PRODUCTION ECONOMICS OF SUMMER FLOUNDER PARALICHTHYS DENTATUS AQUACULTURE IN A RECIRCULATING SYSTEM

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TABLE OF CONTENTS

ABSTRACT

An economic analysis is conducted for a summer flounder grow-out operation using a recirculating aquaculture system (RAS) based on engineering and biological parameters from the University of North Carolina at Wilmington's near-commercial scale RAS facility located in Wrightsville Beach, NC. The analysis determines the profit-maximizing facility scale and harvest size, returns to management, and the sensitivity of financial performance to key biological, engineering, and economic parameters. Monte Carlo analysis is used to assess the impacts of uncertainty in flounder prices, electricity costs, and interest rates on financial performance. The UNCW study of summer flounder production in a near-commercial scale RAS (Carroll et al. in press) is used as a basis for developing simulation models of commercial scale summer flounder RAS facilities. All models assume that fish reach an average of 1.5 lbs (marketable size) with an 80 % survival rate and a feed conversion ratio (FCR) of 1.8 (the average FCR over all growth phases, and the lowest FCR observed during the first 7 months, of the UNCW near-commercial scale field study). The following key characteristics are used to distinguish alternative systems: system scale (0.5-acre, 1-acre, and 3 x 1-acre systems), length of grow-out cycle (13.4 and 20-months), tank size (15, 20, and 27 ft diameters), outdoor (security fence) vs. indoor (building) systems, tank type (fiberglass, steel, and glass coated steel), and fish transfer schedule (between tanks). Each model is analyzed assuming one of two alternative grow-out periods: 20 or 13.4 months. The 20-month cycle corresponds to the mean grow-out period for summer flounder raised in the UNCW near commercial scale field study, and the 13.4-month cycle corresponds to the top 5% of the fastest growing flounder reaching marketable size (1.5 lbs) in the UNCW study. Each commercial-scale system is defined by a set of biological, engineering, and economic parameter values. For each system, estimates of revenues, capital costs, variable costs, fixed costs, and total costs are developed per grow-out cycle and per year. Break-even price, returns to management per grow-out cycle, and returns to management per year are calculated to assess the relative financial performance of alternative systems over a 10-year planning horizon. The most cost-effective system (i.e., the system with the lowest break-even price) is a 3 x 1-acre, 27 ft diameter, steel tank, indoor (using a building) system, with a 13.4-month grow-out cycle, utilizing a fish transfer procedure, with a break-even price of $3.53 (break-even price was $4.43 for the 20-month grow-out cycle). Sensitivity analyses and Monte Carlo analyses revealed that growth rate is the most critical determinant of financial performance, followed by capital costs and fingerling costs. At the 20-month growth cycle, sensitivity analyses revealed that break-even price was most sensitive to changes in growth rates, followed by initial investment costs, fingerling costs, feed costs, and electric costs. Present value returns (cumulative)

for a 10-year planning horizon for one of the 3 x 1-acre facilities using the most cost-effective facility design range from negative $50,000 to positive $300,000 for the 20-month growth cycle model, whereas present value cumulative 10-year returns for the 13.4-month growth cycle model are always positive and range from $675,000 to $1,175,000. The significant impact of growth cycle length on financial returns emphasizes the financial importance of biological research targeting improvements in summer flounder growth rates.

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DEDICATION

I would like to dedicate this thesis to my grandfather, J.C. Yates, whose character and spirit are an even greater inspiration after his passing.

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

High market demand for summer flounder (Dumas and Horton 2001, Zucker 1998) and advances in the culture of flatfish such as turbot (*Scophthalmus maximus*) in Europe (Person Le-Ruyet et al. 1991) and Japanese flounder (*Paralychthys olivaceus*) in Asia (Matsuoka 1995; Min 1995) have sparked interest in summer flounder (*Paralichthys dentatus)* as a candidate for aquaculture in the U.S. (Bisbal and Bengston 1995a; Bengston 1995). The use of recirculating aquaculture system (RAS) technology has been studied by researchers at The University of North Carolina at Wilmington (UNCW) and North Carolina State University (NCSU) for use in the grow-out of summer flounder. Relative to traditional grow-out techniques, such as earthen ponds, flow through tank systems, and net pens, RAS technology has numerous advantages. With RAS technology, culturists have a high degree of environmental control over the system, and the technology requires far less water than traditional systems. To date, research has focused on the biological, environmental, and engineering aspects of summer flounder culture (Bengston 1995, Daniels and Nardi 1999), but little is known about the production economics and profitability of summer flounder aquaculture using RAS technology (Dumas and Horton 2001, Losordo and Westerman 1994, Zucker and Anderson 1999).

Summer Flounder-Profile

The summer flounder (*Paralichthys dentatus*), commonly referred to as fluke can be found from the southern Gulf of Maine to South Carolina. Important commercial and recreational fisheries exist within the Mid-Atlantic Bight (Cape Cod to Cape Hatteras). Summer flounder are concentrated in bays and estuaries from late spring through early autumn. They move offshore to deeper water to spawn during the winter. Larvae are transported toward coastal areas by prevailing water currents. Post-larvae and juveniles develop primarily within bay and estuarine areas, notably Pamlico Sound and Chesapeake Bay. Most of the population is sexually mature by age 2 years. Female summer flounder may live up to 20 years, attaining weights up to 11.8 kg (26 lb), but males rarely live for more than 7 years (Daniels and Nardi 1999, Terceiro 2001). Growth rates differ appreciably between sexes, with females growing much faster.

Fishing regulations may impact the optimal production levels and harvest timing of cultured summer flounder by influencing flounder market supply and prices. The wild summer flounder resource is managed by the National Marine Fisheries Service under the Summer Flounder, Scup, and Black Sea Bass Fishery Management Plan (FMP) as a unit stock from North Carolina to Maine (Terceiro 2001). Amendment 2 to the original Summer Flounder FMP implemented several major regulatory provisions, including annual commercial quotas, recreational harvest limits, a commercial vessel permit moratorium, minimum fish size and gear restrictions, and a recreational fishery possession limit (Daniels and Nardi1999, Terceiro 2001). Each year resource managers determine the number of summer flounder that may be removed from the population, a number referred to as total allowable landings (TAL). TAL is divided between commercial (60%) and recreational sectors (40%), and each state is given an allotment based on historical landings in each sector (NCDMF 2002). North Carolina receives the largest commercial quota of any state, 27%, based on historic landings, but North Carolina accounts for only 5% of the recreational quota along the east coast (NCDMF 2002)

Recreational anglers in North Carolina who fish for flounder in ocean waters (outside of the ocean line boundary, approximately the egress of ocean inlets) face two new regulations (NCDMF 2002). Beginning April 25th, 2002, the minimum length limit for flounder taken or possessed outside of the ocean line boundary (approximately the egress of ocean inlets) increased from 15 inches to 15 ½ inches. Additionally, flounder fishing in ocean waters north of New River Inlet, NC closes entirely beginning May 14th through July 4th of each year. During this closure, recreational anglers cannot possess any flounder while in ocean waters. Except for the closed period, the bag limit in ocean waters remains at 8 flounder per person per day. South of New River Inlet the season remains open year round, and the bag limit in ocean waters is also 8 flounder per person per day in ocean waters. In inland waters it is unlawful to possess flounder less than 14 inches in length, but there is no bag limit in inland waters.

In North Carolina, average commercial landings and ex-vessel value of summer flounder during 1991-2003 were 1,499 mt, and $5,265,432 ($1.59 per pound landed), respectively, while the average recreational landings 1991-2003 were 151 mt, with an unknown value to the overall economy (NCDMF 2002). The commercial season opens January 1st and closes when 70% of the annual NC quota is reached. The season then re-opens November 1st until the annual quota is reached. In North Carolina, for regulatory purposes, all flounder caught outside the ocean boundary line are considered summer flounder, while all flounder caught inside the ocean boundary line are considered southern flounder (NCDMF 2002).

Nationwide, total landings of summer flounder averaged 18,100 mt annually during 1981-1990, peaking at 26,100 mt in 1983 (Terceiro 2001). Since 1989, landings have been much lower, ranging between 9,290 in 1990 to 12,490 in 2000 (NOAA 2004). Commercial landings of summer flounder averaged 11,700 mt during 1981-1990, reaching a high of 17,100 mt in 1984 (Terceiro 2001). Commercial landings during 1991-2003 have been markedly lower (4,000 - 7,500 mt per year) (NOAA 2004). Recently, average commercial landings increased from 4,998 mt in 2002 to 6,497 mt, in 2003. The recreational fishery for summer flounder harvests a significant proportion of the total catch, and in some years recreational landings have exceeded commercial landings. Estimated recreational landings accounted for 35 percent of the total landings during 1981-1990, averaging 6,400 mt during that period, and peaking at 12,700 mt in 1983 (Terceiro 2001). Recreational landings averaged 3,200 mt during 1990-1995. Since 1997, recreational landings have increased and have usually exceeded commercial landings. Recreational landings in 2000 were 7,100 mt, the highest estimated level since 1986, but have declined to 5,290 in 2003 (Terceiro 2001) (NOAA 2004) (Table 1). Landings have steadily decreased over the past 20 years compared to historic levels, but the species is reportedly in a state of recovery (NCDMF 2002). Commercial culture of summer flounder could be implemented as an additional tool to accelerate the recovery of the species.

Table 1. – Average national landings (mt) of Summer Flounder from 1981-2003.

Year	Average Commercial Landings (mt)	Average Recreational Landings (mt)
1981-1990	11,700	6,400
1991-2000	5,700	4,455
2001-2003	5,937	4,740

Source: NOAA, Fisheries Statistics and Economics Division

Summer Flounder – A Prime Candidate for Aquaculture

Globally, the overall trend in flatfish supply between 1990 and 2002 is slightly negative. Supply dropped from 1.2 million mt in 1990 to 958,00 mt in 2002 (FAO 2004). The drop appears to be a result of declines in U.S. and Japanese catches. Aquaculture of flatfish is helping to sustain the flatfish supply. World aquaculture production of flatfish in 2002 was approximately 38,909 mt, while world wild-caught supply catch was 918,840 mt (FAO 2004). Hence, aquaculture accounted for about 4% of total production of flatfish in 2002. Japanese flounder culture produced 6,000 mt in 1999, an amount nearly equal to Japanese wild caught supply of 7,000 mt (FAO 2004). The volume of wild caught turbot in 2002 was 6,781 mt, while the volume of farmed turbot was 5,071 mt (FAO 2004). Although the wild catch volume of turbot is expected to stay fairly stable, the farmed volume is expected to increase (FAO 2004). The culture of these flatfish has proven to be economically sustainable using various grow-out technologies such as concrete raceways and offshore net pens. While the number of summer flounder being cultured is currently negligible relative to other flatfish, it is hoped that the culture of this species will be economically sustainable as well.

For summer flounder aquaculture producers in the U.S. to be commercially profitable, farmers must produce reliable supplies of fish throughout the year. Capturing wild juvenile fish for grow-out or relying on seasonal spawning of captive fish will not produce reliable supply. To produce large numbers of fish, farmers need to successfully maintain broodstock, obtain fertilized eggs as required, and grow fish larvae to market size.

Successful spawning requires proper husbandry and an understanding of the physiology of the fish. Summer flounder broodstock are usually fed a diet of Atlantic silversides *Menidia menidia*, krill, and vitamin supplements. Tanks are stocked at low densities to decrease stress. Sex ratios are optimized, with the females usually outnumbering the males to increase the chances of fertilization. To encourage spawning of captive broodstock researchers have been able to artificially manipulate photoperiod and temperature to simulate the environmental conditions needed to stimulate gametogenesis. If natural spawns are not obtained using photothermal control alone, then broodstock can be treated with hormones (usually Luteinizing Hormone Releasing Hormone analog, LHRH-a) to induce spawning (Watanabe et al. 1998). Captive broodstock must be spawned year-round to ensure commercial viability of summer flounder culture.

Nurturing of fertilized eggs and newly hatched larvae is critical due to their sensitivity to a variety of environmental conditions, including, but not limited to pH, salinity, and light intensity. Of major importance is the sustenance of the larvae during the crucial first feeding period. Fish larvae hatch with a yolk sac that carries them through the first few days of life, however, suitable microscopic live prey need to be presented to the larvae for their early nourishment. A typical feeding regime for larvae after the yolksac stage is to first provide rotifers, then weaning from rotifers to artemia nauplii, and then to an artificial pelleted diet (Bisbal and Bengston 1993, 1995 a,b, Watanabe personal communication).

A major bottleneck for summer flounder culture occurs at the point where larvae begin to mature into juveniles. There is a high rate of cannibalism at this point where the larger juveniles eat their smaller siblings, reducing the number of fish that make it to young adult. The bottleneck occurs in that it is difficult to cull the larger juveniles from the smaller ones without constantly grading them one at a time, which is difficult on a commercial scale (Watanabe personal communication).

Research on summer flounder spawning and larval growth has shown that summer flounder can be successfully cultured through the juvenile stage (Bisbal and Bengston 1993, 1995 a,b, Watanabe et al. 1998, King et al. 2000**)**. A commercial hatchery operation (Great Bay Aquafarms, Portsmouth, NH, USA) is now capable of producing fingerlings to support grow-out operations. However, potential entrepreneurs will require additional information on grow-out stage production methods and economics before committing the large capital requirements necessary for commercial scale summer flounder aquaculture.

Recirculating Systems

One of the more promising new ways to produce fish on a commercial scale is to use recirculating aquaculture system (RAS) technology. Recirculating systems conserve heat and water by reusing water after filtration. A typical RAS requires only 0-10% of system water volume be replaced with make up water each day (Carroll personal communication; Timmons et al. 2001), whereas traditional aquaculture systems such as flow through tank systems may require make up water sufficient to replace system volume 12 times each day (Carroll personal communication; Timmons et al. 2001). In addition, there is the potential for a high degree of control over the culture environment (Losordo et al.1999, Timmons et al. 2001). Environmental factors such as temperature, pH, salinity, and photoperiod can be manipulated for species-specific culture conditions. Recirculating systems have enabled certain species, such as tilapia, to be cultured under diverse climatological conditions (Losordo et al. 1999, Timmons et al. 2001).

Relative to traditional aquaculture systems, an advantage of tank based RAS is that fish can be more closely monitored for feed intake and health because they are more readily accessible. In addition, intensive water treatment and supplemental oxygenation allow the grower to achieve higher stocking densities than are possible with traditional systems.

Relative to traditional salt water aquaculture systems, salt water recirculating systems may be located farther from the coast because the system recycles and reuses seawater. It may be practical to pump, truck, or produce on site (via concentrate) sufficient quantities of seawater. Building a facility farther from the coast is desirable in order to avoid the high cost of coastal land. Recirculating systems minimize freshwater requirements and reduce pressure on diminishing groundwater supplies. But like other systems, disposal of waste associated with production is a major concern for growers. Federal and state agencies now require permits for discharge of solids, nutrients, and chemical compounds (Federal Register, 40 CFR Part 451). Waste disposal could be a major constraint to RAS production, depending on future regulatory requirements.

A disadvantage of using recirculating aquaculture systems is that they require larger initial capital investments relative to other types of aquaculture production systems due to larger equipment requirements, such as tanks and filtration systems (Losordo and Westerman 1994; Zucker 1999). The risk of losing a relatively large capital investment motivates increased interest in determining the potential profitability of RAS production methods.

Economics and Profitability

Research concerning RAS technology has focused historically on the biological and engineering aspects of the production facility (Zucker and Anderson 1999). An important constraint to more widespread development of commercial flounder grow-out farms in the U.S. has been uncertainty regarding the profitability of culturing juveniles to a marketable size using RAS technology (Losordo and Westerman 1994; Zucker 1994). Economic analyses have produced information useful for improving production efficiency and profitability in commonly cultured finfish species, such as catfish (Bailey et al.1989) and tilapia (Head et al. 1994; Head and Watanabe 1995). Recently, researchers have begun to investigate the economic viability of culturing summer flounder on a commercial scale using recirculating technology (Dumas and Horton 2001; Zucker and Anderson1999). Much of the research in the area of production economics and profitability of recirculating systems has benefited from the use of computer simulation models to estimate economic viability without physically testing each scenario (Dumas and Horton 2001;

Losordo 1989; Losordo and Westerman 1994; O'Rourke 1991; Thacker and Griffen 1994; Zucker and Anderson 1999). In general, these studies have sought to identify the profit-maximizing levels of various engineering, biological, and economic parameters and to determine the impacts of exogenous changes in these parameters on profitability.

An economic model seeks to optimize financial results, given engineering and biological constraints. Engineering, biological, and economic factors can be manipulated using model simulations to determine optimal production decisions and resulting profitability. Financial results are typically modeled using computer spreadsheets. Dunning et al. (1998) provides an example of a financial spreadsheet model used for economic analysis of an aquaculture operation. This spreadsheet uses Tilapia as an example. The spreadsheet is divided into five sections, with the operator supplying data for the first three: 1) the initial investment, 2) the cost of inputs, sale price, and system parameters, and 3) operating parameters per production unit. The other two sections are calculated using output from the first three: 4) use of primary inputs and costs per production unit and 5) a summary of annual costs and returns to a system in full production. Spreadsheet models can be used to develop the cash-flow budgets, balance sheets, income statements and the financial analysis ratios used to examine the financial implications of alternative management scenarios (Bailey et al 1992; Crews and Jenson 1989; Pomeroy et al. 1989).

Models and The Use of Sensitivity Analysis

A sensitivity analysis of a modeled system can provide a means for estimating the impact of changes in system parameters on management decisions and financial results (Crews and Jenson 1989). The results of the sensitivity analysis can be used to identify issues requiring further research and development. For example, sensitivity analysis can be used to determine which improvements in recirculating system technology would have the greatest impact on system performance and financial results (Losordo and Westerman 1994).

Sensitivity analysis can be conducted on the biological, engineering, and economic aspects of recirculating systems. Losordo et al. (1989) developed a computer model to compare the performance of closed systems across two species, catfish and hybrid striped bass. The authors found that hybrid striped bass production appeared to be economically feasible while catfish did not (Losordo et al. 1989). Losordo and Westerman (1991,1994) manipulated biological, operational, engineering, and fixed costs parameters in sensitivity analyses of two recirculating systems, one used for hybrid striped bass (1991) and the other used for tilapia (1994). Both of these studies suggested that future studies should concentrate on the intensification (i.e. increasing stocking density) of the system as a key to potential profitability.

Recently, Zucker and Anderson (1999) used sensitivity analysis to investigate production and marketing scenarios for a land-based summer flounder firm. Zucker and Anderson used a physical production facility sub model to characterize the physical capital required for production. A growth and biology sub model characterized the process by which fish grow and die. A marketing and sales sub model characterized product marketing, and the financial sub model summarized the financial health of the operation. It is important to note that Zucker and Anderson lacked the data needed to construct detailed, empirical production relationships because summer flounder had not been grown beyond juvenile size on a commercial scale. As a result, Zucker and Anderson were forced to rely on assumed values for key engineering and biological parameters.

New data on summer flounder production methods using near-commercial scale recirculating systems have recently become available via cooperative research conducted by UNCW and NCSU. The purpose of the present study is to develop an economic model of summer flounder aquaculture production based on engineering and biological parameters derived from UNCW's near-commercial scale RAS facility located in Wrightsville Beach, NC. The model is used to determine the profit maximizing scale of operation for a commercial-scale summer flounder RAS facility, the profit-maximizing harvest size and grow-out period, and the sensitivity of financial performance to biological, engineering, and economic parameters. We use sensitivity analysis and Monte Carlo analysis to optimize management decisions.

METHODS

The System

Experimental trials were conducted to evaluate the grow-out performance of hatchery reared summer flounder fingerlings at UNCW's near-commercial scale RAS facility located at Wrightsville Beach, NC (Carroll 2002). The outdoor system consists of four circular, covered, insulated tanks with water depths of 7 ft wide x 2.6 ft deep (vol. = 399^3), and associated water treatment components. Each tank is fitted with a particle trap and a sludge collector for removing settleable waste solids. Each group of two tanks shares a common water treatment and reuse system, which includes a drum screen filter (60 micron), a trickle floating bead biological filter, a ultra-violet sterilizer, a foam fractionator, and a down-flow oxygen saturator cone. Summer flounder fingerlings (0.16 lb mean initial weight) supplied by a commercial hatchery (Great Bay Aquafarms, Portsmouth, NH, USA) were stocked into two tanks at a density of 1,014 fish/tank (0.06 lb/gal^3). Fish were fed an extruded dry floating flounder diet consisting of 50% protein and 12% lipid. Temperature was maintained between 68-73 degrees C, and the salinity was 34 ppt. Under these conditions, growth, feed utilization, and fish survival were measured. Fish in two tanks were fed at 100% satiation rate while those in the other two tanks were fed to 90% satiation rate. Some fish grew to a marketable size, between 3/4 lb – 1.5 lbs. Existing studies by the Minnesota Department of Agriculture (1997) provide examples on the relative efficiency of alternative equipment configurations. The relative cost of alternative configurations could be determined from existing recirculating aquaculture facilities, equipment catalogs, representative wage rates, and current utility unit costs (Carroll 2002).

Methods for Economic Analysis:

Following Losordo and Westerman (1994), Dunning et al. (1998), and Zucker and Anderson (1999), an economic simulation model of a commercial-scale summer flounder grow-out facility was created using biological and engineering parameters from the near-commercial scale RAS facility at UNCW. The spreadsheet model was developed using Microsoft Excel software (Microsoft 2001). Sensitivity analysis was used to investigate the impacts of changes in economic, biological, and engineering parameters (a list of parameters is presented below) on the profitability of summer flounder aquaculture.

Monte Carlo simulation is a mathematical technique for analyzing relatively complex systems containing stochastic (random) elements. The Monte Carlo method is used extensively in finance for such tasks as pricing stock derivatives or estimating the value of a portfolio. Stochastic elements are specified by probability density functions. Monte Carlo analysis determines the probability distributions of system outcome variables based on given probability distributions of system input variables. The method uses a series of trials, drawing one value for each input from its respective probability distribution during each trial, calculating the values of system outcome variables, and repeating for a large number of trials. The collection of outcome variable values from all trials is used to form the probability distribution of system outcomes (Sobol 1994).

For this study, probability distributions were specified for key system input parameters, output price, electricity rates, and interest rates, and a Monte Carlo analysis was used to identify the probability distribution of the primary system outcome variable: the present value of returns to management over a ten-year planning horizon. A ten-year planning horizon was chosen for the analysis because it corresponds to the assumed useful lifetime of the initial capital equipment purchase (i.e., at the end of ten years, a new capital purchase decision must be made, and a new financial analysis would be needed). The results of Monte Carlo analysis can be used to make probabilistic statements about system outcomes. For example, one might say: "The probability is thirty percent that returns to management over a ten year planning horizon would fall between $1.1 million and $1.4 million" (Sobol 1994). Such probabilistic statements are a way to characterize the degree of financial risk associated with a proposed summer flounder RAS facility. Monte Carlo analyses were implemented via macro programs written within Microsoft Excel.

The Model

The UNCW study of summer flounder production in a near-commercial scale RAS (Carroll et al. in press) is used as a basis for developing alternative models of commercial scale summer flounder RAS facilities. (The UNCW near-commercial scale production facility is described in Appendix A.) The following key characteristics are used to distinguish alternative systems: system scale (0.5-acre, 1-acre, and 3 x 1-acre systems), length of grow-out cycle (13.4 and 20-months), tank size (15, 20, and 27 ft diameters), outdoor (security fence) vs. indoor (building) systems, tank type (fiberglass, steel, and glass coated steel), and fish transfer schedule (between tanks). Each commercial-scale system is defined by a set of biological, engineering, and economic parameter values. For each system, estimates of revenues, capital costs, variable costs, fixed costs, and total costs are developed per grow-out cycle and per year. Break-even price, returns to management per grow-out cycle, and returns to management per year are calculated to assess the relative financial performance of alternative systems.

RESULTS

Determining the Cost-Effective System Design

System Scale

The 0.10 acre UNCW near-commercial scale system is scaled up to 0.5-acre, 1-acre, and three 1-acre systems. At the 0.5-acre and 1-acre facility sizes (using 27 ft diameter tanks), facility production under the 13.4-month grow-out cycle is 54,000 lbs and 108,000 lbs, respectively (Table 4). These levels of production are deemed to be realistic in current markets and would be exempt from recent EPA waste management regulations that require "Best Management Practices" (BMPs) to be implemented for managing wastewater at facilities producing at least 100,000 lbs/yr.

The 1-acre model has a maximum production of 108,000 lbs per 13.4-month cycle. The 100,000 lbs/yr threshold is assumed to be reached between the 12 and 13.4-month timeframe. At this level of production, the 1-acre model would be exempt from the new EPA regulations, avoiding the potential costs of implementing the mandatory BMPs for facilities producing at least 100,000 lbs/yr.

The 3 x 1-acre system was designed to increase scale and lower production costs by reducing fingerling costs. To get the lowest price per fingerling from the single supplier ($1.25/fingerling), the facility would need to purchase at least 200,000 fingerlings. The 1-acre system can only accept 90,000 fingerlings at maximum capacity (using 27 ft diameter tanks), so in order to receive the $1.25/fingerling price, a model is created with 3 x 1-acre systems that collectively purchase 270,000 fingerlings (90,000 fingerlings/facility) at one time. The 3 x 1-acre facilities produce 324,000 lbs/yr, but since the facilities are not contiguous or concentrated, the EPA regulations do not apply (Federal Register, 40 CFR Part 451). All else equal, the 3 x 1 acre system has the lowest break-even price (Table 2). Hence, the remaining analysis will focus on the 3 x 1-acre facility, and the 0.5-acre and 1-acre facilities are not considered further.

Grow-Out Cycle Length

All models developed here assume that fish reach an average of 1.5 lbs, with an 80 % survival rate, and a feed conversion ratio (FCR) of 1.8, which is the average of the FCR over all growth phases in the UNCW near-commercial scale study and the lowest FCR observed during the first 7 months of the UNCW near-commercial scale study. Each model is analyzed assuming one of two alternative grow-out periods: 20 and 13.4 months. The 20-month cycle corresponds to the mean grow-out period for summer flounder raised in the UNCW near commercial scale facility. However, the top 5% of the fastest growing flounder reached marketable size in just 13.4 months. Marketable size, 1.5 lbs, is defined in this study as the minimum size required to receive an average sale price of $5.00/lb, based on sales data from an existing, non-RAS flounder aquaculture operation in North Carolina. All else equal, the 13.4-month grow-out cycle produces lower break-even prices relative to the 20-month cycle (Tables 2, 3). The results for the 20-month cycle reflect average growth rates of currently available summer flounder fingerlings, while the results for the 13.4-month growth cycle reflect potential growth rates after selective breeding (based on the 5% fastest growers from the pilot-study).

Tank Sizes

Using the fiberglass tank design and system components of the UNCW near-commercial scale facility, conceptual models of commercial scale outdoor facilities are developed, using tank sizes scaled up from 15 ft diameter tanks (used in the near-commercial scale study) to 20 and 27 ft diameter tanks, all containing a water depth of 3 ft. The 3 ft tank depth is maintained for two reasons: (1) flounder typically utilize the bottom of the tank rather than the full water column, so additional depth does not provide additional production capacity, while it does add additional water heating cost and (2) maintenance and fish transfer activities are more difficult with deeper tanks. A maximum tank diameter of 27 ft tank was considered because tanks begin to lose their self-cleaning properties at a diameter to depth ratio greater than 4.5:1. Tank diameters greater than 27 ft would require either much greater cleaning expenses or deeper water levels with greater water heating expenses (Losordo, personal communication). The facility sizes are also scaled up to 0.5-acre, 1-acre, and 3 x 1-acre system sizes, to accommodate the 15, 20, and 27 ft diameter tanks, respectively, with correspondingly larger recirulating system components at each scale (Table 4). At the 1-acre scale, the 15 ft diameter tanks have a maximum capacity of 48,000 lbs/cycle, using 24 tanks that hold 95,136 total gallons (Table 4). The 20 ft diameter tanks, at the 1-acre scale, hold 140,920 gallons, and has a maximum capacity of 68,995 lbs/cycle (Table 4). At the 1-acre scale, the 27 ft diameter tanks have a maximum capacity of 108,000 lbs/cycle, using 16 tanks that hold 205,504 total gallons (Table 4). All tanks and systems have a harvest density of approximately 0.5 lb per gallon, the approximate safe, maximum density for each system. Of the three sizes analyzed, the 27 ft tank size is the most cost-effective (lowest break-even price) across facility scales and grow-out cycle lengths (Table 2). Hence, the remaining analyses will focus on the 27 ft tank size, and the 15 ft and 20 ft tank sizes are not considered further.

Table 2. - Break-even price ($) for the 15, 20, and 27 ft diameter fiberglass tanks at the 0.5-acre, 1-acre, and 3 x 1-acre scales, using indoor and outdoor systems.

Tank Size & Tank Type	Grow-Out Cycle (months)	System Type (outdoor / indoor)	System Scale		
			0.5-acre	1-Acre	3 x 1-Acre
15 ft Fiberglass Tank	20	outdoor	$11.01	$8.83	$7.56
	13.4	outdoor	$8.63	$7.15	$6.22
20 ft Fiberglass Tank	20	outdoor	$9.09	$7.32	$6.29
	13.4	outdoor	$6.86	$5.63	$4.84
27 ft Fiberglass Tank	20	outdoor	$6.82	$6.14	$5.44
	20	indoor	$5.73	$4.93	$4.63
	13.4	outdoor	$5.66	$4.92	$4.37
	13.4	indoor	$4.58	$3.97	$3.70
27 ft Steel Tank	20	indoor	$5.64	$4.82	$4.53
	13.4	indoor	$4.52	$3.91	$3.64
25 ft Aquacare Tank	13.4	indoor	$4.71	$4.17	$3.89

Table 3. - Break-even price ($) of commercial 3 x 1-Acre 27 ft steel tank with building systems, using fish transfer schedule.

Fish Transfer Schedule	Grow-Out Cycle	Break-Even Price ($)
Standard	20-month cycle	4.53
	13.4-month cycle	3.64
Energy saving	20-month cycle	4.43
	13.4-month cycle	3.53

Table 4. – Capacity of the 0.5-acre, 1-acre, and 3 x 1-acre systems with 15 ft, 20 ft, and 27 ft diameter tanks.

Scale of System	0.5-acre	1-acre	3 x 1-acre systems
15 ft diameter			
Number of Tanks	12	24	(3) 1-acre replicates
Number of Gallons	47,568	95,136	(3) 1-acre replicates
Final System Biomass (lbs)	24,000	48,000	(3) 1-acre replicates
20 ft diameter			
Number of Tanks	10	20	(3) 1-acre replicates
Number of Gallons	34,498	140,920	(3) 1-acre replicates
Final System Biomass (lbs)	34,498	68,995	(3) 1-acre replicates
27 ft diameter			
Number of Tanks	8	16	(3) 1-acre replicates
Number of Gallons	102,752	205,504	(3) 1-acre replicates
Final System Biomass (lbs)	54,000	108,000	(3) 1-acre replicates

System Type: Outdoor vs. Indoor

Given the cost-effective tank size of 27 ft diameter, an "outdoor system" is compared with an "indoor system" at each facility scale, assuming fiberglass tank construction. The outdoor system consists of the aquaculture tank system and equipment, a security fence, and a security camera system. The security fence consists of a 6 ft high fence, with barbed-wire, a walk-in gate, and a swing-gate, at a cost of $10,000 an acre (Seegars Fence Co. Wilmington, NC, USA). The camera system consists of two cameras that can provide surveillance for a 1-acre system at an installation cost of $3,500 an acre and a monthly service fee of $50 (ADT Security Systems, Inc. Wilmington, NC, USA). The "indoor system" consists of the aquaculture tank systems and equipment housed inside a building. Using the building for a one-acre system as an example, the building is 33,600 ft2 (leaving 0.23 acre of outdoor open space for a small parking lot and loading/unloading area), with a design based on that of the N.C. State Fish Barn aquaculture facility (Raleigh, NC, USA) (Fig. 1). The 33,600 ft2 building consists of sheet metal siding, insulation, two large doors, concrete foundation and floors, heat pumps, heating conduit, feed bins, a plumbed and finished bathroom/shower/septic system, lighting, electrification, and labor at a total cost of $369,914.

Assuming 27 ft diameter fiberglass tanks, the outdoor and indoor systems are compared at the three system scales and for the 13.4 and 20-month grow-out cycles. Although the initial investment in the building is considerable, facility break-even price is lower with a building at all system scales and for both grow-out cycles (Table 2). Using a building reduces the amount of electricity required to heat and cool the water in the fish grow-out tanks. For example, assuming 27 ft fiberglass tanks at the 3 x 1-acre facility scale with a 13.4-month grow-out cycle, the indoor system requires 496,800 kilowatt hours of electricity per cycle and results in a break-even price of $3.70, while the outdoor system requires 2,554,941 kilowatt hours per cycle with a break-even price of $4.37. Electricity requirements for outdoor and indoor systems are based on the UNCW (outdoor) near-commercial scale study, the N.C. State Fish Barn (indoor) system, and information from a private aquaculture company, Southern Farm Tilapia, (Louisburg, NC, USA).

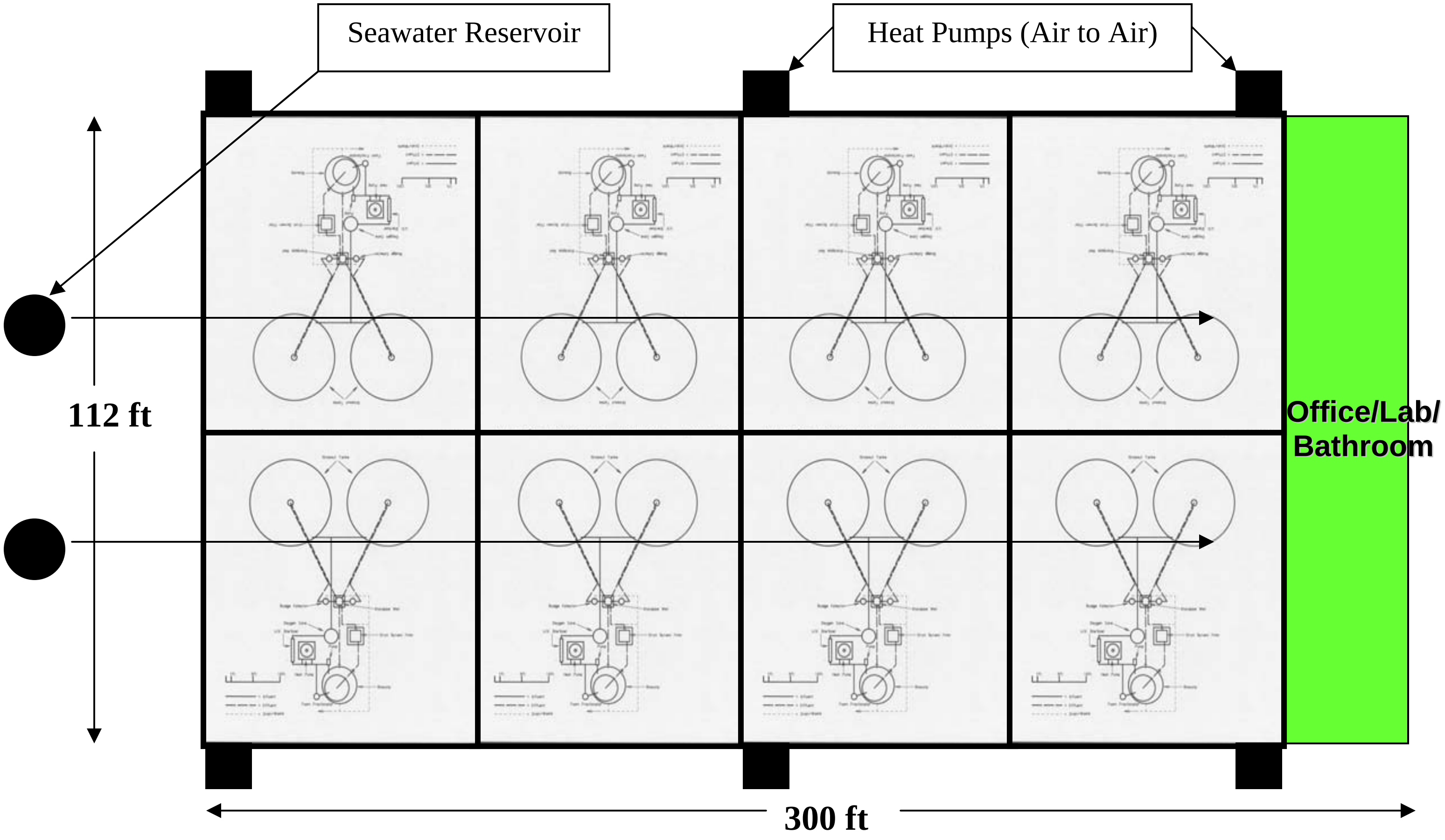

Figure 1. – General diagram of the 27 ft diameter tanks, at the 1-acre scale, enclosed in a buidling. Tanks are shown in the center, with one biofilter for every two tanks. Note: One drumscreen filter for every 4 tanks not pictured. Also not pictured: belt filter, seawater pump unit, lighting, and HVAC.

Tank Type

Since tank costs account for a large portion of capital costs, alternative tank types are analyzed to determine whether further cost reductions are possible. In addition to the fiberglass tanks used in the UNCW near-commercial scale study, commercial steel tanks with vinyl liners (Aquatic Ecosystems, Inc., Apopka, FL, USA) are considered. The steel tank is substituted for the fiberglass tank used in the indoor, 27 ft tank model, at all three facility scales (0.5-acre, 1-acre, and 3 x 1-acre) and both 13.4 and 20-month grow-out cycles. With costs of a 27 ft diameter steel tank with liner at $2,284 per tank, compared with fiberglass tank costs at $5,000 per tank, it is not surprising that using steel tanks lowers break-even prices.

Bolt-together, glass-coated steel tanks that are safe for salt-water use--part of a commercially available turn-key recircualting aquaculture system package available from Aquacare Environment Inc. (Bellingham, WA, USA) are also considered. The glass-coated tank is analyzed assuming use of the Novaculture Filter Module provided by Aquacare. This filter technology is very similar to the reciruclating technology used in the UNCW near-commercial scale study. An oxygen/aeration system is added to the Aquacare system to achieve system specifications comparable to those of the other two tank systems. A 25 ft diameter glass-coated tank size is considered because it is closest to the cost-effective 27 ft diameter steel and fiberglass tank size. The glass-coated tank is analyzed at all three indoor facility scales at the 13.4-month grow-out cycle. Break-even prices using the glass-coated tanks are higher than the break-even prices using the 27 ft diameter steel tanks, and so glass-coated tanks are dropped from further analysis.

Energy-Saving Fish Transfer Procedure

In order to further reduce total costs, a fish stocking transfer schedule was designed to redistribute fish from initial stocking tanks to unused tanks as the biomass within each tank increases to its maximum capacity. All tanks reach maximum capacity at the end of the grow-out cycle. Maximum capacity for each 27 ft steel tank is approximately 0.5 lbs/gal. The fish transfer procedure saves electricity, which was reduced from approximately 7% to 4%, of the total cost per grow-out cycle, by not running the full system when the tanks are not at full capacity.

The fish transfer schedule is as follows: On day 0, all 1,980 lbs of fish (90,000 fingerlings) are distributed evenly among 4 tanks for an initial stocking density of 0.04 lbs/gal. Between day 0 and day 40, we assume that approximately 20% of the fingerlings die, which leaves 80% survival (assumed for all models). At day 40, the fish achieve a density in the 4 tanks of approximately 0.49 lbs/gal and are transferred to 8 tanks (biomass split evenly). At day 150, the fish reach maximum capacity in the 8 tanks, and the biomass is split evenly among 12 tanks. Finally, at day 250 of the grow-out cycle the fish are split evenly among all 16 tanks until harvest. Final harvest density is 0.53 lbs/gal. The stocking transfer schedule reduces electricity costs, equipment wear, and tank maintenance. The savings in electricity costs lowers the break-even price from $3.64 without the transfer schedule to $3.53 with the transfer schedule at the 13.4-month growth cycle (Table 3).

Summary

The most cost-effective system (i.e., the system with the lowest break-even price) is the 3 x 1-acre, 27 ft diameter, steel tank, indoor (using a building) system utilizing the fish transfer procedure (Table 2,3). Because all three 1-acre units in the 3 x 1-acre system have the same assumptions, parameters, and costs, results for just one of the 1-acre units will be reported below.

Base Case Commercial Scale System Assumptions

The assumptions for one of the 1-acre units in the 3 x 1-acre system in the base case commercial scale model are shown in Table 5. It is assumed that one acre of coastal land located in North Carolina with access to seawater and zoned light industrial is owned by the owner/manager. The market value of the land is $125,000 (Graham, personal communication). If the owner's money were not invested in the land, it is assumed that the money would earn interest at an annual rate of 3.60% in the owner's next best investment opportunity. Money for the initial construction and equipment of the facility is borrowed from a secured bank line of credit with a term of 10-years at an annual interest rate of 5.60%. The money for operating capital is borrowed from an unsecured line of credit at an annual interest rate of 7.60% (Table 5). All interest rates are based on current market conditions in the United States (Branch, Banking & Trust, 2004). The owner/manager sells the harvest to a niche market (e.g. sushi market) buyer who purchases the harvest at the farm gate. Access to seawater is free. No waste disposal permit is needed for the facility, as it produces less than 100,000lbs./facility/yr (Federal Register, 40 CFR Part 451). Financial returns are calculated on a before tax basis, and the owner/manager retains any profits. Any hired workers are paid no benefits.

Table 5. - Assumptions for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy-saving fish transfer schedule.

Assumptions	
Market value of 1-acre of coastal land (already owned)	$125,000
Interest rate of alternative investment	3.60%
Interest rate on initial constr. & equip. (10-yr. Loan)	5.60%
Interest rate on operating capital	7.60%
Months in the operating cycle	20 or 13.4
Live hauler collects fish (niche marketing)	
No waste disposal permit needed if production is less than 100,000lbs./facility/yr	
Financial returns calculated on before tax basis	
Owner works as manager	
Access to seawater is free	
No paid benefits to workers	

Economic, Engineering, and Biological Parameters

The economic, engineering, and biological parameters are shown in Tables 6 and 7, respectively. The design of the 1-acre, commercial-scale facility is based on that of the UNCW near-commercial scale facility, except that there is only one drumscreen filter for every 4 tanks. One hydrotech, model 802 drum screen filter from Water Management Technologies is sufficient to filter approximately 52,000 gallons, or 4 tanks. (The commercial-scale facility is also enclosed by a building, unlike the UNCW facility, which is outdoors.) The 1-acre commercial scale facility consists of sixteen 27 ft diameter tanks with a total capacity of 205,504 gallons (Tables 6). The average product price of $5.00/lb is based on the average selling price received by an on-going flounder operation in North Carolina. Because the three 1-acre facilities collectively purchase over 200,000 fingerlings during each production cycle, the fingerling prices ($1.25/fingerling) are the lowest offered by the supplier, Great Bay Aquafarms (Newington, NH, USA) (Table 6). Fish feed is supplied by a commercial supplier, Melick (Catawissa, PA, USA) at a cost of $0.30/lb. Electricity price per kilowatt hour ($0.05) is based on the “Medium General Service” rate charged by Progress Energy, the local energy provider. In addition to the charge per kilowatt hour, electricity service also requires a monthly "electric demand charge" of $400/mo. that does not vary with the amount of electricity used. The kilowatt hours used in the 13.4 and 20-month grow-out cycles are 282,662 and 528,527, respectively, based on electricity usage data from the N.C. State Fish Barn and a private company, Southern Farm Tilapia.

Table 6.- Economic and engineering parameters for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy-saving fish transfer schedule.

	Per 1-acre unit 13.4-month grow-out cycle	20-month grow-out cycle
Economic parameters		
Product price (farm gate price) ($/lb)	5.00	5.00
Fingerling cost ($/10 g fingerling)	1.25	1.25
Total fingerlings needed per cycle	90,000	90,000
Feed cost ($/lb feed)	0.30	0.30
Electricity Cost per kWh ($/kWh)	0.05	0.05
Interest rate on 10-yr secured line of credit	7.6%	7.6%
Interest rate on unsecured bank line of credit	5.6%	5.6%
Return on owner's next best investment	3.6%	3.6%
Engineering parameters		
#Months/cycle	13.4	20
#Days/cycle	406	609
Cycles/year	0.6	0.9
Number of tanks	16	16
System volume (gal)	205,504	205,504
Flow rates (gal/min)	85	85
Oxygen rates (ft^3/cycle)	887	887
Feed used (lbs)	196,128	196,128
kWh used	282,662	528,527

Table 7. – Biological parameters for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy-saving fish transfer schedule. The biological parameters are the same for the 13.4 and 20-month grow-out cycles.

	Per 1-acre unit	
Biological Parameters	lbs.	kg.
Initial size of fish	0.022	0.01
Average harvest size	1.5	0.68
Harvest density	0.50/gallon	30.27/m^3
Initial biomass	1980	989
Final biomass	108,000	48,989
Lbs of production	106,020	48,000
Harvestable weight	108,000	48,989
Survival	80%	
Feed Conversion Ratio	1.8	

The biological parameters are based on results from the UNCW near commercial-scale facility. Average harvest size per fish is 1.5 lbs., harvest density is 0.5 lbs/gallon, and survival is 80% (Table 7). These values are the same for the 0.5-acre, 1-acre, and 3 x 1-acre models and for the 13.4 and 20-month grow-out cycles. Final biomass per 1-acre unit within the 3 x 1-acre system is 108,000 lbs.

Production costs per 1-acre unit within the 3 x 1-acre, 27 ft steel tank, indoor system utilizing the energy-saving fish transfer schedule are shown in tables 8, 9, and 10. Costs are divided into capital costs (Table 8) and operating costs, where operating costs are sub-divided into fixed costs (Table 9), and variable costs (Table 10). Variable costs and fixed costs are reported on a per-cycle basis (for both 13.4 month and 20-month grow-out cycles).

Capital Costs

Capital costs ($718,595) per 1-acre unit of the 3 x 1-acre system include building and equipment, construction labor, and miscellaneous costs (Table 8). Building and equipment costs ($672,595) are divided into building, tanks and plumbing, heating, biological filtration, and oxygen/aeration costs. Building costs ($369,914) include the costs of sheet metal/siding ($97,440), electrifying the building/HVAC ($74,151), the concrete foundation ($67,200), labor cost ($60,000), a plumbed and finished bathroom/shower/septic system ($18,000), insulation ($14,784), heat pumps for heating the building air ($13,800), feed bins ($9,600), light fixtures ($7,539) other heating/ventilation ductwork ($6,000), and two large doors ($1,400). Remaining equipment costs include those for drum screen filters ($40,000), tanks and liners ($36,544), a belt filter for waste ($30,000), a generator ($22,000), and additional heat pumps for heating the tank water ($19,600). The labor hours (800 hrs.) and wages ($36,000) necessary to install the aquaculture system within the completed building are estimated from construction time data for the UNCW pilot-scale system and current labor wage rates paid by an existing aquaculture operation in North Carolina. Miscellaneous capital costs are $5,000.

Table 8.- Capital costs for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy-saving fish transfer schedule.

		Unit	Price/Unit ($)	# of Units	Total ($)
Equipment:	Tanks and Plumbing:				
	Aquatic Ecosystems steel tank	27ft dia.	1,4890	16	23,824
	Aquatic Ecosystems liner	39 ft dia.	795	16	12,270
	Freight for Tanks and Liners	One trip	6,743	1	6,743
	Pumps (Main) (Jacuzzi, S45A)	1	315	8	2,520
	Standpipe Well	1	224	8	1,788
	Fiberglassing	1	10	8	78
	Mesh	1	119	8	948
	Water Level Switches	1	85	8	676
	Cover Hardware	1	13	8	100
	Sikaflex sealent	1	15	8	119
	Flow Meter	1	176	8	1,408
	Pipes	1	1000	8	8,000
	Misc.	1	394	8	3,158
	Heating:				
	Heat Pump (Heat Syphon, 122,000BTU)	1 5-hp	2,450	8	19,600
	Mechanical Filtration:				
	Drum Screen Filter (Water Management Tech. model 802)	1	10,000	4	40,000
	Drum Screen Pvc	1	27	8	215
	Swirl Seperator (Eco Trap 250)	1	1,300	8	20,800
	Double Drain	1	37	16	595
	Foam Fractionater (Top Fathom S12A2)	1	1,450	8	11,600
	Biological Filtration:				
	8ft. Bio. Sump (Steve Wolfe)	1	1,600	8	12,800
	6ft. Insert - Bio Sump (Big Blue Store)	1	247	8	1,976

Table 8 (Cont.)

	Unit	Price/Unit ($)	# of Units	Total ($)
Biological Filtration: (Cont.)				
Biosump Install	1	345	8	2,760
Pipe/ Valves	1	1368	8	10,948
PVC	1	4	8	28
Drain Pvc	1	38	8	306
Poly Beads (Aquatic Ecosystems)	1 m^3	150	6	900
Drip Plate	1	45	8	360
Filter Plate Hanger	1	53	8	424
Tank Hardware	1	181	8	1,450
Blower (Jacuzzi)	1	187	8	1,496
UV Sterilizer (Emperor Aquatics)	1	1728	8	13,824
Water Level Sensor	1	104	8	832
Double Drain Hose	1	100		800
Backwash Pump(Jacuzzi)	1	287	8	2,296
Blowers (Jacuzzi)	1	445	8	3,560
Belt Filter, Backwash, & Controls (hydrotech, model 537)	1	30,000	1	30,000
Oxygenation / Aeration:				
Oxygen Cone (Steve Wolfe)	1	700	8	5,600
Plumbing	1	261	8	2,090
Plumbing	1	34	8	272
Flow Meter & Oxygen Solenoid	1	261	8	2,090
Pvc	1	8	8	65
Oxygen Hose	1	22	8	182
Oxygen System	1	242	8	1,936
PT4 Oxygen Monitor (Aquatic Ecosystems)	1	5,100	2	10,200

Table 8 (Cont.)

		Unit	Price/Unit ($)	# of Units	Total ($)
	Generator (Perkins)	1 250 kw	22,000	1	22,000
Building:	(0.77 acre of building per acre of land)				
	Sheet/Metal Siding (Heritage Building Systems)	1 ft^2	3	33,600	97,440
	Insulation (Heritage Building Systems)	1 ft^2	0.44	33,600	14,784
	Concrete (Heritage Building Systems)	1 ft^2	2	33,600	67,200
	Large Doors (Heritage Building Systems)	1	700	2	1,400
	Heating and Ventilation duct (Heritage Building Systems)	16,800 ft^2	3,000	2	6,000
	Heat Pumps (Smarterway)	1 5-ton	2,300	6	13,800
	Feed Bins (Ace Rotomold)	1 5000 gl	2,400	4	9,600
	Bathroom (plumbed & finished, shower, septic system)	1	18,000	1	18,000
	Lighting (Farm Tek) Waterproof fluorescent	4’ tube	49	152	7,539
	Electrification (installation, wiring, HVAC)				74,151
	Labor for Building				60,000
	Seawater System and Distribution:				
	PVC 6” diameter	1 ft	2.74	2000	5,480
	6” Gate Valves	1	12	24	288
	2 hp High Vol Pump (3,450 rpm)	1	915	1	915
	10,500 gl storage tank (Ace Rotomold)	1	6,326	2	12,652
	Construction Materials				1,000

(Table 8 cont.)

		Unit	Price/Unit ($)	# of Units	Total ($)
Construction:	Unskilled	hr	10	800	8,000
	Technical Assistant	hr	15	800	12,000
	Management	hr	20	800	16,000
			Total Construction Labor Costs		$36,000
Miscellaneous Expenses (permitting, materials, lab equipment):					$5,000
			Total Initial Investment		$718,595

Operating Costs--Variable Costs

Operating Costs are divided into variable costs and fixed costs (Tables 9 and 10). Variable and fixed cost information for each 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing the energy-saving fish transfer schedule is provided per grow-out cycle for both the 13.4 month and 20-month grow-out cycles. Unit costs are based on information from an operating commercial aquaculture facility located in North Carolina. Fingerling costs ($112,500, either cycle length), account for the largest proportion of variable costs per cycle, followed by feed costs ($58,838), labor costs ($25,728 per 13.4-month cycle / $38,400 per 20-month cycle), energy costs ($14,415, 13.4-month / 26,965, 20-month), and waste removal ($21,038, either cycle length). Waste removal costs include landfill fee, hauling fee, and sludge flocculating materials. Total variable costs are $250,785 for the 13.4 month grow-out cycle and $285,153 for the 20-month grow-out cycle.

Operating Costs--Fixed Costs

Fixed costs are divided into cash fixed costs and non-cash fixed costs (Table 10). Non-cash fixed costs reflect items that do not require monetary payments but nonetheless reduce profits. For example, the opportunity cost of the land used for the aquaculture facility ($5,031 per 13.4-month grow-out cycle / $7,509 per 20-month grow-out cycle) is a non-cash fixed cost. The opportunity cost of land is the rental income forgone by the owner/manager when he chooses to operate a fish farm rather than to rent his land to someone else. The other non-cash fixed cost, depreciation (loss of value due to wear and tear) of the building and equipment, is accounted for by the principal portion of the owner's construction loan payment (accounted for under Capital Costs); hence, a value of zero is entered in Table 10 to avoid double-counting depreciation cost (nonetheless, information on the monthly cost of depreciation is provided in Table 10 for tax planning purposes). Insurance (fish mortality, property, liability, and workers compensation) accounts for the largest proportion of cash fixed costs ($11,161 per 13.4-month grow-out cycle / $14,164 per 20-month grow-out cycle), followed by electricity demand charge ($5,360 per 13.4-month grow-out cycle / $8,000 per 20-month grow-out cycle), and miscellaneous overhead ($4,020 per 13.4-month grow-out cycle/ $6,000 per 20-month grow-out cycle) (Table 10). Total fixed costs are $26,385 for the 13.4-month grow-out cycle and $37,395 for the 20-month cycle.

Table 9. – Variable costs for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy-saving fish transfer schedule. Includes results for 13.4 and 20-month grow-out cycles.

Variable costs		Unit Cost ($)	Unit	Units/Cycle (months)		Costs/Cycle($) (months)	
				13.4	20	13.4	20
Oxygen Refill (National Welders)		0.40	100 cubic ft	887	887	355	355
Oxygen Tank Rental (National Welders)		325	Month	13.4	20	4,355	6,512
Bicarbonate (10% feed used/cycle) (Sam's Club)		0.19	Lbs	19,613	19,613	3,726	3,726
Energy (1.4 kWh / gallon of water) (Progress Energy)		0.05	kWh	282,662	528,527	14,416	29,965
Fingerlings (Great Bay Aquafarms)		1.25	Fingerling	90,000	90,000	112,500	112,500
Feed (Melick Aquafeed)		0.30	Lbs	196,128	196,128	58,838	58,838
Labor	unskilled	10	Hour	0	0	0	0
	technical assistant	12	Hour	2,144	3,200	25,728	38,400
Water (freshwater)		20	Month	13.4	20	268	400
Sludge Floculators (Polymer and Alum)		1,742	Cycle	1	1	1,742	1,742
Waste Removal ($55/ton landfill fee; $25 Hauling Fee) (Waste Management)		80	Trip	18	18	19,296	19,296
Interest on Variable Costs						9,561	16,431
Total Variable Costs						250,785	285,166

Table 10. – Fixed costs for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy-saving fish transfer schedule. Includes results for 13.4 and 20-month grow-out cycles.

Fixed Costs	Unit Cost ($/mo.)	Costs/Cycle ($) 13.4 months.	20 months.
Non-Cash Fixed Costs			
Opportunity Cost of Land (Dumas-personal communication)	375	5,031	7,509
Monthly depreciation (10% of initial equipment cost/year, useful life = 10)	4,046	0	0
Cash fixed costs (not including payment on initial construction & equip. loan)			
Electrical demand charge (Progress Energy)	400	5,360	8,000
Misc. Overhead	300	4,020	6,000
Insurance (mortality of fish =4.5% value of fish (The Hartford)	253 / 378	5,063	5,063
Insurance (property, liability, workers comp) (Farm Bureau)	455	6,098	9,101
Interest on Fixed Costs		814	1,722
Total Fixed Costs		26,385	37,395

Total costs

Total costs for each 1-acre unit of the 3 x 1 acre system (Table 11) include capital loan payments used to finance capital costs over a 10-year term and operating loan payments used to finance operating costs over the grow-out cycle. Capital loan payments (including interest) are $104,512 and $155,988 per 13.4 and 20-month grow-out cycle, respectively. Total costs are $381,682 and $478,549 per cycle for the 13.4 and 20-month grow-out cycles, respectively, or $341,805 and 287,129 annually. If the owner wishes to use his/her own money to "self-finance" production costs rather than use bank loans, then the interest portion of loan payments may be subtracted from costs. However, by using his/her own money to finance the aquaculture operation, the owner loses the interest or other return he/she would have earned on that money in his/her next-best investment opportunity. The "foregone" interest/return on the next-best investment is an opportunity cost that must be subtracted from profit should the owner choose to self-finance (This is analogous to subtracting forgone rent from profit when the owner's land is used as an aquaculture facility rather than as rental property.). This possibility is not pursued further here.

Production costs are shown by cost category in Figs. 2 and 3. Fingerling costs (29%) account for a majority of the production costs for the 13.4-month grow-out cycle, followed by the building and equipment loan payment (27%), feed (15%), labor (7%), and waste removal (6%) (Fig. 2). The building and equipment loan payment (33%), account for a majority of the production costs for the 20-month grow-out cycle, followed by fingerling costs (24%), feed (12%), labor (8%), and electricity (6%) (Fig. 3).

Table 11.- Total costs for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy saving fish transfer schedule.

Includes results for 13.4 and 20-month grow-out cycles.

($) Total Costs	Costs/Cycle($)		Costs/Year ($)	
	13.4 mo. cycle	20 mo. Cycle	13.4 mo. cycle	20 mo. cycle
Operating Costs--Variable Costs				
Total variable costs (not including interest)	241,224	268,735	216,022	161,241
Interest on variable cost portion of operating capital loan	9,561	16,431	8,562	9,859
Total variable costs (includes interest on variable cost portion of operating loan)	250,785	285,166	224,583	171,100
Operating Costs--Fixed Costs				
Total fixed costs (not including interest)	25,572	35,673	22,900	21,164
Interest on cash fixed cost portion of operating capital loan	814	1,722	729	1,019
Total fixed costs (includes interest on cash fixed cost portion of operating loan)	26,385	37,395	23,629	21,164
Capital Costs--Payment on Capital Cost Loan (Building & Equipment) (includes interest)	104,512	155,988	93,593	93,592
Total Costs	381,682	478,549	341,805	278,129

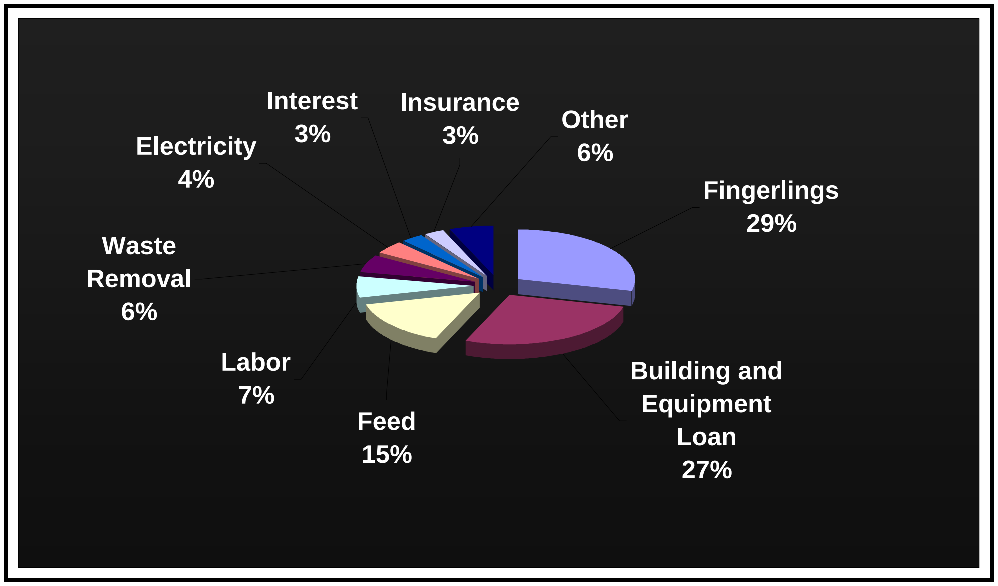

Figure 2. – Production costs for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy saving fish transfer schedule and a 13.4 month grow-out cycle.

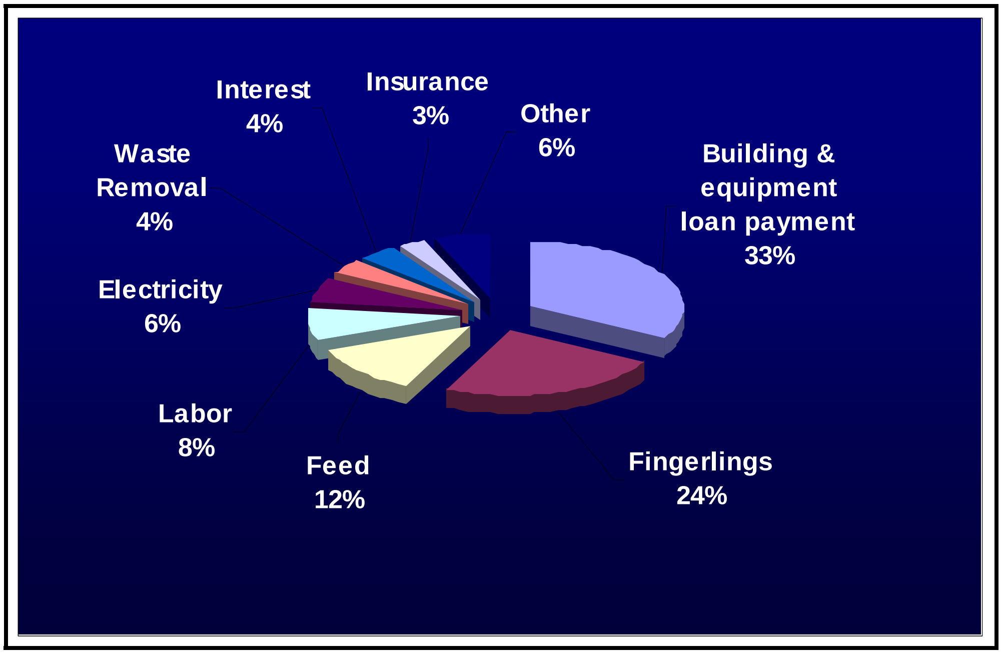

Figure 3. – Production costs for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy saving fish transfer schedule and a 20 month grow-out cycle.

Financial Performance

Break-even prices for each one 1-acre unit of the 3 x 1-acre system are $3.53 and $4.43, for the 13.4 and 20-month cycles, respectively (Table 12). Assuming a farm-gate price of $5.00/lb harvestable weight, total revenues for both the 13.4 and 20-month cycles are $540,000 per cycle. The cycles differ in the length of time and cost required to achieve a specified harvestable weight that produces $540,000 in revenue. Returns to management before taxes for the 13.4 and 20-month grow-out cycles are $158,318 and $61,464 per cycle, or $141,777 and $36,878 annually (Table 12).

Table 12.- Financial performance measures for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy saving fish transfer schedule. Includes results for 13.4 and 20-month grow-out cycles.

Financial Performance Measures	Costs/Cycle ($)		Costs/Year ($)	
	13.4 mo. cycle	20 mo. cycle	13.4 mo. cycle	20 mo. cycle
Total Revenue	540,000	540,000	483,582	324,000
Break-Even Price	3.53	4.43		
Returns to Management above Variable Cost (including opportunity cost of owner's land)	289,215	254,834	258,999	152,900
Returns to Management above Total Cost (including opportunity cost of owner's land)	158,318	61,451	141,777	36,870

Sensitivity Analysis

A sensitivity analysis was conducted to determine the influence of key model parameters on break-even price. Fish growth rate, fingerling costs, equipment costs, feed costs, waste removal costs, and electric costs were examined. The impact on break-even price of changing each parameter by +/- 5% was determined.

At the 13.4-month growth cycle, sensitivity analyses revealed that break-even price was most sensitive to changes in growth rates (+/- 2.83%)[1], followed by fingerling costs (+/- 1.41%)[1], the initial investment (+/- 1.13%)[1], feed costs (+/- 0.56%)[1], and waste removal costs (+/- 0.28%)[1] (Table 13). For example, a 5% change in growth rates at the 13.4-month growth cycle, caused the break-even price to change by $0.10 or 2.83%. As well, at the 20-month growth cycle, sensitivity analyses revealed that break-even price was most sensitive to changes in growth rates (+/- 2.70%)[1], followed by initial investment costs (+/- 1.58%)[1], fingerling costs (+/- 1.35%)[1], feed costs (+/- 0.67%)[1], and electric costs (+/- 0.22%)[1] (Table 14).

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[1] Represents percent change in break-even price.

Table 13. – Sensitivity of break-even price to 5% changes in model parameters for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy saving fish transfer schedule and a 13.4-month grow-out cycle. Parameters are listed from left to right in order of increasing impact on break-even price.

	Waste Removal Costs	Feed Costs	Initial Investment	Fingerling Costs	Growth Rates
Baseline Parameter Value	$21,038/cycle	$0.30/ lb	$718,595	$1.25/fingerling	13.4-month
Impact of 5% Change in Parameter on Break-Even Price	$0.01	$0.02	$0.04	$0.04	$0.10
Percent Change in Break-Even Price	0.28%	0.56%	1.13%	1.41%	2.83%

Table 14. – Sensitivity of break-even price to 5% changes in model parameters for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy saving fish transfer schedule and a 13.4-month grow-out cycle. Parameters are listed from left to right in order of increasing impact on break-even price.

	Electric Costs	Feed Costs	Fingerling Costs	Initial Investment	Growth Rates
Baseline Parameter Value	0.051/kw	$0.30/ lb	$1.25/fingerling	$718,595	20-month
Impact of 5% Change in Parameter on Break-Even Price	$0.01	$0.03	$0.06	$0.07	$0.12
Percent Change in Break-Even Price	0.22%	0.67%	1.35%	1.58%	2.70%

Monte Carlo Analysis

A Monte Carlo simulation was conducted for the 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing the energy saving fish transfer schedule at the 13.4 and 20-month grow-out cycles. Interest rates, electricity prices, and output prices were selected as the random variables to be used in the Monte Carlo simulation. These variables were selected for the Monte Carlo analysis because each has a significant impact on returns to management and yet each is beyond the control of the owner. A probability distribution of electricity prices was developed from U.S. Department of Energy data on nominal residential electricity rates for the last 30 years, adjusted to real prices using the consumer price index (USDE 2003). The real electric rates ranged from $0.045 to $0.08 over a 30 year period. A probability distribution for interest rates was based on the 5-year U.S. Treasury constant maturity rate from 1953 to 2003 (Federal Reserve 2003). Interest rates ranged from 3% to 15%. The flounder price probability distribution was generated from whole price per pound retail prices at North Carolina retail fish markets during the season of peak retail prices for the last 10-years (Various Retail Markets, NC). The prices ranged from $4.50 to $6.00 per pound whole weight.

A value was drawn at random from each variable's probability distribution for each year in a 10-year planning horizon. Returns to management were calculated for each of the ten years, and the present value of returns to management was calculated for the 10-year planning horizon. This process was repeated 500 times for both the 13.4 and 20-month grow-out cycles, yielding a probability distribution of present value returns to management for each grow-out cycle as shown in Figs. 4 and 5.

The 13.4-month growth cycle model produced present value returns to management ranging from $675,00 to $1,175,00, with an average of $890,477 (equivalent to an annual average return to management of $89,048) per 1-acre facility (Fig. 4). Present value returns to management ranged between $850,000 and $950,000 in 44% of the 500 model runs (Fig. 4). In the 13.4-month growth cycle model (only), none of the model runs produced negative present value returns to management.

The 20-month growth cycle model produced present value returns to management ranging from -$50,000 to $300,000, with an average of $119,800 (equivalent to an annual average return to management of $11,981) per 1-acre facility (Fig. 5). Present value returns to management range between $75,000 and $175,000 in approximately 64% of the 500 model runs. In the 20-month growth cycle model, present value returns to management were negative in 1.5% of the 500 model runs (Fig. 5).

The present value returns to management reported above reflect the financial performance of just one 1-acre unit of the of the 3 x 1-acre system. These results should be multiplied by three to determine the financial performance of the complete 3 x 1-acre system.

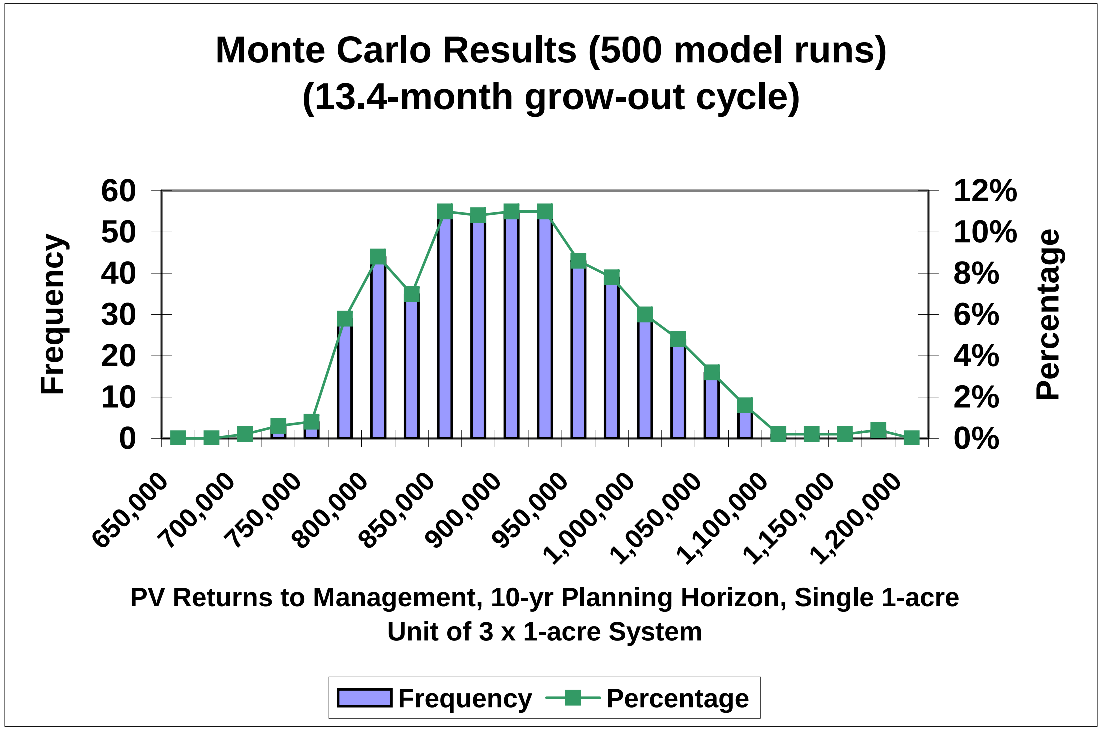

Figure 4. – Histogram of Monte Carlo results for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy saving fish transfer schedule and a 13.4 month grow-out cycle. The x-axis represents bin ranges of present value returns to management over a 10-year planning horizon. The y-axis represents the frequency and percentage of present value returns to management in a certain bin range for 500 model runs.

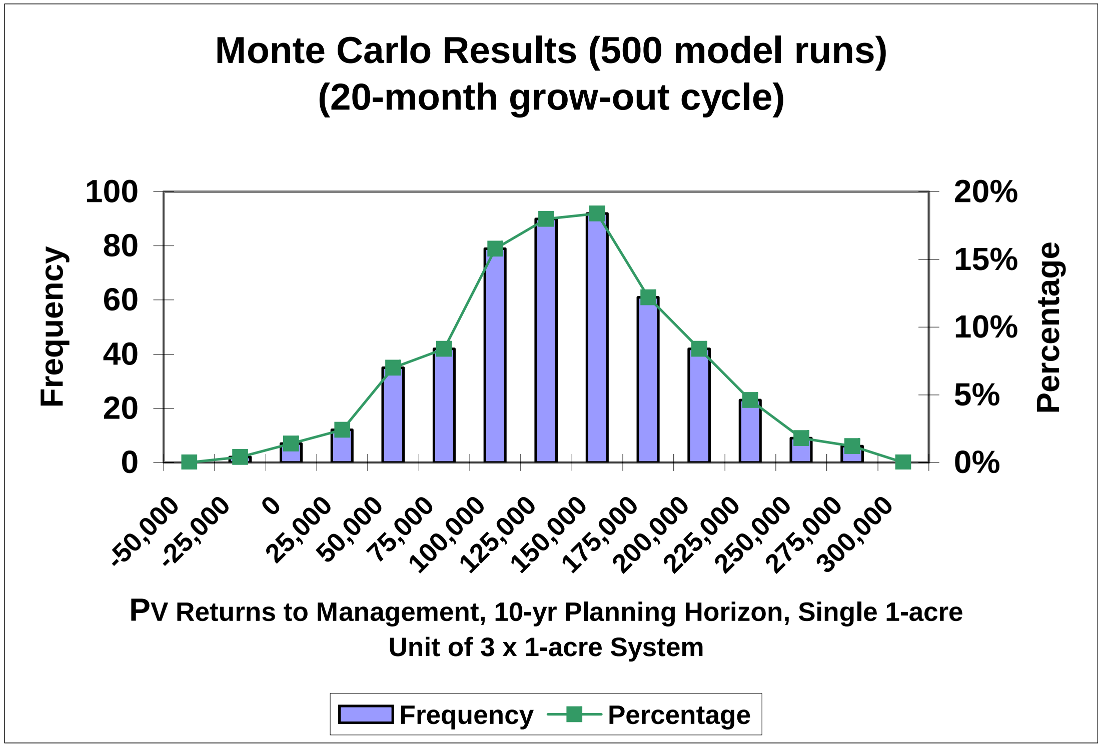

Figure 5. – Histogram of Monte Carlo results for 1-acre unit of the 3 x 1-acre, 27 ft diameter, steel tank, indoor facility utilizing energy saving fish transfer schedule and a 20 month grow-out cycle. The x-axis represents bin ranges of present value returns to management over a 10-year planning horizon. The y-axis represents the frequency and percentage of present value returns to management in a certain bin range for 500 model runs.

DISCUSSION

This study investigated the relative financial performance of alternative RAS summer flounder production facilities. The most cost-effective system (i.e., the system with the lowest break-even price) is the 3 x 1-acre, 27 ft diameter, steel tank, indoor (using a building) system utilizing the fish transfer procedure.

Importance of Fingerling Growth Rate

Fingerling growth rate (indexed by the length of the grow-out cycle) has a large impact on financial returns. The 13.4-month grow-out cycle was demonstrated to be achievable in approximately 5% of the fingerling population in the UNCW near-commercial scale field study, but the 20-month grow-out cycle reflects average fingerling growth rates using current culture methods. Using the Monte Carlo simulation, the 20-month growth cycle produces a break-even price of $4.43 (Table 3) and an annual average present value returns to management of $11,981/yr per 1-acre facility, or $35,943/yr, for all three 1-acre facilities combined (Fig. 5). The 20-month cycle also has a 1.5% chance per year over the 10 year planning horizon of producing negative returns to management (Fig. 5). In contrast, the 13.4-month cycle produces a break-even price of $3.53 (Table 3) and exhibits annual average present value returns to management of $89,048/yr per 1-acre facility, or $267,144/yr, for all three 1-acre facilities combined (Fig. 4). The average financial returns of the 13.4-month grow-out cycle model are more than 7 times greater than those of the 20-month model, emphasizing the importance of future biological research on growth rates to financial performance (Figs. 4 and 5).

Economies of Scale

The term "economies of scale" refers to the potential reduction in per unit production costs resulting from increased scale of production, realized through operational efficiencies. The potential for economies of scale was investigated by scaling up the UNCW near-commercial scale pilot facility to a commercial scale via a simulation model. The pilot-scale facility was scaled up by increasing tank size and facility size.

Tanks sizes with diameters of 15, 20 and 27 ft were considered. The 15 ft tank size was used in the UNCW pilot facility, and the 27 ft tank is approximately the maximum tank size for which partial self-cleaning properties of a tank in a recirculating system can be maintained.

Alternative facility sizes of 0.5-acre, 1-acre, and 3 x 1-acre were considered. The numbers and sizes of recirculating system components, variable input requirements, and per unit variable input costs were scaled consistent with changes in tank size and facility size. For example, fingerling costs range from $2.00 to $1.25/fingerling, depending on quantity purchased (Fig. 6). The 3 x 1-acre system size was considered in order to model a system that would be of sufficient size to take advantage of the full fingerling price discount. Larger facility scales of 1, 5, and 10-acres were initially considered. However, the volume of product to be sold from the 5 and 10-acre facilities, up to 540,000 lbs and 1,080,000 lbs. respectively, per 13.4-month grow-out cycle, was predicted to drastically drive down market price (Dumas and Horton 2001) and profit margin. Summer flounder grow-out operations at such large scales were deemed to be too risky, due to fluctuations in market demand and market price (Dumas and Horton 2001). As well, there would be an additional cost incurred (approximately $300,000 annually) due to new U.S. Environmental Protection Agency (EPA) regulations published on August 24, 2004, regarding effluent discharges for the aquatic animal production industry. The EPA's final rule (Federal Register, 40 CFR Part 451) applies to direct discharges of wastewater from existing and new facilities "that produce at least 100,000 pounds a year, and recirculating systems that discharge wastewater at least 30 days a year (used primarily to raise trout, salmon, hybrid striped bass and tilapia)." The rule requires that all applicable facilities:

- Prevent discharge of drugs and pesticides that have been spilled and minimize discharges of excess feed.
- Regularly maintain production and wastewater treatment systems.
- Keep records on numbers and weights of animals, amounts of feed, and frequency of cleaning, inspections, maintenance, and repairs.
- Train staff to prevent and respond to spills and to properly operate and maintain production and wastewater treatment systems.
- Report the use of experimental animal drugs or drugs that are not used in accordance with label requirements.
- Report failure of or damage to a containment system.
- Develop, maintain, and certify a Best Management Practice plan that describes how the facility will meet the requirements.

The rule requires flow through and recirculating facilities to minimize the discharge of solids such as uneaten feed, settled solids, and animal carcasses (EPA Aquatic Animal Production, Fact Sheet). The 5 and 10-acre models would be well over the production rate of 100,000 lbs/yr.; therefore, they would be required to implement the above management plan. As a result, it was decided to scale up the pilot-scale study using the smaller scales of the 0.5, 1, and 3 x 1-acre systems, which would not trigger the EPA rule. Model results indicate that significant economies of scale exist in RAS summer flounder production: break-even price decreased from $11.01/lb. for the smallest 0.5-acre, 15 ft, outdoor fiberglass system, to $3.53/lb. for the larger, indoor, most cost-effective system.

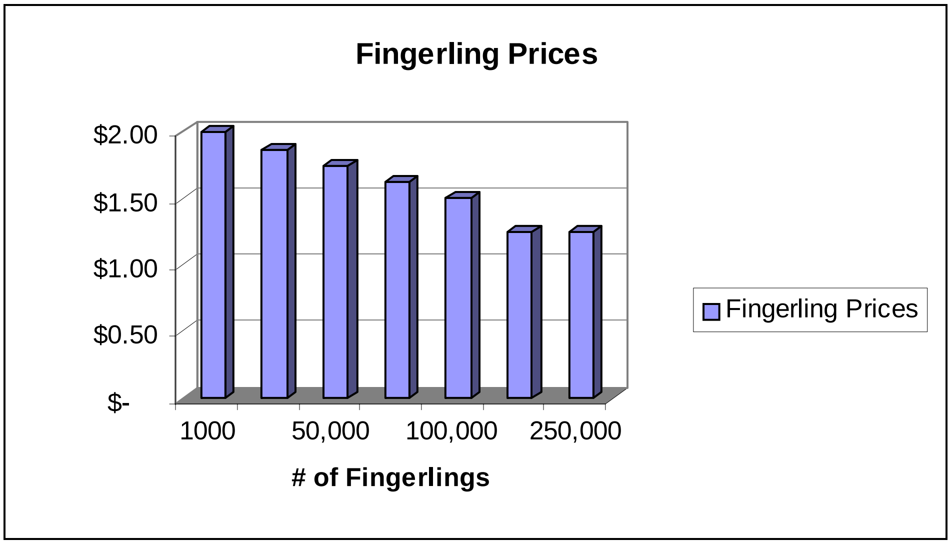

Figure 6. - Fingerling cost schedule. The x-axis represents the number of fingerlings that must be purchased to receive the indicated cost. The y-axis represents the cost per fingerling.

Analysis of Production Costs

The largest components of production costs in the 13.4-month grow-out cycle model are fingerlings, building and equipment loan payments, feed, and labor. In the 20-month cycle model, building and equipment loan, fingerlings, feed, and labor are the largest cost components. Fingerlings are a higher proportion of production costs in the fast growth rate (13.4-month) model because faster growth allows more growth cycles to be completed within the 10 year planning horizon, and more growth cycles requires more fingerling purchases.

The building and equipment loan payment necessary to finance initial capital costs are the first and second-largest cost components of total production costs in the 13.4 and 20-month cycles, representing 27% and 33% respectively. A disadvantage of using recirculating aquaculture systems is that they require larger initial capital investments relative to other types of aquaculture production systems due to larger equipment requirements, such as tanks and filtration systems (Losordo and Westerman 1994; Zucker 1999). Reduction in capital costs per unit of production may be accomplished via economies of scale in overall facility size, as discussed previously, but an effort was also made to investigate potential economies in the configuration of recirculating system equipment at the sub-facility level. Specifically, additional economies were found by integrating filtration equipment with multiple tanks, where feasible. This is accomplished by using one drumscreen filter for every 4 tanks rather than every 2 tanks, saving a total of $32,000 or $0.05 in break-even price, in the most cost-effective model. Further economies may be possible by reducing the number of heat pumps used per facility, by fine tuning ambient environmental conditions within the building to constant temperatures using wall heaters, or by integrating the seawater reservoirs with a central heating and cooling unit before the water reaches the tanks. These possibilities for further economies are beyond the scope of this study, due to technological limitations of the pilot scale facility. However, economic advantages associated with these facility modifications may be significant. Finally, it may be possible to reduce capital costs further by even greater integration of bio-filtration systems with multiple tanks (which is also outside the scope of this study), but there would be an inherent risk of losing more biomass per tank if the system were to fail.

Fingerling costs accounted for 29% and 24% of total production costs in the 13.4 and 20-month cycle models. Currently, there is a single supplier of summer flounder fingerlings, creating a monopoly. If so, it may be possible to reduce fingerling costs by constructing hatcheries and producing summer flounder fingerlings "in house" (Daniels and Watanabe 2003, Copeland et al. 2004). At the moment there is still a large bottleneck in hatchery production of summer flounder fingerlings due to cannibalism in juveniles. Alternatively, fingerling costs might fall if fingerling production is concentrated in specialized hatchery facilities able to benefit from economies of scale and supply multiple grow-out operations (as long as concentrated hatchery facilities do not set monopolistic prices). The results in Tables 13 and 14 indicate that reductions in fingerling cost have a moderate impact on break-even price and profitability.

In other commonly cultured finfish species, such as catfish (Bailey et al.1992) and tilapia (Engle and Pounds 1993, Head et al. 1994, Head and Watanabe 1995), feed costs normally account for the highest proportion of total production costs. In the summer flounder production modeled considered here, feed costs per pound of production are comparable to those for other cultured species, but capital and fingerling costs are a much greater proportion of total production costs. Over time, the general expansion of the mariculture industry may increase the scale of production of extruded feed pellets, reducing the price of feed to growers. Model results reflect the lowest available price of feed to growers. In comparison to fingerling growth rates and capital costs, changes in feed costs have only moderate impacts on break-even price ($0.02 to $0.03 per %5 change in feed costs for the 13.4 and 20-month cycles, respectively). Waste removal is accomplished by hauling the flocculated waste from the facility to a landfill/spray field via a slurry truck, which can haul a ton of slurry per trip. Waste removal costs $19,296 per cycle and represents minor production costs in the 13.4 and 20-month cycles, 6% and 4%, respectively. However, if the saline waste can be re-used by a nursery as fertilizer for saline tolerant plants, the cost is negated, and break-even prices fall from $3.53 and $4.43, to $3.35 and $4.24, in the 13.4 and 20-month grow-out cycles, respectively.

Interest (capital cost and operating cost loan), a relatively minor production costs (3% and 4% in the 13.4 and 20-month cycles, respectively), could be lowered somewhat by using personal savings, or finding investors (costs would decrease according to the difference between the interest rates charged by lenders and the facility owner's or investors' interest rate on his/her/their next-best investment).

Insurance is a minor cost as well, amounting to approximately 3% of total production costs in either the 13.4 or the 20-month cycle model. Insurance coverage includes property, liability, and workers' comprehensive, as well as fish mortality. Fish mortality insurance is 4.5% of fingerling cost and is optional for the grower; however, it covers loss of fish due to disease, mechanical and electrical failure, frost, and flood, and it is recommended due to the unpredictability of environmental conditions from year to year.

Sensitivity analysis revealed that changes in fingerling growth rate have the greatest impact on financial performance in the 20-month grow-out cycle model, followed by changes in initial investment costs, and fingerling costs. An increase in fingerling growth rate that reduces grow-out time in the 20-month grow-out cycle model by 5% reduces break-even price (initially $4.43) by $0.12 or 2.70%. A 25% reduction in grow-out time would reduce the break-even price by $0.60 to $3.83. A 5% reduction in initial investment costs ($718,595) in the 20-month cycle would reduce break-even price by $0.07 or 1.58%. A 25% reduction would reduce break-even price by $0.35 to $4.08. A 5% reduction in initial fingerling costs ($1.25/fingerling) in the 20-month cycle would reduce break-even price by $0.06 or 1.35%. A 25% reduction would reduce the break-even price by $0.30 to $4.13. Changes in feed, electricity or waste removal costs produced relatively minor changes to the break-even price in the 20-month cycle model.

It is important to keep in mind that the financial performance results reported in this study reflect production conditions in eastern North Carolina circa 2003-2004. Potential profitability in other regions of the U.S. would likely differ due to regional differences in fingerling availability and cost; the quality and availability of substitute products; the costs of land, construction, feed and energy (for example: energy prices can range from $0.15-$0.20 per kWh, in other parts of the country); the cost of transporting product to market; interest rates; and insurance. The sensitivity analyses and Monte Carlo simulation results presented here should help potential investors plan for regional differences and changes in market conditions.

Conclusion

The purpose of this study is to develop an economic model of summer flounder aquaculture production based on engineering and biological parameters derived from UNCW’s near-commercial scale RAS facility located in Wrightsville Beach, NC. The model is used to determine the profit maximizing scale of operation for a commercial-scale summer flounder RAS facility, the profit-maximizing harvest size, returns to management, and the sensitivity of financial performance to key biological, engineering, and economic parameters. Monte Carlo analysis is used to assess the impacts of uncertainty in flounder prices, electricity costs, and interest rates on financial performance.

Sensitivity analyses and Monte Carlo analyses revealed that growth rate is the most critical component of financial performance, followed by capital costs and fingerling costs. Future research on improving mariculture techniques and selective breeding of summer flounder for all female culture may improve growth rates (and FCR's). Two growth rates are considered in the analysis. A slow growth rate is modeled by a 20-month grow-out cycle, and a fast growth rate is modeled by a 13.4-month grow out cycle. Present value returns for a 10 year planning horizon for one of the 3 x 1-acre facilities in the most cost-effective model range from negative $50,000 to positive $300,000 for the 20-month growth cycle, whereas returns are always positive and range from $675,000 to $1,175,000 for the 13.4-month growth cycle. Recent black sea bass test marketing trials in Philadelphia, PA, revealed a Chinese market preference for smaller black sea bass (1.5 lbs or less) (Watanabe, personal communication). Although, flounder is used more in Korean and Japanese cultures, this test marketing trial may demonstrate that further efforts need not focus on attaining larger summer flounder, but rather faster growth rates to a target weight of 1.5 lbs. UNCW had 2% of summer flounder reach 2 lbs in 454 days, and these goals are realistic given additional research. Note that improved grow-out methods for other cultured species have significantly increased growth rates; for example, the modern broiler chicken reaches marketable size in just 42 days; twice as fast as 30 years ago.

Future studies will need to focus on integrating recirulating components with multiple tanks, without compromising survivability, in order to reduce capital costs. Fingerling costs might fall if fingerling production is concentrated in specialized hatchery facilities able to benefit from economies of scale, assuming hatcheries do not price monopolistically. In the long-term, fingerling costs might fall if there are advances in reducing cannibalism among juveniles, therefore improving post-hatch success and reducing hatchery costs per fingerling.

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