currently, financial incentives aimed at nutrient reductions in the Chesapeake Bay focus on source reductions from specific point source and nonpoint sources, such as wastewater treatment plant upgrades and Best Management Practices (BMPs) for agricultural entities. Programs in the Chesapeake Bay have not yet been used to compensate nutrient removal services provided by nutrient assimilative technologies such as oyster aquaculture. Thus, this chapter focuses on evaluating the potential for existing and future programs to be either modified or used to create demand for nutrient assimilation credits.

Information was collected on a large portion of the existing and emerging water quality programs throughout the Bay region that pay for nutrient reducing investments. Some of these programs currently exist, while others are emerging, but not fully implemented. Each program was also evaluated as a potential source of demand. Additionally, programs were analyzed based on the ability to pay for nutrient assimilation credits given annual estimates of the nutrient removal capabilities of oysters. Emphasis is placed on identifying whether programs could produce direct payments for nutrient assimilation credits (performance-based programs). Barriers and obstacles to creating demand for nutrient assimilative credits were also evaluated.

Next, potential monetary sources of demand for compensation for nutrient assimilation credits were examined based on the total amount of funding available. Funding sources were reviewed based on the ability for a potential source of demand to provide enough revenue to finance significant reductions in the relative scale of the oyster industry. The magnitude describes the potential for a demand source to provide payments for a scale up in oyster production. As estimated in Chapter 3, every additional one million oysters sent to market through a baseline representative cage oyster aquaculture facility removed an estimated 630 pounds of N. Assuming a price or cost of $5.00 to $50.00 per pound of N removed, approximately $3,000 to $32,000, respectively, would be needed to compensate the N water quality services for each additional one million oysters sold per year[6]. Thus, a 10 million oyster increase in oyster aquaculture production would approximately require between $32,000 and $315,000. It is important to note that the brief analysis above assumes no price effect given a change in demand of

[6] For illustrative purposes, the quantity and price of N are only used.

oysters. If oyster prices fell, as a response to increased supply, enterprises would need increased compensation for water quality services in order to meet their targeted rate of return (TRR). For example, the sensitivity analysis in Chapter 3 illustrated that when oyster prices decreased by $0.02, assuming 90% of oysters are sold to the halfshell market, credit prices increased by nearly $30.00. These estimates presented here are, therefore, a minimum cost. Finally, the question of the amount of demand uncertainty for nutrient assimilation credits will be qualitatively assessed. Investments in nutrient assimilation credits may be more forthcoming if credit suppliers faced more certainty in demand, *ceteris paribus*.

4.3 Funding Incentive-Based Water Quality Enhancement Programs in the Chesapeake Bay

Three potential revenue sources for nutrient assimilation credits in the Chesapeake Bay sources were analyzed. The programs investigated include nutrient credit trading programs (administered markets), public non-point source mitigation programs, and private voluntary payments.

4.3.1 Nutrient Credit Trading Programs in the Chesapeake Bay

Point sources discharging into the Chesapeake Bay both face nutrient mass load effluent limits. The limit is referred to as a wasteload allocation (WLA) or the total annual mass load (in pounds) of N and P that can be released by the point source on an annual basis (9 VAC 25-40). Wasteload allocations in Virginia and Maryland are calculated by applying limits of technology nutrient concentration limits multiplied by the plant's design flow (expressed in million gallons per day or mgd). All plants are expected to eventually make upgrades to their capital structure to meet these limits. Plants that upgrade are initially expected to meet the WLA due to the fact that actual plant flows are only a percentage of design flows (Aultman 2007; DEQ 2007).

Elements of a nutrient trading program have been added to this basic structure in both Virginia and Maryland in order to increase compliance options for point sources. In 2005, Virginia enacted the *Chesapeake Bay Watershed Nutrient Credit Exchange Program* (Virginia Code § 62.1-44.19:12-19) while Maryland developed the *Maryland Policy for Nutrient Cap Management and Trading in Maryland's Chesapeake Bay Watershed* in 2008 (MDE 2008). Since the policy framework for trading in Maryland is similar to Virginia, the structure for trading in Virginia is described below.

In Virginia, separate trading rules have been established for *existing* point sources (sources permitted at the start of the program) and *new* sources (sources permitted after the start of the trading program). For an *existing* point source, a discharger (A) who exceeds their WLA in a given year must purchase sufficient credits to offset the excess. Credits are created from other existing point sources when the amount of effluent emitted in a particular year is less than the WLA for that particular source. If credits are not used after a year, the credits expire. Virginia places a priority on the source of credits for discharger A. First, discharger A must seek credits from another point source (B). Discharger A can therefore buy credits from discharger B in order to meet its individual WLA. If point source credits are not available through the trading market, offsetting the nutrient load is required and may be accomplished through the payment of fees into the state managed Water Quality Improvement Fund (WQIF) (§ 10.1-2128 of the Code of Virginia). The state is then required to achieve equivalent nutrient reductions from point and nonpoint sources. Currently the state sets the cost of N and P credit at $11.06 and $5.04 per pound, which is based on the cost to remove one pound of N and P from a publicly owned wastewater treatment plant in Virginia, respectively (9 VAC 25-820-10). Credit acquisition by the WQIF must achieve nutrient reductions within the same tributary and the reductions must be beyond those required by federal or state laws and programs (e.g. tributary strategies) (§ 62.1-44.19:18).

New and expanding point sources face different requirements (§ 62.1-44.19.15). First, new and expanding sources must meet limits of technology nutrient concentration requirements (3 mg/l for N and .3 mg/l for P) (§ 62.1-44.19:13). Second, new and expanding sources will not be granted any new WLA by the government. These sources must acquire a WLA from existing sources. A priority system is established on where new and expanding sources must acquire a WLA. First, *new and expanding* point sources must attempt to offset their new nutrient loads through acquiring WLA from an existing point source within the same tributary. If existing point-sources are unable to supply a WLA, the new or expanding point source must acquire nonpoint source load allocations, called offsets, through the use of BMPs. The nonpoint source offsets must achieve reductions past those mandated by the state and must be installed in the same tributary as the *new or expanded* facility is located. The trading ratio also requires that two pounds must be reduced for every pound that is in need of being offset. The *new and expanding* source may also achieve offset reductions by other means approved by the state on a case-by-case basis evaluation (§ 62.1-44.19:15 B 1 c). This provision therefore allows for offsets to be created by methods other than agricultural nonpoint source reductions and would seem to allow for at least the possibility of using nutrient assimilative services, from oyster aquaculture for example, as a source of offsets. Finally, if methods for offsetting point source load allocations are not available the state allows for payments to be made into the WQIF. The cost of the payment is based off of the estimated cost of acquiring a one pound reduction for the out of compliance source's facility, or the cost of acquiring a two pound reduction from a nonpoint source. The maximum cost of the two calculated scenarios is the payment that is made.

Thus, demand for nutrient assimilation credits could potentially be created from *existing* as well as *new and expanding* point sources. *Existing* point sources have an option to make payments into the WQIF, which the state could in turn potentially use to purchase credits from oyster aquaculture enterprises. While § 62.1-44.19:18 B states that the WQIF must find equivalent point or nonpoint source reductions from the same tributary, it does not specify that credits are required to come from nonpoint source BMPs. Demand for credits may also potentially exist from *new and expanding* sources that need long-term offsets. Credits could be generated as *new and expanding* sources turn to the state department for case-by-case approval of long-term offsets. These offsets are of lower priority, however, and approval is needed to utilize them (i.e. further transaction costs). If a WLA is not available from another source, and other offset options are not feasible, it is also plausible that demand for nutrient assimilation credits could come from the WQIF as *new and expanding* point sources make payments into the fund in order to create long-term offsets.

The Maryland trading program makes a more direct reference to the possible use of nutrient assimilative technologies as a compliance option under phase two of the *Policy for Nutrient Cap Management and Trading in Maryland's Chesapeake Bay*

Watershed. Phase one focuses on point source trading as well as the criteria for trades to occur with nonpoint sources. Phase two, which is currently under development, further addresses the mechanics of point source and nonpoint source trades. Once phase two is fully implemented, 5.4.6 of the trading guidance illustrates that the creation and sale of nutrient credits and offsets from an oyster aquaculture enterprises is potentially a valid option (MDE 2008). While this program is still under development, the move to consider the use of reductions from oyster aquaculture through an administrated market structure is encouraging and may emerge as a realistic option. Additionally, Maryland also specifies that, above and beyond facilitating compliance with end of year regulatory requirements, nutrient credits are to be used for the purpose of securing additional long-term improvements in water quality.

Thus, both Virginia and Maryland's programs leave open the possibility to use nutrient assimilative credits in their respective point source trading programs. A possible barrier for development of this option, however, is whether nutrient assimilation credits in general would be considered a legally acceptable method of point source compliance under the Clean Water Act (CWA). The CWA requires specific point sources to implement technology based effluent limits, which are established for specific industries and based on specific source reduction technologies. If water quality standards are not met, water quality based effluent limits are to be imposed. During early implementation of the CWA, it was determined that instream treatment measures (low flow augmentation, instream aerators, etc.) could not be implemented in lieu of implementing end-of-pipe controls even if equivalent water quality outcomes could be achieved.

Therefore the use of nutrient assimilative technologies might be interpreted as instream treatment and could not be used to meet regulatory requirements.

Legally, however, nutrient trading programs in the Chesapeake Bay may differ in important ways from the original prohibitions of instream treatment under CWA. For example, point sources are expected to apply advanced treatment before being allowed to purchase nutrient offsets from sources outside the point source cap. The need for nutrient offsets will be driven by inevitable and unavoidable growth in wastewater flows. Therefore, purchasing a nutrient assimilation credit does not allow the source to avoid end-of-pipe treatment but to offset growth in unavoidable wastewater loading.

While the ability to create a means to purchase nutrient assimilation credits may be ambiguous under some interpretations of current statute, nutrient assimilation credits may have the potential to be created given some explicit acknowledgements in the regulatory language. Maryland's proposed statutory language for the use of oyster aquaculture as an offset appears to be an important first step in overcoming legal ambiguities and an example for creating demand for nutrient assimilation credits within administrated markets. The use of nutrient assimilation credits still requires the explicit approval in Virginia from DEQ. While the instream treatment obstacle may require some initial legal clarification, policy makers may face pressure to recognize nutrient assimilation credits as wastewater flows (and consequently loads) increase.

In the near term, point sources are expected to maintain compliance within a mass load cap. Projected wastewater flows, however, will most likely grow beyond the capacity of the cap and offsets will be necessary (Chesapeake Bay Watershed Blue Ribbon Finance Panel 2004). Over the past thirty years the population throughout the

Chesapeake Bay region has increased by over a million people every ten years (Chesapeake Bay Watershed Blue Ribbon Finance Panel 2004). Wastewater flows, in general, will increase as populations do. For example, an additional 10,000 people would produce an additional one mgd in wastewater flows (Liu and Liptak 2000). Given that the N concentration in new wastewater effluent will likely be around 3 mg/l in Virginia and Maryland, every additional one mgd would create about 9,000 pounds of new N loading per year. Given the representative cage enterprise results from the simulation model in Chapter 3 and the N trading ratio, more than 28 million marketed oysters would be needed for each additional one mgd increase in wastewater flows. Furthermore, the demand for nutrient reductions and offsets will likely be significant. Nutrient assimilation credits may potentiality be an option for wastewater treatment plants.

4.3.2 Public Agency Nutrient Control Financing in the Chesapeake Bay

Currently there are a variety of public programs that finance point and nonpoint source nutrient management programs. Point source funding avenues from public agencies have traditionally focused on administrating financial assistance for nutrient removal technology upgrades while nonpoint source programs have focused on funding source reductions using agricultural BMPs. Conceptually, similar public financing programs for nutrient removal could be created for nutrient assimilation credits. For the purposes of identifying potential demand for nutrient assimilation credits from oyster aquaculture, the focus here is on public financing for nonpoint source mitigation as opposed to point source programs that specifically target wastewater treatment plant upgrades. More specifically, nonpoint source programs have more in common with nutrient assimilation credits and also offer the ability to explore the potential possibilities for expansion into nutrient assimilation services. The programs in Virginia are presented as they are relatively similar to Maryland.

4.3.2.1 Federal Nutrient Control Financing in the Chesapeake Bay within the State Government

In order for a state government to receive federal funding for nonpoint source mitigation projects, § 319 of the CWA of 1987 dictates that state governments must enact a nonpoint source pollution management program. Here, states are required to determine waters impaired by nonpoint source effluent and subsequently administer specific projects and programs to mitigate the impacts (DCR 2007b). In Virginia, Section 10.1-2127.D., Chapter 21.1 of Title 10 of the *Code of Virginia* charges the Department of Conservation and Recreation (DCR) with managing federal and state nonpoint source mitigation.

There are three primary federal programs that specifically generate funding for nonpoint source pollution for use within the Commonwealth of Virginia. These include the Chesapeake Bay Implementation program under § 117 of the CWA, the Coastal Nonpoint Source Implementation program under the Coastal Zone Act Reauthorization Amendments (CZARA § 6217), and § 319 of the CWA.

The opportunity to use federal funding under § 117 of the CWA in order to compensate documented reductions in nutrients from ambient waters (nutrient assimilation services) appears to be challenging. In a broad sense, § 117 of the CWA establishes the Chesapeake Bay Program, and is charged by section § 117(b) to implement and coordinate federal, state, and local efforts to follow through with the mandates outlined within the Chesapeake Bay Agreement. It therefore appears that funding is largely intended for broad water quality program management. While the ability to use funding for nutrient assimilative services is not specifically precluded within these programs, the language for awarding grant funds to states is not encouraging, however. For example, § 117(e)(2)(B) explains that when submitting a proposal for funding, a description of the "proposed management mechanisms that the jurisdiction commits to take within a specified time period, such as reducing or preventing pollution into the Chesapeake Bay…" must be included. Given the emphasis on large program management and the fact that nutrient assimilative technologies do not remove nutrients at the source, the use of § 117 to create demand for nutrient credits is unlikely.

Using funding under § 6217 of the CZARA to pay for nutrient assimilation services also appears to be improbable. For example, § 6217(a)(1) specifically states that "the purpose of the program shall be to develop and implement management measures for nonpoint source pollution to restore and protect coastal waters, working in close conjunction with other state and local authorities." This does not rule out the use of funding to pay for nutrient assimilation services, but it does give rise to the assumption that priority is given to reducing nutrients at the source. For example § 6217(b)(1) states that each state program must identify land uses that contribute to a degradation of coastal waters. The focus for funding is therefore geared toward nutrient source reduction. It is therefore unlikely that funding from § 6217 could be used to compensate oyster aquaculturists.

While an indirect opportunity may potentially be feasible, the ability to pay for nutrient assimilation services using oyster aquaculture appears to be largely limited through § 319 of the CWA. Section 319 was established to directly address the consequences of nonpoint source pollutants to water quality throughout the United States. In a general sense, § 319 helps state and local nonpoint source programs with financial assistance for implementing technologies and demonstration projects that prevent or minimize local nutrient loading. These federal funds typically support specific projects, which are sometimes congressionally earmarked. Project examples include cost-share funding for a BMP cover crop demonstration projects or a total maximum daily load (TMDL) implementation program. A TMDL is a calculated daily maximum amount of a particular pollutant that a watershed basin. Typically, specific types of BMPs are identified in order to meet a geographical TMDL. As § 319 funding has been allocated to TMDL programs in the past, the use of § 319 TMDL funding could potentially be used indirectly in order to include oyster aquaculture within a TMDL. For example, Golen (2007) argues that the filter feeding characteristics of oysters could be used as a tool within TMDL implementation.

In a general sense, the language within § 319 does not appear to be advantageous toward creating demand for nutrient assimilative credits. For example, § 319 gives focus to nonpoint source mitigation from the source, which is, for the purposes of § 319, the terrestrial environment. Furthermore, § 319(a)(1) charges the Governor of each state to identify waters degragated by nonpoint source pollution, identify categories of nonpoint source pollution, and develop a process using BMPs to control each nonpoint source category. It is important to note, however, that § 319 does not preclude the use of assimilative technologies or the use of such practices through a TMDL.

Previous funding under § 319 for the extensive use of BMPs also gives rise to the conclusion that deriving demand for performance based nutrient assimilation credits will be difficult. For example, Virginia divided § 319 federal funding into ten core program areas that included nutrient management, agricultural cost-share management, database & GIS support, and others. Nearly than 20% of all funding went to TMDL development and planning while 40% was allocated for TMDL implementation projects. Nutrient management and database & GIS support received 10% and 5%, respectively, while other program areas such as storm water management received 5% (DCR 2007b). As mentioned above, using § 319 funding indirectly through a TMDL oyster implementation project may provide demand for the water quality services that oyster aquaculture provides.

While the majority of the options to fund nutrient assimilative technologies within the context of § 319 may be limited, the potential to indirectly create demand for nutrient credits through a TMDL program creates the rationale to further investigate § 319 funding in Virginia. The reliability of federal funding allocations to Virginia's nonpoint source program appears to be robust from FY2003 to FY2006 (Table 4.1). While other nonpoint source federal funding programs for Virginia are listed, § 319 allocations are the most substantial. Total funding for § 319 programs and projects totaled more than 17 million dollars between FY2003 to FY2006. Given the estimated \$32,000 to \$315,000 needed for a 10 million increase in the number of aquaculture oysters in the Bay, *ceteris paribus*, the federal funding source described here would have the potential capacity to support such a nutrient assimilation credit demand (see section 4.2). Moreover, given the 40% allocation to TMDL projects, from an average of $4.3 million dollars for § 319 programs in Virginia, the resulting $1.7 million dollars would easily support this increase with the ability to also continue funding traditional TMDL projects.

Table 4.1

Summary of Federal Funding for Nonpoint Source Pollution Programs in Virginia

Funding Source	FY 2003	FY 2004	FY 2005	FY 2006
EPA-CWA § 319 (h) Nonpoint Source Grant	$4,580,100	$4,533,900	$3,968,400	$3,968,400
EPA-CWA § 117 Chesapeake Bay Grant	$0	$2,487,000	$2,339,000	$2,227,000
NOAA-CZARA § 6217 Coastal Nonpoint Grant	$50,000	$185,385	$197,000	$187,000
Total	$4,630,100	$7,206,285	$6,504,400	$6,382,400

***Source: (DCR 2007b)**

4.3.2.2 State Nutrient Control Financing in the Chesapeake Bay

Virginia's nonpoint source pollution management program is charged by Virginia's *Water Quality Improvement Act of 1997* (WQIA) to carry out program activities using the Water Quality Improvement Fund (WQIF). The WQIF also has a point source program, directed by the Department of Environmental Quality (DEQ), which largely provides capital improvement upgrade grants to point sources (DEQ 2007). The nonpoint source component of the WQIF, however, is managed by DCR and is authorized to assist local municipalities and individuals with financial backing. These initiatives create financial incentives that largely target the voluntary use of BMPs, such as agricultural conservation tillage for nonpoint source effluent mitigation.

The state funded nonpoint source program, in cooperation with the WQIF in Virginia, is divided into four different focus areas. These include the agricultural BMP cost-share program, conservation reserve enhancement program (CREP), the cooperative non-point source local programs, and nonpoint source programs, projects, and competitive grants (i.e. water quality initiatives) (Commonwealth of Virginia 2006; DCR 2007b).

The agricultural BMP cost share program assists farmers with a financial incentive in exchange for installing a BMP. For example cost-share funding may be provided to a farmer for installing a cover crop that limits the amount of nutrients that leave the field. Agricultural BMP cost share initiatives are largely part of local tributary strategies. Cost-share programs are based on a percentage of direct implementation costs (material, equipment, and labor) and are not based on pounds of nutrients removed (performance-based). For example, a farmer does not receive funding based on the number of pounds of nutrients that are removed or held at bay (Commonwealth of Virginia 2006; DCR 2007b).

The state also manages the Conservation Reserve Enhancement Program (CREP). The program allows qualifying landowners the ability to obtain financial assistance for installing eligible BMPs such as riparian buffers and wetlands, or put land into an easement. The CREP is largely federally funded by the USDA's NRCS up to 75% with the remaining difference contributed by the state WQIF. The WQIF and DCR also provide further financial incentives to enter land into easements on riparian lands (Commonwealth of Virginia 2006; DCR 2007b).

As pursuant to § 10.1-2127.B and C of the *Code of Virginia* DCR is charged with working with local governments in order to provide matching funding for nonpoint source pollution projects. Funding from the WQIF is used to support this program. Here DCR works with local governments in order to provide financial assistance for nonpoint source projects that address local nonpoint source water quality problems. Projects often include implementing urban and suburban BMPs. The projects are funded on a competitive basis based on their ability to meet state goals for water quality initiatives, if the project is to be implemented on an impaired stream, and whether or not such a project would be part of a tributary strategy (Commonwealth of Virginia 2006; DCR 2007b).

The final funding category by the state WQIF is the nonpoint source programs, projects, and competitive grants. This sector also includes the water quality initiatives program. Here the WQIF provides financial assistance for initiatives that advances Virginia's current nonpoint source programs and provide measurable water quality improvements. The Virginia DCR states that it considers methods and projects that provide measurable water quality improvements from cost effective, innovative, and new initiatives. For example, these projects might include further incentives for agricultural and urban nutrient implementation initiatives (Commonwealth of Virginia 2006; DCR 2007b).

Opportunities to use state funding resources to pay for enhanced nutrient assimilation credits under the WQIF appear to be limited. Nonpoint source mitigation statutes and subsequent funding programs in Virginia, through the WQIF, focus on the control nonpoint source pollution at the source, typically through the use of agricultural BMPs. For example, § 10.1-2132(C) of the WQIF gives priority to agricultural practices, in addition to § 10.1-2128(B) noting that funds are intended for nonpoint source pollution prevention, reduction, and control programs. Furthermore, § 10.1-2117 defines nonpoint source pollution as "pollution of state waters washed from the land surface in a diffuse manner and not resulting from a discernible, defined or discrete conveyance." Given the statutory language in § 10.1-2117, § 10.1-2128(B), and § 10.1-2132(C), using the WQIF to create demand for nutrient credits from oyster aquaculture will be challenging.

Paying for enhanced nutrient credits on a performance basis will also be difficult under the WQIF grant guidelines. For example, section § 10.1-2132(C) explains that grants are funded based on "initiatives that are clearly demonstrated as likely to achieve reductions in nonpoint source pollution." Moreover, the ability to pay for nutrient removal from ambient waters does not appear to be included, as the focus is given to paying for practices. The focus on nonpoint source pollution continues to reveal the intentions of the statute, which from the analysis conducted here, appears to be a focus toward reducing nutrients from land based entities.

While demand for nutrient assimilative credits from the WQIF may be limited at this time, the breadth of the statutory language may someday be expanded to include assimilative technologies. Furthermore, given the challenges that Bay states are facing in meeting their nutrient reduction goals, additional reduction options will be needed. It is therefore appropriate to examine the funding resources for the WQIF. Funding nonpoint source mitigation in Virginia from the WQIF is derived from the governor's WQIF budget, the WQIF General Assembly amended budget, the WQIF General Assembly actions, and the WQIF mandatory budget surplus deposits. Furthermore, all budgets are approved by the state legislature and are either direct appropriations to the fund or mandatory deposits made from budgetary surplus (DCR 2007b). During 2002, 2003, and 2004, no funding was appropriated to the WQIF. Total funding for fiscal year 2005 and 2006, however, approached $70 million (Table 4.2). Within the $70 million dollar allocation, approximately $9M was appropriated for 2005 while nearly $61 million dollars were designated for 2006. Funding for fiscal years 2007 and 2008 has not been reported through DCR's annual non-point source sector report concerning the WQIF.

Table 4.2
Summary of Non-Point Source Program Appropriations within different Virginia WQIF Programs

WQIF Program	FY 2005	FY 2006	FY 2006 (Supplemental)
Agricultural BMP Cost Share Program	$5,629,875	$20,000,000	$28,000,000
Conservation Reserve Enhancement Program	$2,000,000	$2,514,910	$860,000
NPS Programs, Initiatives, Projects & Grants	$1,500,000	$1,250,000	$1,500,000
Cooperative NPS Local Programs	$00.00	$3,000,000	$3,536,550
Total	**$9,129,875**	**$26,764,910**	**$33,896,550**

***Source: (DCR 2007b)**
***Adjustments were made to the in-text funding allocation numbers as it was verified by DCR that the initial numbers in the 2007 report were incorrect. The numbers presented in Table 4.2 are correct according to Russ Perkinson at DCR.**

Given previous funding allocations in 2005 and 2006, it appears that if the WQIF could potentially create demand for nutrient assimilative credits, that adequate funding would exist to support an increase of 10 million oysters (for N credits prices ranging from $5.00-$50.00). While prior appropriations to the non-point source sector of Virginia's WQIF have been strong over 2005 and 2006, the lack of funding between 2002 to 2004, however, indicates considerable year to year variation in funding levels (DCR 2004). It is also important to note that given recession years, and the challenges that states face in order to balance their budgets, future funding allocations for non-point source mitigation may be reduced. To maintain a scale up in oyster production, consistent funding would be required and paying for nutrient credits would have to be a plausible option within the WQIF.

4.3.3 Private Voluntary Payments in the Chesapeake Bay

Private entities, such as non-profit organizations, also have the ability to voluntarily purchase nutrient credits from oyster aquaculture enterprises. The notion of using voluntary incentive-based credits to improve environmental quality is not particularly a new concept as initial efforts were developed through voluntary carbon offset markets. While voluntary nutrient offsets are still new and developing, these projects represent a move to allow direct payments to oyster aquaculture for the water quality services they provide.[7]

With concerns that increasing levels of greenhouse gases are contributing to global climatic changes, voluntary private contributions for carbon offsets have surfaced. Voluntary offsets, which totaled $331 million in 2007, were subsequently established by private organizations to increase the efforts to reduce concentrations of carbon in the atmosphere (Bardelline 2008). Here, private organizations and individuals voluntarily purchase carbon offsets to negate increasing concentrations of carbon. For example, a private party might purchase a carbon offset with the guarantee that an organization will create a sink for carbon through investing in a reforestation activity that sequesters the pollutant. Voluntary offset contributions have tripled since 2006. Furthermore, the ability to attract funding sources from unregulated private parties has been an appealing and a plausible option for offsetting carbon (Bardelline 2008).

The establishment of an analogous private voluntary offset for nutrients in the Chesapeake Bay region could create funding opportunities for oyster aquaculturists. Private organizations have become frustrated with the nutrient reductions achieved by regulated point sources and non-point source BMP's (Clougherty 2008; DeMetrick 2008). In an effort to increase nutrient mitigation activities, a number of different private organizations, namely nonprofits, have proposed the use of voluntary nutrient offset

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[7] The process of credit certification and verification is not explicitly part of the discussion in this chapter as it is assumed that the procedure will be plausible.

programs. For example, in 2008 the National Fish and Wildlife Foundation (NFWF) awarded a conservation innovation grant to the Chesapeake Bay Foundation in order to develop a "Nutrient Neutral Fund." The project plans to construct a monetary fund where private parties can make donation or payments to the fund, and in return the fund invests in cost effective projects that remove quantities of nutrients through verified nutrient reductions. The degree of specification for what types of projects would receive funding has not directly been determined as it has only been referred to as "high quality nutrient pollution reduction projects" (NFWF 2008). In any case, private organizations and individuals can potentially make contributions or payments into the fund in order to subsequently create demand for nutrient removal. The NFWF also awarded a 2008 grant to the Pinchot Institute for Conservation to develop an innovative market for environmental services called a "Bay Bank." Here private citizens, organizations, and businesses will theoretically have the ability to participate in an online marketplace where ecosystems services, such as nutrient offsets, can be bought and sold. As private contributions or payments are made, demand is created for possible nutrient assimilation services (NFWF 2008).

As voluntary nutrient offset markets in Chesapeake Bay prove their potential contributions to enhancing water quality, private funding sources from businesses and corporations will also potentially increase. Funding sources will also likely escalate in a similar manner as voluntary offsets for carbon have done. Furthermore, the focus toward environmental stewardship and the ever increasing need to create public relation campaigns that promote the "green" side of companies will likely continue to become a part of contemporary business models. For example, agricultural or wastewater treatment plant operations with significant nutrient loads into the Bay may want to develop a competitive advantage and promote their products as “Nutrient Neutral” or “Bay Friendly.” A similar approach is used to promote Fortune 500 companies that want to create a ‘carbon neutral’ image to consumers. The use of voluntary nutrient markets and the associated funding available to purchase nutrient offsets will therefore likely become a reliable and robust means to achieve the water quality enhancement initiatives for the Chesapeake Bay. While not only reducing their individual loads, companies and corporations could also potentially sponsor nutrient offsets through the payment of funds to a private organization, as described above, that would, in return, create payments for nutrient removal from nutrient assimilative technologies. Additional efforts could be taken to purchase nutrient assimilation credits directly from entities such as oyster aquaculturists in order to stay in compliance with their individual wasteload allocations.

4.4 Conclusion

This chapter presented the conceptual framework and outlined the current funding opportunities available to potentially pay for nutrient removal services from oyster aquaculture enterprises in the Chesapeake Bay. Three broad funding sources were presented with the opportunities that potentially exist to pay for nutrient removal services from ambient waters.

The ability to pay for nutrient assimilation services through an administrated market structure, such as the nutrient credit trading program presented for Virginia and Maryland, may be plausible given some adjustments. The most promising opportunity in Virginia may lie within the discretion to allow sources to offset their loads “by other means approved by the department." Federal and state agencies, however, will need to insure that the use of oyster aquaculture (nutrient assimilative services in general) is not classified as in-stream treatment and impede the regulations set forth by the Clean Water Act. Along the same lines, the ability to offset loads using oyster aquaculture will need to be recognized in a similar manner as Maryland is proposing.

Given current funding appropriations and initiatives, it appears that the use of federal and state derived nonpoint source funding resources, within the State of Virginia, will be a challenging and a difficult means to compensate oyster aquaculturists for the water quality services they provide. Furthermore, the statutory language throughout the potential funding resources analyzed does not appear to offer the ability to pay for performance based nutrient assimilation credits. It is important to note, however, that it may be conceivable to use § 319 funds indirectly through a TMDL program that approves the use of oyster aquaculture in order to meet a daily nutrient load limit for a particular water body. Further investigations are needed; however, to better understand the feasibility of this option. Additionally, any future publicly supported programs would require authorization from the Virginia General Assembly.

While not in full operation as of yet, funding from voluntary private markets may serve to also become a significant resource in creating demand for nutrient assimilation services from oyster aquaculture. Until funding from administrated markets and public agencies turn to funding assimilative technologies, private markets have the ability to set an example of how such a funding regime may work. In addition to setting a precedent, private voluntary nutrient markets also have the potential to extend the nutrient credit funding programs that may someday surface through administrated markets and public agency programs.

Chapter 5

Summary and Conclusion

5.1 Overview

As the Bay states continue to reach towards their goal of reducing nutrient loading in order to support the living resources of the Bay, oyster aquaculture appears to be an additional cost comparable option to add to the toolbox when offsetting marginal nutrient loads. Furthermore, the nutrient removal contribution from oyster aquaculture in Virginia compared to the total number of pounds of reduction needed to meet the 2010 nutrient reduction goal is small. The analysis conducted here estimated that on average approximately 630 pounds of N were removed for every one million oysters sold annually. Doubling the oyster aquaculture industry in Virginia from nearly 5 million oysters to nearly 10 million oysters would only increase the nutrient removal capacity to about 6,000 pounds a year. With the 78 million pounds of N estimated to have enter the tidal waters of Virginia in 2002 and the 51 million pound goal for 2010, the N removal provided from a modest doubling of the oyster aquaculture industry is small given the 27 million pound shortfall (Commonwealth of Virginia 2005). Even with an increased demand for nutrient credits, oyster aquaculture will by no means significantly meet the 2010 goal unaccompanied. Oyster aquaculture; however, appears to be a cost comparable option to aid in water quality enhancement when looking to offset small nutrient loads.

As shown, the cost of nutrient removal from oyster aquaculture is cost comparable to other nonpoint source nutrient removal technologies employed throughout the Bay region. Using a bio-economic simulation model, it was determined that a baseline representative oyster aquaculture cage and float enterprise in the Bay would need to receive approximately $3.00 to $30.00 per pound or approximately $0.002 to $0.02 per oyster in order to meet a 12%-15% targeted rate of return (TRR) over a ten year period. This is also interpreted as the cost to supply water quality enhancements using oyster aquaculture. Such a payment may encourage oyster aquaculturists to expand their enterprise and encourage new firms to come online; consequently increasing the filter-feeding capacity of the Bay.

There is limited demand for nutrient credits at this time, however. While some policy options may be available given modifications and future appropriations, the ability to compensate nutrient reduction from oyster aquaculture may be the largest obstacle to enhancing the water quality benefits from oyster aquaculture. Creating payments from private voluntary donations in conjunction with exploring possible options within current state and federal programs may provide the most realistic opportunities for paying for performance based nutrient assimilation services at this time.

5.2 Recommendations for Future Research

Although the methods employed here to determine the cost to provide nutrient assimilation services from oyster aquaculture incorporated the most available resources, three additional areas of research can provide a more robust simulation model.

First, refinements and improvements need to be made as they relate to quantifying biodeposition rates and estimating the percentage of denitrification that occurs from a representative oyster aquaculture enterprise in the Chesapeake Bay. The equations used to estimate the biodeposition rate (in dry weight), given different temperatures, seston densities, and oyster sizes were based off of the work done by (Jordan 1987). These estimates were comprised using data from the field and lab and did not directly estimate biodeposition rates of commercial aquacultured oysters. Using data collected directly from an oyster aquaculture setting may provide for better estimates of the biodeposition rate. The use of biodeposition rates, estimated from oyster aquaculture growout facilities, would theoretically provide for better estimates within the simulation model. Also, additional studies from oyster aquaculture field sites are needed to provide more insight into the total amount of N processed into N^2 gas through the nitrification and denitrification process. While Newell (2004); Newell et al. (2005) references literature that explains that 20%-70% of N from the marine benthos is removed as gas; these estimates are modeled estimates (not observed) and are not directly linked to conditions at an oyster aquaculture enterprise location. Furthermore, the use of biodeposition rates and nitrification and denitrification processes that are uniquely derived from oyster aquaculture field trials will further improve the validity of the bio-economic simulation model used within this study to estimate N removal costs. It is anticipated that future results from ongoing field trials conducted by Virginia Commonwealth University's Department of Biology may have the ability to present these refined aquaculture based estimates. Once acquired, this data can easily be integrated into the current bio-economic simulation and further economic analysis can be conducted.

Second, this thesis does not directly address the procedures and protocols necessary for certifying and enforcing nutrient assimilation credits. Furthermore, the cost of certifying nutrient assimilation credits is currently zero. Creating nutrient assimilation credits, however, includes more costs than only oyster production costs. These transaction costs are the costs incurred by making an exchange in order to receive a payment for water quality services. For example, it is conceivable that reductions in nutrients from oyster aquaculture would need to be verified by a central registry of authorized verifiers. Similar to carbon credit verification and certification, the Chicago Climate Exchange, a pilot program for trading carbon credits, has a registry of authorized verifiers for carbon-offset projects. Conceivable transaction costs for verifying and certifying reductions in nutrients from oyster aquaculture might include the cost of a state permit, baseline analysis to determine amount the of N and P removed from oyster biomass and through denitrification at a specific location, as well as a clerk to verify the number of market sized oysters sold.

Third, future improvements to the bio-economic model might include risk analysis. While the bio-economic model has the ability to conduct risk analysis, this type of analysis was not included within this thesis. A better understanding of the influence of risk variables would allow for further guidance concerning what the nutrient credit price would need to be in order to support an expansion of the oyster aquaculture industry. Examples of risk analysis variables include the availability of oyster seed, disease outbreaks, environmental events (e.g. red tides), and weather events (e.g. hurricanes).

References:

Adey, W.H., and K. Loveland. 1991. *Dynamic Aquaria: Building Living Ecosystems*. San Diego: Academic Press.

———. 1998. *Dynamic Aquaria: Building Living Ecosystems*. 2nd ed. San Diego: Academic Press.

———. 2007. *Dynamic Aquaria: Building and Restoring Living Ecosystems*. 3rd ed. Amsterdam; Boston: Academic Press.

Allen, Jr., S.K., and A. Frank-Lawale. 2008. Triploid 3n Advantage. Gloucester Point, VA: Virginia Institute of Marine Science.

Aprill, G., and D. Maurer. 1976. The Feasibility of Oyster Raft Culture in East Coast Estuaries. *Aquaculture* 7:147-160.

Aultman, S. 2007. Analyzing Cost Implications of Water Quality Trading Provisions: Lessons from the Virginia Nutrient Credit Exchange Act. MS Thesis, Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Barber, B. J., and R. Mann. 1991. Sterile Triploid *Crassostrea virginica* (Gmelin 1791) Grow Faster than Diploids but are Equally Susceptible to *Perkinsus marinus*. *Journal of Shellfish Research* 10:445-450.

Bardelline, J. 2008. *Voluntary Carbon Market Tripled in Value in 2007, Mandatory Market Doubled*, May 12 2008, <http://www.climatebiz.com/news/2008/05/12/voluntary-carbon-market-tripled-value-2007-mandatory-market-doubled> (November 22 2008).

Blankenship, K. 2004. 'Flush Tax' to Fund MD Nutrient Reduction Programs. *Bay Journal* 14 (3).

———. 2007. Chesapeake Cleanup Update: Reductions in Nutrient, Sediment Loads Need to be Accelerated. *Bay Journal* 16 (10).

Boesch, D. F., R. B. Brinsfield, and R. E. Magnien. 2001. Chesapeake Bay Eutrophication: Scientific Understanding, Ecosystem Restoration, and Challenges for Agriculture. *Journal of Environmental Quality* 30 (2).

Bosch, D., N.V. Kuminoff, A. Harris, J.C. Pope, K. Stephenson, and P. Mason. 2008. Economic Implications of Alternative Management Strategies for Virginia Oysters and Clams. Richmond, Virginia: Virginia Department of Environmental Quality.

Brown, B. L., A. J. Butt, D. Meritt, and K. T. Paynter. 2005a. Evaluation of Resistance to Dermo in Eastern Oyster Strains Tested in Chesapeake Bay. *Aquaculture Research* 36:1544-1554.

Brown, B. L., A. J. Butt, S. W. Shelton, D. Meritt, and K. T. Paynter. 2005b. Resistance of Dermo in Eastern Oysters, *Crassostrea virginica* (Gmelin), of North Carolina but not Chesapeake Bay Heritage. *Aquaculture Research* 36:1391-1399.

Brown, B. L., A. J. Butt, S. W. Shelton, and K. T. Paynter. 1998. Growth and Mortality of North Carolina-Heritage Oysters, *Crassostrea virginica,* in North Carolina and in Chesapeake Bay. *Journal of Applied Aquaculture* 8 (3):25-39.

Butt, A. J., and B. L. Brown. 2000. The Cost of Nutrient Reduction: A Case Study of Chesapeake Bay. *Coastal Management* 28:175-185.

Cairns Jr., J. 1997. Assimilative Capacity–the Key to Sustainable Use of the Planet. *Journal of Aquatic Ecosystem Stress and Recovery* 6:259-263.

Camacho, R. 1992. Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation: Financial Cost Effectiveness of Point and Nonpoint Source Nutrient Reduction Technologies in the Chesapeake Bay Basin Rockville, MD.

Castro, P., and M.E Huber. 1992. *Marine Biology*. St. Louis, MO: Mosby-Year Book, Inc.

Chesapeake Bay Commission. 2004. Cost-Effective Strategies for the Bay: 6 Smart Investments for Nutrient and Sediment Reduction. Annapolis, MD.

Chesapeake Bay Program. 2008a. *History of the Bay Program*, February 13 2008, <http://www.chesapeakebay.net/historyofcbp.aspx?menuitem=14904> (March 6 2008).

———. 2008b. *Oyster Management and Restoration*, February 22 2008, <http://www.chesapeakebay.net/oystersmanagement.aspx?menuitem=14770> (March 8 2008).

Chesapeake Bay Watershed Blue Ribbon Finance Panel. 2004. *Saving a National Treasure: Financing the Cleanup of the Chesapeake Bay*. Annapolis, MD: Chesapeake Bay Program.

Chesapeake Executive Council. 1987. 1987 Chesapeake Bay Agreement. Annapolis, MD: Chesapeake Bay Program.

———. 2000. Chesapeake 2000: A Watershed Partnership Agreement. Annapolis, MD: Chesapeake Bay Program.

Clougherty, S. 2008. *Maryland Ag's Effect on Bay Analyzed at Law School*, November 18 2008, <http://www.americanfarm.com/TopStory11.18.2008a.html> (November 28 2008).

Colwell, R.R. 1984. *Vibrios in the Environment*. New York: Wiley.

Commonwealth of Virginia. 2005. Chesapeake Bay Nutrient and Sediment Reduction Tributary Strategy. Richmond, VA: Office of the Governor.

———. 2006. Virginia Water Quality Improvement Fund Guidelines. Richmond, VA: Office of the Governor.

Congrove, M. 2008. Hatchery Timing. Gloucester Point, VA. Personal Communication, April 6, 2008.

Cornwell, J.C., D.J. Conley, M. Owens, and J.C. Stevenson. 1996. A Sediment Chronology of the Eutrophication of Chesapeake Bay. *Estuaries* 19 (2B):488-499.

Daily, G.C. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington, DC: Island Press.

Dales, J.H. 1968. *Pollution, Property, and Prices*. Toronto, Ontario, Canada: University of Toronto Press.

Dame, R. F. 1972. The Ecological Energies of Growth, Respiration and Assimilation in the Intertidal American oyster *Crassostrea virginica*. *Marine Biology* 17 (3):243-250.

Day Jr., J.W., J. Ko, J. Rybczyk, D. Sabins, R. Bean, G. Berthelot, C. Brantley, L. Cardoch, W. Conner, J.N. Day, A.J. Englande, S. Feagley, E. Hyfield, R. Lane, J. Lindsey, J. Mistich, E. Reyes, and R. Twilley. 2004. The Use of Wetlands in the

Mississippi Delta for Wastewater Assimilation: A Review. *Ocean & Coastal Management* 47:671-691.

DCR, Department of Conservation & Recreation. 2004. Virginia Nonpoint Source Pollution Management Program 2004 Annual Report. Richmond, VA: Department of Conservation and Recreation

———. 2007a. *Virginia Agricultural BMP Cost Share and Tax Credit Programs*, August 19 2008, <http://www.dcr.virginia.gov/soil_&_water/costshar.shtml> (November 5 2007).

———. 2007b. Virginia Water Quality Improvement Fund and the Cooperative Nonpointsource Pollution Program and the Federal Clean Water Act Section 319 Nonpoint Source Pollution Management Program. Richmond, VA.

DeMetrick, A. 2008. *Chesapeake Bay Foundation Plans to Sue EPA*, October 29 2008, <http://wjz.com/seenon/chesapeake.bay.environment.2.851110.html> (November 26 2008).

DEQ, Department of Environmental Quality. 2007. Annual Report on the Virginia Water Quality Improvement Fund: Point Source Pollution Control. Richmond, VA.

Erskine, A.J. 2008. Oyster Aquaculture Diagrams. Lottsburg, Virginia. Personal Communication, February 19, 2008.

Ewart, J.W., and S.E. Ford. 1993. History and Impact of MSX and Dermo Diseases on Oyster Stocks In the Northeast Region. North Darmouth Massachusetts: Northeastern Regional Aquaculture Center University of Massachusetts Dartmouth.

Fahrenthold, D.A. 2004. Oyster Project Consumed With Problems. *Washington Post*.

Fisher, J., and M. C. Acreman. 2004. Wetland Nutrient Removal: A Review of the Evidence. *Hydrology and Earth System Sciences* 8 (4):673-685.

Gallivan, T. 2008. Oyster Aquaculture Information. Franktown, Virginia. Personal Communication, February 21, 2008.

Gangnery, A., C. Bacher, and D. Buestel. 2001. Assessing the Production and the Impact of Cultivated Oysters in the Thau Lagoon (Mediterranee, France) with a Population Dynamics Model. *Canadian Journal of Fisheries and Aquatic Sciences* 58:1012-1020.

Golen, R.F. 2007. *Incorporating Shellfish Bed Restoration into a Nitrogen TMDL Implementation Plan*. Paper read at *Water Environment Federation, TMDL 2007 Conference*, at Portland, OR.

Higgins, C., B. Brown, and K. Stephenson. 2009. *Nutrient Removal in Aquacultured Oysters (C. virginica) Biomass Harvest in Chesapeake Bay*. Working Paper. Richmond, VA: Virginia Commonwealth University, Department of Biology.

Horn Point Laboratory. 2008. *Oyster Life Cycle*, 2008, <http://hpl.umces.edu/hatchery/home.html> (March 20 2008).

Jackson, J. B. C. 2001. What Was Natural in the Coastal Oceans? Paper read at the National Academy of Sciences Colloquium, "The Future of Evolution", March 16-20, 2000, at Irvine, CA.

Jahncke, M. 2008. Post Harvest Treatment. Hampton, VA. Personal Communication, April 28, 2008.

Jordan, S.J. 1987. Sedimentation and Remineralization Associated with Biodeposition by the American Oyster *Crassostrea virginica* (Gmelin). Doctor of Philosophy, Marine, Estuarine and Environmental Science, University of Maryland, College Park, MD.

Kallen, R.S., K.J. Morse, D.J. Grosse, and D.L. Leonard. 2001. Small-Scale Oyster Farming for Chesapeake Watermen-A Sustainable Business Marketing Plan. Washington, DC: TerraAqua Environmental Science and Policy, LLC. Prepared for the Campbell Foundation for the Environment.

Kauffman, D. E. 2008. Oysters for the Shucking Houses. Hampton, VA. Personal Communication, December 15, 2008.

Kennedy, V.S., R.I.E. Newell, and A.F. Eble. 1996. *The Eastern Oyster: Crassostrea virginica*. College Park, MD: Maryland Sea Grant College.

Leggett, T. 2008. Oyster Aquaculture Information. Gloucester Point, Virginia. Personal Communication, February 22, 2008.

Lenihan, H. S., C. H. Peterson, and J. M. Allen. 1996. Does Flow Speed Also Have a Direct Effect on Growth of Active Suspension-Feeders: An Experimental Test on Oysters. *Limnology and Oceanography* 41 (6):1359-1366.

Lindahl, O., R. Hart, B. Hernroth, S. Kollberg, L. O. Loo, L. Olrog, A. S. Rehnstam-Holm, J. Svensson, S. Svensson, and U. Syversen. 2005. Improving Marine Water Quality by Mussel Farming: A Profitable Solution for Swedish Society. *AMBIO: A Journal of the Human Environment* 34 (2):131-138.

Lipton, D. 2007. Economic Assessment of Aquaculture Alternatives to Restore Chesapeake Bay's Oyster Population. College Park, MD: University of Maryland College Park.

Liu, D.H.F., and B.G. Liptak. 2000. *Wastewater Treatment*. Boca Raton, FL: Lewis Pub.

Livingston, R. J. 2003. *Trophic Organization in Coastal Systems*. Boca Raton, Fla. : CRC Press.

Livingston, R.J. 2006. *Restoration of Aquatic Systems*. Boca Raton, FL: Taylor & Francis.

Louisiana Sea Grant. 2007. *Oyster Farming in Louisiana*, November 13 2007, <http://www.lamer.lsu.edu/classroom/halfshell/pdf/cycle_info.pdf> (December 22 2008).

Luckenbach, M. W., X. O. Francis, and J. Taylor. 1999. *An Introduction to Culturing Oysters in Virginia*: School of Marine Science, Virginia Institute of Marine Science, College of William & Mary.

Maryland Sea Grant. 1987. *Oyster Aquaculture: Difficult Present Promising Future*. Edited by M. Leffler. Vol. 8. College Park, MD: The University of Maryland.

Mason, P. 2008. Identification of Management Strategies for Promoting Aquaculture in Virginia. Gloucester Point, VA: Virginia Institute of Marine Science.

Matthiessen, G. C., and J. P. Davis. 1992. Observations on Growth Rate and Resistance to MSX (*Haplosporidium nelsoni*) Among Diploid and Triploid Eastern Oysters (*Crassostrea virginica* Gmelin, 1791). *Journal of Shellfish Research* 11:449–454.

McCombie, H., S. Lapègue, F. Cornette, C. Ledu, and P. Boudry. 2005. Chromosome Loss in Bi-parental Progenies of Tetraploid Pacific Oyster Crassostrea gigas. *Aquaculture* 247 (1-4):97-105.

MDE, Maryland Department of the Environment. 2008. Maryland Policy for Nutrient Cap Management and Trading in Maryland's Chesapeake Bay Watershed. edited by Water Management Administration. Baltimore, MD.

Metcalfe, T., D. J. Bosch, J. W. Pease, M. M. Alley, and S. B. Phillips. 2007. Yield Reserve Program Costs in the Virginia Coastal Plain. *Agricultural and Resource Economics Review* 36 (2):15.

Moore, G. 2007. Cost Share Program. Richmond, VA. Personal Communication, July 11, 2007.

Murray, T.J., and M.J. Oesterling. 2006. Virginia Shellfish Aquaculture, Situation and Outlook Report, Results of Virginia Shellfish Aquaculture Crop Reporting Survey 2004-2006. Gloucester Point, VA: Virginia Institute of Marine Science.

———. 2007. Virginia Shellfish Aquaculture, Situation and Outlook Report, Results of Virginia Shellfish Aquaculture Crop Reporting Survey 2005-2007. Gloucester Point, VA: Virginia Institute of Marine Science.

———. 2008. Virginia Shellfish Aquaculture, Situation and Outlook Report, Results of Virginia 2007 Shellfish Aquaculture Crop Reporting Survey. Gloucester Point, VA: Virginia Institute of Marine Science.

Muth, M. K., S. A. Karns, D. W. Anderson, and B. C. Murray. 2002. Effects of Post-Harvest Treatment Requirements on the Markets for Oysters. *Agricultural and Resource Economics Review* 31 (2).

Nell, J. A. 2002. Farming Triploid Oysters. *Aquaculture* 210:69-88.

Newell, R. I. E. 2004. Ecosystem Influences of Natural and Cultivated Populations of Suspension-Feeding Bivalve Molluscs: A Review. *Journal of Shellfish Research* 23 (1):51-61.

Newell, R.I.E., T.R. Fisher, R R. Holyoke, and J.C. Cornwell. 2005. Influence of Eastern Oysters on Nitrogen and Phosphorus Regeneration in Chesapeake Bay, USA. In

The Comparative Roles of Suspension-feeders In Ecosystems, edited by R. Dame and S. Olenin. Dordecht, The Netherlands: Springer.

NFWF, National Fish and Wildlife Foundation. 2008. *Market-Based Approaches to Nutrient Reduction on Working Lands*, 2009, <http://www.nfwf.org/Content/NavigationMenu/ChesapeakeBayStewardshipFund/ConservationResults/AgriculturalConservation/MarketbasedConservation/default.htm> (September 17 2008).

Novotny, V. 2003. *Water quality: Diffuse Pollution and Watershed Management*. 2nd ed. Hoboken, NJ: J. Wiley.

Nowicki, B. L., J. R. Kelly, E. Requintina, and D. Van Keuren. 1997. Nitrogen Losses Through Sediment Denitrification in Boston Harbor and Massachusetts Bay. *Estuaries* 20 (3):626-639.

Oesterling, M. 1993. *Marine Aquaculture In the Commonwealth of Virginia*. Edited by S. C. Waters. Gloucester Point, VA: Virginia Institute of Marine Science.

Paynter, K. T., and L. Dimichele. 1990. Growth of Tray-Cultured Oysters (*Crassostrea virginica* Gmelin) in Chesapeake Bay. *Aquaculture* 87:289-297.

Paynter, K. T., M. E. Mallonee, and S. H. Shriver. 1992. Cost Analysis of Floating Raft Oyster Production in Chesapeake Bay. *Journal of Shellfish Research* 11 (1):163-167.

Pelz, R. 2008. Oyster Aquaculture Information. Ridge, Maryland. Personal Communication, February 20, 2008.

Santopietro, G.D. 1986. The Evolution of Property Rights to a Natural Resource: The Oyster Grounds of the Chesapeake Bay. Doctor of Philosphy, Agricultural Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Sea Fish Industry Authority. 2001. The Oyster Cultivation Economic Model. Edinburgh, UK: Sea Fish Industry Authority.

Shabman, L., and K. Stephenson. 2007. Achieving Nutrient Water Quality Goals: Bringing Market-Like Principles to Water Quality Management. *Journal of the American Water Resources Association* 43 (4):1-14.

Shulyer, L.R. 1995. Cost Analysis for Nonpoint Source Control Strategies in the Chesapeake Bay Basin. Annapolis, MD: Chesapeake Bay Program Office CBP/TRS 136/95, EPA 903-R-95-0005.

Stanley, J.G., and M.A. Sellers. 1986. Species Profiles: Life Histories and Environmental Requirements of Coastal Fisheries and Invertebrates (Mid-Atlantic) American Oyster. U.S. Fish and Wildlife Service Biol. Rep. 82 (11.65). U.S. Army Corps of Engineers, TR EL-82-4.

Vigliotta, J. 2008. Oyster Aquaculture Information Ware Neck, Virginia. Personal Communication, February 22, 2008

VIMS, Virginia Institute of Marine Science. 2005a. *Oyster Diseases of the Chesapeake Bay, Dermo Fact Sheet*, December 8 2005, <http://www.vims.edu/env/research/shellfish/dermo.html> (May 2 2008).

———. 2005b. *Oyster Diseases of the Chesapeake Bay, MSX Fact Sheet*, December 8 2005, <http://www.vims.edu/env/research/shellfish/msx.html> (May 2 2008).

VMRC, Virginia Marine Resource Commission. 1998. *Guide To Virginia's Laws, Regulations and Requirements for Marine Shellfish Aquaculture Activities*. Richmond, VA: Virginia Marine Resource Commission Habitat Management Division.

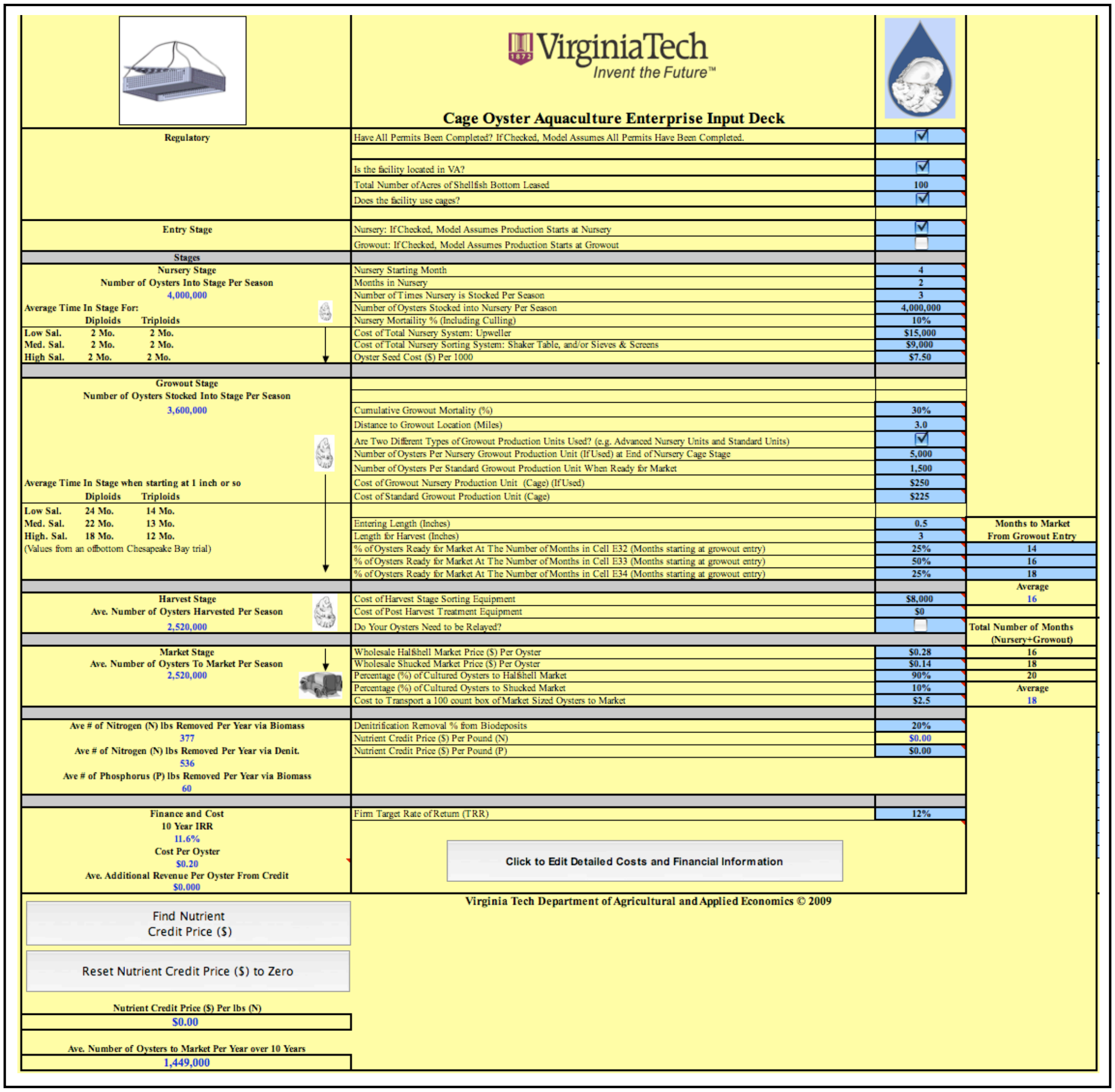
Weston, J. F., and E.F. Brigham. 1985. *Essentials of Managerial Finance*: CBS College Publishing.

Wieland, R. 2007. Costs and Returns to Oyster Aquaculture In the Chesapeake Bay. Trappe, MD: Main Street Economics. Prepared for the NOAA Chesapeake Bay Program Office Non-Native Oyster Research Program.

Appendices:

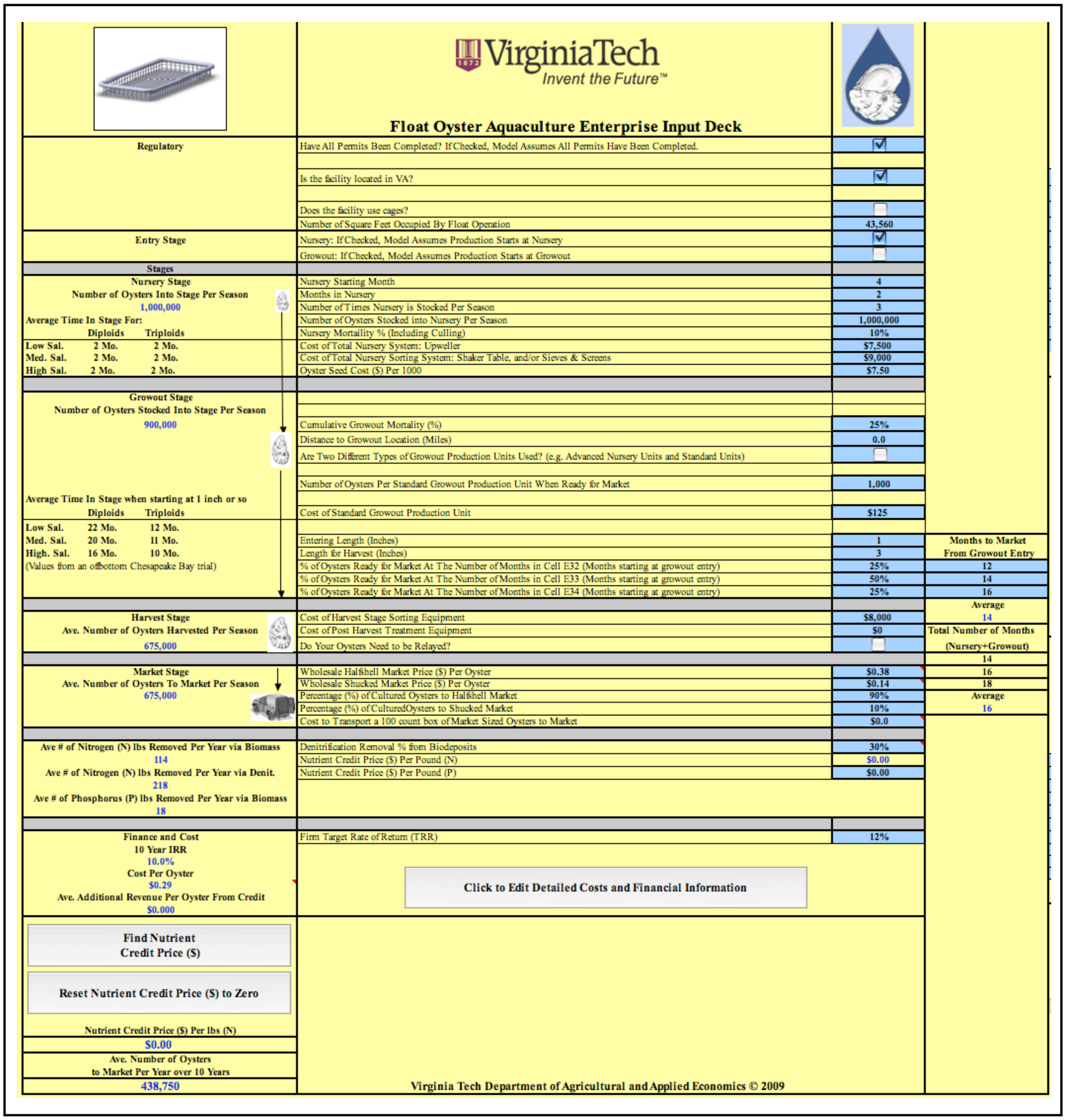
Appendix A: Screen Shots of the Bio-economic Simulation Model.

Appendix A.1. Screen Shot of the Representative Cage Oyster Aquaculture Enterprise Input-Output Deck.



(Economic modeling program created by Alexander Miller)

Appendix A.2. Screen Shot of the Representative Float Oyster Aquaculture Enterprise Input-Output Deck.



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Float Oyster Aquaculture Enterprise Input Deck

Regulatory	Have All Permits Been Completed? If Checked, Model Assumes All Permits Have Been Completed.	☑	
	Is the facility located in VA?	☑	
	Does the facility use cages?	☐	
	Number of Square Feet Occupied By Float Operation	43,560	
Entry Stage	Nursery: If Checked, Model Assumes Production Starts at Nursery	☑	
	Growout: If Checked, Model Assumes Production Starts at Growout	☐	
Stages			
Nursery Stage	Nursery Starting Month	4	
Number of Oysters Into Stage Per Season	Months in Nursery	2	
1,000,000	Number of Times Nursery is Stocked Per Season	3	
Average Time In Stage For:	Number of Oysters Stocked into Nursery Per Season	1,000,000	
Diploids Triploids	Nursery Mortaility % (Including Culling)	10%	
Low Sal. 2 Mo. 2 Mo.	Cost of Total Nursery System: Upweller	$7,500	
Med. Sal. 2 Mo. 2 Mo.	Cost of Total Nursery Sorting System: Shaker Table, and/or Sieves & Screens	$9,000	
High Sal. 2 Mo. 2 Mo.	Oyster Seed Cost ($) Per 1000	$7.50	
Growout Stage			
Number of Oysters Stocked Into Stage Per Season			
900,000	Cumulative Growout Mortality (%)	25%	
	Distance to Growout Location (Miles)	0.0	
	Are Two Different Types of Growout Production Units Used? (e.g. Advanced Nursery Units and Standard Units)	☐	
	Number of Oysters Per Standard Growout Production Unit When Ready for Market	1,000	
Average Time In Stage when starting at 1 inch or so			
Diploids Triploids	Cost of Standard Growout Production Unit	$125	
Low Sal. 22 Mo. 12 Mo.	Entering Length (Inches)	1	**Months to Market**
Med. Sal. 20 Mo. 11 Mo.	Length for Harvest (Inches)	3	**From Growout Entry**
High. Sal. 16 Mo. 10 Mo.	% of Oysters Ready for Market At The Number of Months in Cell E32 (Months starting at growout entry)	25%	12
(Values from an offbottom Chesapeake Bay trial)	% of Oysters Ready for Market At The Number of Months in Cell E33 (Months starting at growout entry)	50%	14
	% of Oysters Ready for Market At The Number of Months in Cell E34 (Months starting at growout entry)	25%	16
			Average
Harvest Stage	Cost of Harvest Stage Sorting Equipment	$8,000	14
Ave. Number of Oysters Harvested Per Season	Cost of Post Harvest Treatment Equipment	$0	**Total Number of Months**
675,000	Do Your Oysters Need to be Relayed?	☐	**(Nursery+Growout)**
			14
Market Stage	Wholesale Halfshell Market Price ($) Per Oyster	$0.38	16
Ave. Number of Oysters To Market Per Season	Wholesale Shucked Market Price ($) Per Oyster	$0.14	18
675,000	Percentage (%) of Cultured Oysters to Halfshell Market	90%	**Average**
	Percentage (%) of CulturedOysters to Shucked Market	10%	16
	Cost to Transport a 100 count box of Market Sized Oysters to Market	$0.0	
Ave # of Nitrogen (N) lbs Removed Per Year via Biomass	Denitrification Removal % from Biodeposits	30%	
114	Nutrient Credit Price ($) Per Pound (N)	$0.00	
Ave # of Nitrogen (N) lbs Removed Per Year via Denit.	Nutrient Credit Price ($) Per Pound (P)	$0.00	
218			
Ave # of Phosphorus (P) lbs Removed Per Year via Biomass			
18			
Finance and Cost	Firm Target Rate of Return (TRR)	12%	
10 Year IRR			
10.0%			
Cost Per Oyster	**Click to Edit Detailed Costs and Financial Information**		
$0.29			
Ave. Additional Revenue Per Oyster From Credit			
$0.000			
Find Nutrient Credit Price ($)			
Reset Nutrient Credit Price ($) to Zero			
Nutrient Credit Price ($) Per lbs (N)			
$0.00			
Ave. Number of Oysters to Market Per Year over 10 Years			
438,750	**Virginia Tech Department of Agricultural and Applied Economics © 2009**		

(Economic modeling program created by Alexander Miller)

Appendix B: Results from the Cage Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis.

Appendix B.1.
Results from the Cage Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis as a Function of Cumulative Growout Mortality.

	HS Oyster Price	HS Oyster Price	HS Oyster Price	HS Oyster Price
Cum. Growout Mort. (%)	$0.24	$0.26	$0.28	$0.30
10%	**$26.55**	**$0.00**	**$0.00**	**$0.00**
15%	**$33.38**	**$4.75**	**$0.00**	**$0.00**
20%	**$41.06**	**$12.43**	**$0.00**	**$0.00**
25%	**$49.77**	**$21.14**	**$0.00**	**$0.00**
30%	**$59.72**	**$31.09**	**$2.46**	**$0.00**
35%	**$70.69**	**$42.06**	**$13.43**	**$0.00**
40%	**$84.04**	**$55.41**	**$26.78**	**$0.00**
45%	**$99.83**	**$71.20**	**$42.57**	**$13.94**
50%	**$118.76**	**$90.13**	**$61.50**	**$32.87**
55%	**$141.91**	**$113.28**	**$84.65**	**$56.02**
60%	**$170.84**	**$142.21**	**$113.58**	**$84.95**

Appendix B.2.
Results from the Cage Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis as a Function of the Denitrification Percentage.

	HS Oyster Price	HS Oyster Price	HS Oyster Price	HS Oyster Price
Denitrification (%)	$0.24	$0.26	$0.28	$0.30
0%	**$144.40**	**$75.17**	**$5.95**	**$0.00**
5%	**$106.61**	**$55.50**	**$4.39**	**$0.00**
10%	**$84.49**	**$43.99**	**$3.48**	**$0.00**
15%	**$69.98**	**$36.43**	**$2.88**	**$0.00**
20%	**$59.72**	**$31.09**	**$2.46**	**$0.00**
25%	**$52.08**	**$27.11**	**$2.14**	**$0.00**
30%	**$46.18**	**$24.04**	**$1.90**	**$0.00**
35%	**$41.48**	**$21.59**	**$1.71**	**$0.00**
40%	**$37.64**	**$19.60**	**$1.55**	**$0.00**
45%	**$34.46**	**$17.94**	**$1.42**	**$0.00**
50%	**$31.77**	**$16.54**	**$1.31**	**$0.00**
55%	**$29.47**	**$15.34**	**$1.21**	**$0.00**
60%	**$27.48**	**$14.31**	**$1.13**	**$0.00**
65%	**$25.75**	**$13.40**	**$1.06**	**$0.00**
70%	**$24.22**	**$12.61**	**$1.00**	**$0.00**

Appendix B.3.
Results from the Cage Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis as a Function of Halfshell Oyster Prices Per Oyster.

	% to HS Market	% to HS Market	% to HS Market	% to HS Market
HS Oyster Prices	60%	70%	80%	90%
$0.18	**$152.77**	**$150.38**	**$148.00**	**$145.61**
$0.20	**$133.68**	**$128.11**	**$122.55**	**$116.98**
$0.22	**$114.59**	**$105.85**	**$97.10**	**$88.35**
$0.24	**$95.51**	**$83.58**	**$71.65**	**$59.72**
$0.26	**$76.42**	**$61.31**	**$46.20**	**$31.09**
$0.28	**$57.33**	**$39.04**	**$20.75**	**$2.46**
$0.30	**$38.25**	**$16.77**	**$0.00**	**$0.00**
$0.32	**$19.16**	**$0.00**	**$0.00**	**$0.00**
$0.34	**$0.07**	**$0.00**	**$0.00**	**$0.00**
$0.36	**$0.00**	**$0.00**	**$0.00**	**$0.00**
$0.38	**$0.00**	**$0.00**	**$0.00**	**$0.00**

Appendix B.4.
Results from the Cage Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis as a Function of Average Total Number of Months to Market.

	HS Oyster Price	HS Oyster Price	HS Oyster Price	HS Oyster Price
Average Months in Growout	$0.24	$0.26	$0.28	$0.30
12	**$0.00**	**$0.00**	**$0.00**	**$0.00**
14	**$0.00**	**$0.00**	**$0.00**	**$0.00**
16	**$28.48**	**$0.00**	**$0.00**	**$0.00**
18	**$59.72**	**$31.09**	**$2.46**	**$0.00**
20	**$113.59**	**$82.97**	**$52.36**	**$21.75**
22	**$205.50**	**$170.80**	**$136.11**	**$101.41**
24	**$304.70**	**$268.31**	**$231.93**	**$195.54**

Appendix C: Results from the Float Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis.

Appendix C.1.
Results from the Float Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis as a Function of Cumulative Growout Mortality.

	HS Oyster Price	HS Oyster Price	HS Oyster Price	HS Oyster Price
Cum. Growout Mort%	$0.34	$0.36	$0.38	$0.40
10%	**$32.99**	**$9.35**	**$0.00**	**$0.00**
15%	**$40.59**	**$16.96**	**$0.00**	**$0.00**
20%	**$49.15**	**$25.51**	**$1.87**	**$0.00**
25%	**$58.84**	**$35.21**	**$11.57**	**$0.00**
30%	**$69.92**	**$46.29**	**$22.65**	**$0.00**
35%	**$82.71**	**$59.07**	**$35.44**	**$11.80**
40%	**$97.63**	**$73.99**	**$50.35**	**$26.71**
45%	**$115.26**	**$91.62**	**$67.98**	**$44.34**
50%	**$136.41**	**$112.77**	**$89.14**	**$65.50**
55%	**$162.27**	**$138.63**	**$114.99**	**$91.35**
60%	**$194.58**	**$170.95**	**$147.31**	**$123.67**

Appendix C.2.
Results from the Float Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis as a Function of the Denitrification Percentage.

	HS Oyster Price	HS Oyster Price	HS Oyster Price	HS Oyster Price
Denitrification (%)	$0.34	$0.36	$0.38	$0.40
0%	**$172.33**	**$103.11**	**$33.88**	**$0.00**
5%	**$130.41**	**$78.03**	**$25.64**	**$0.00**
10%	**$104.90**	**$62.76**	**$20.62**	**$0.00**
15%	**$87.73**	**$52.49**	**$17.25**	**$0.00**
20%	**$75.39**	**$45.11**	**$14.82**	**$0.00**
25%	**$66.10**	**$39.55**	**$13.00**	**$0.00**
30%	**$58.84**	**$35.21**	**$11.57**	**$0.00**
35%	**$53.02**	**$31.72**	**$10.42**	**$0.00**
40%	**$48.25**	**$28.87**	**$9.49**	**$0.00**
45%	**$44.27**	**$26.49**	**$8.70**	**$0.00**
50%	**$40.89**	**$24.47**	**$8.04**	**$0.00**
55%	**$37.99**	**$22.73**	**$7.47**	**$0.00**
60%	**$35.48**	**$21.23**	**$6.98**	**$0.00**
65%	**$33.28**	**$19.91**	**$6.54**	**$0.00**
70%	**$31.33**	**$18.75**	**$6.16**	**$0.00**

Appendix C.3.
Results from the Float Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis as a Function of Halfshell Oyster Prices Per Oyster.

	% to HS Market	% to HS Market	% to HS Market	% to HS Market
HS Oyster Prices	60%	70%	80%	90%
$0.28	**$184.91**	**$166.52**	**$148.14**	**$129.76**
$0.30	**$169.15**	**$148.14**	**$127.13**	**$106.12**
$0.32	**$153.39**	**$129.76**	**$106.12**	**$82.48**
$0.34	**$137.63**	**$111.37**	**$85.11**	**$58.84**
$0.36	**$121.88**	**$92.99**	**$64.10**	**$35.21**
$0.38	**$106.12**	**$74.60**	**$43.09**	**$11.57**
$0.40	**$90.36**	**$56.22**	**$22.07**	**$0.00**
$0.42	**$74.60**	**$37.83**	**$1.06**	**$0.00**
$0.44	**$58.84**	**$19.45**	**$0.00**	**$0.00**
$0.46	**$43.09**	**$1.06**	**$0.00**	**$0.00**
$0.48	**$27.33**	**$0.00**	**$0.00**	**$0.00**

Appendix C.4.
Results from the Float Oyster Aquaculture Enterprise Nutrient Credit Price ($/lbs of N) Sensitivity Analysis as a Function of Average Total Number of Months to Market.

	HS Oyster Price	HS Oyster Price	HS Oyster Price	HS Oyster Price
Average Months in Growout	$0.34	$0.36	$0.38	$0.40
12	**$18.99**	**$0.00**	**$0.00**	**$0.00**
14	**$31.04**	**$0.00**	**$0.00**	**$0.00**
16	**$58.84**	**$35.21**	**$11.57**	**$0.00**
18	**$84.01**	**$63.89**	**$43.78**	**$23.67**
20	**$133.36**	**$112.18**	**$91.01**	**$69.83**
22	**$231.35**	**$207.79**	**$184.23**	**$160.66**
24	**$336.71**	**$312.11**	**$287.51**	**$262.90**