Bio-economic Factors Affecting Feasibility of Floating In-pond Raceway Systems: A Stella Modeling Approach

by

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Abstract

Floating in-pond raceway (FIPR) systems have the potential to efficiently compete with conventional ponds in their ability to produce large quantities of fish profitably. However, little is known about the biological and economic capabilities of these systems, so this thesis investigates a bio-economic modeling approach to help researchers better understand the system and determine what factors most affect its potential. Findings from model simulations provide insights into what field research areas are most important to conduct. A bio-economic model was developed to simulate the stocking, grow-out and harvest of hybrid striped bass (HSB) in an FIPR. HSB were chosen as a model species because FIPR field trials in West Alabama were already incorporating this species and because their relatively high market value ($7.00/kg and up).

System/species feasibility was analyzed in terms of HSB biomass production and net returns through the process of completing four modeling objectives with water temperature dependent fish growth at the core of the developed model. Objectives explored include stocking density and density dependent mortality rate relationships, influence of stochastic loss events, fingerling stocking size and date of stocking relationship to final harvest, and using the bio-economic model to construct longer term production plans that maximize net returns.

At this stage, data produced by the bio-economic model simulations is not intended for direct use by producers in making production decisions, but to explore what bio-economic factors most affect the feasibility of the floating in-pond raceway systems and to use this

information to prioritize where further field research is needed to improve model accuracy and value as a management tool. Eventually, as field trials fill current gaps in knowledge, the refined model will be useful in making on-farm decisions to improve the production efficiency and operation profitability.

Results from the four objectives indicate that understanding fish growth rate as it relates to seasonal water temperature and species specific biology is essential to producing an accurate model. Secondly, a better understanding of density dependent mortality is needed to determine stocking densities that optimize system performance and maximize net returns. Third, stochastic mortality loss events were identified as critically important factors affecting economic feasibility and further field research is needed to refine the frequency and magnitude parameters in the model. Finally, analysis using the bio-economic model indicated that overwintering HSB in the FIPR is expensive, especially in the case of holding larger fish. As growth parameters used in the model are refined through field research the model can become a useful tool for producers and researchers in making profit maximizing HSB FIPR system management decisions.

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Introduction

Over the past 15 years, floating in-pond raceway (FIPR) systems have been developed as complements and even as possible alternatives to traditional pond aquaculture production systems. FIPR systems combine cage and raceway techniques by floating an enclosed raceway inside a traditional aquaculture pond and using injected air pressure to produce a stream flow through the raceway structure. Although a number of research projects and field trials have been conducted to test FIPR systems and their potential as a technique for fish culture, there is still much to be learned about them. In an attempt to better understand the production potential and economic potential of this system, a bio-economic computer model was developed using Stella software to simulate production of hybrid striped bass (HSB) (female white bass (*Morone chrysops)* X male striped bass *(Morone saxatilus))* in a FIPR system. This species was chosen for the bio-economic model development because it had been reared with some success in FIPR trials in West Alabama. By modeling a FIPR system, we hope to gain insight into the biological, physical and economic factors that influence feasibility of FIPR systems for HSB.

The current bio-economic model uses data on survival, growth, stocking numbers and sizes from the literature and expert opinion. Adjustable bio-economic model parameters include stocking densities, temperature dependent growth rates, feed and fingerling costs and market prices. The bio-economic model automatically harvests fish when the average size is ≥0.68 kg. Profits are calculated based on receipts minus variable and fixed costs (net return) resulting from quantities harvested and expenses incurred during the production process. The bio-economic model tracks cumulative net returns over time. It also tracks fixed costs including construction, equipment and machinery depreciation, loan interest amounts, taxes, insurance, repairs and maintenance. Enterprise budgets were developed from the bio-economic model results and follow standard farm enterprise budget practices so results are comparable to other aquaculture enterprise budgets.

Based on limited research with FIPR systems in West Alabama, it appears that HSB in these systems can have high survival rates, better feed conversion ratios and be easier to harvest than in pond aquaculture systems. However, there is little research that quantifies the biological and economic differences between the FIPR and pond production systems for HSB. Building and managing FIPR systems for experimental research purposes is both costly and time consuming. By using a computer simulation bio-economic model, researchers can manipulate a variety of interconnected environmental, biological, and economic variables to predict, with some degree of certainty, the expected total yield, production costs, survivorship, net returns, etc., for any point during the grow out period. The modeling of aquaculture production systems is difficult and not perfect, but with more data from research systems, model parameters can be refined for improved predictive abilities.

Literature Review

With more Americans consuming fish than ever before, the southeastern United States has the opportunity to provide for the increased demand for aquaculture products. However, southeastern fish farmers are finding it increasingly difficult to keep their farms profitable. Fluctuating and increasingly higher domestic input costs and increasing competition of low priced import substitutes from Asia are keeping profit margins razor thin for many US fish producers (Hanson and Sites, 2011). For southeastern fish farmers to remain competitive, they need to consider alternative production systems that may be more efficient than their present systems.

The traditional method of culturing fish in the southeastern United States uses shallow earthen ponds which are relatively inexpensive to construct and straightforward to manage. In west Alabama ponds are built so the surrounding watershed provides water to fill them through runoff, therefore decreasing reliance on a deepwater aquifer that is expensive to use. Once filled, ponds are drained infrequently (every 10 to 15 years). Ponds can self-regulate their water quality through naturally occurring biological processes such as photosynthesis, denitrification and other reactions (Brune et al., 2003b). Ponds can provide supplemental food to developing fish through naturally occurring insect larvae, algae and other nutrient sources.

Pond production also has its challenges. Ponds require ample land for the pond to be constructed and the ponds must be strategically placed to take advantage of the topography and retain sufficient water for the ponds. For ponds to be easily harvested, they need to be shallow and rectangular for harvest seines to be most efficiently used. In hilly areas, building proper ponds requires more earth moving which translates to higher construction costs. Ponds also require periodic maintenance and upkeep.

Although naturally occurring biological processes can help maintain pond water quality these same processes are much less controllable at high production intensity levels. Ponds need daily monitoring to make sure they are maintaining tolerable ranges of dissolved oxygen, pH, water temperatures to support fish health and growth. Weather events, such as droughts or storms can affect production as well as cause thermal stratification and turnovers in the water. Natural events can make pond production difficult because they are uncontrollable, unpredictable, and increase risk of mortality associated with fluctuating water quality.

There are other disadvantages for pond production concerning care for the fish being produced. Fish in a pond are more dispersed and more difficult to see or inventory compared to other types of enclosed systems. Even when feeding a floating feed pellet it can be difficult to identify potential health or disease problems (Brune et al., 2003a; Masser and Lazur 1997). Control over an aquaculture system is the most important managerial aspect and obtaining more control over all biological aspects of a production system often means higher associated costs. A system that is both cost effective and highly controllable is desirable.

In an attempt to obtain more complete control over fish production systems, raceway systems were developed and have been much used in the trout industry. Raceway systems maintain higher water quality by flowing clean water through the system continuously, but, in general, very little water is reused or recycled in these systems. These systems are ideal for freshwater fish that require cold and highly oxygenated water such as rainbow trout (*Oncorhynchus mykiss*) and in areas where clean water is abundant, such as near a river, stream or spring (Lim and Webster, 2006). Raceway systems are advantageous for culturing species that are sensitive to water quality and dissolved oxygen, but have one particular disadvantage; they require flowing water at all times and are therefore not conducive for areas such as the coastal plain where streams are intermittent, especially in the summer months. Nor are they conducive where there are other uses of the water that may contaminate water supply to the facility.

Cage culture is another production system type used in many parts of the world. Cages are usually made of rigid mesh boxes that float in the water (Alabama Aquaculture Best Management Practice (BMP); Masser, 1997; Masser and Lazur, 1997). Water and other material can flow passively through the cage but the fish cannot escape. The Southern Regional Aquaculture Center states that the maximum pounds of fish produced in such systems is maximized at 14 lb/ft^3 and this quantity is highly influenced by species choice and pond conditions (Masser, 1997).

Cages can be built and maintained with relatively low costs and can be fully harvested by extracting and emptying the cage of fish. Fish can be more easily observed during feeding when compared to ponds. But cages have several disadvantages. Because water is not pumped through the cage, stocking densities are limited based on any natural flow in the water, or how quickly fresh water can flow through the cage. Decreased water quality in the form of low dissolved oxygen and high ammonia levels can be a problem for cages that are stocked at high densities or when many multiple cages are placed in the same vicinity. Fish wastes accumulate on the substrate below the cages and degrade the sediments and overall water quality.

Recirculating systems require the least amount of water of any aquaculture production system due to their water reuse. However, recirculating systems do not rely on natural components to maintain water quality; instead they rely on equipment such as mechanical filters, water pumps, temperature controls and aerators to maintain water quality (Masser and Lazur, 1997). This equipment requirement increases construction costs compared to ponds and requires higher levels of management skill to keep them in continuous operation at efficient levels. Water quality is usually the most limiting factor in these systems (Lazur and Britt, 1997). Fish in recirculating systems are highly visible and can be more easily monitored. Disease recognition and treatment is more easily managed in recirculating systems resulting in higher production rates. Because recirculating systems use less water than other systems to grow the same amount of fish and can be built above ground, they usually require less land for construction and can be constructed closer to markets.

Each type of fish production system has its advantages and disadvantages. Traditional pond production systems are relatively inexpensive to build but costly and time-consuming to completely harvest. Discovering and treating diseases and accurately determining feeding rates is difficult in ponds when compared to other systems. Raceway systems combat these issues because fish are held in relatively small enclosure areas, but their continuous need for water is so great that they are often eliminated as a viable option for warm water aquaculture (Masser and Lazur, 1997). Cage culture may provide easier waste collection, more effective disease recognition and treatment, more efficient feeding, and in some cases, easier harvesting, but is limited by stocking densities because of decreased water quality.

Floating In-Pond Raceway Systems (FIPRs)

In the early 1990's a culture system was developed that combined the advantages of pond, raceway and cage systems into a caged raceway structure located in a pond. Early systems were developed by researchers at Auburn University, and it was called the floating in-pond raceway or FIPR (Masser and Lazur, 1997; Yoo, Masser and Hawcroft, 1995). The pond provides a constant source of flowing oxygenated water via airlift pumps through a raceway with a mesh barrier on the end, creating a raceway like enclosure (Masser and Lazur, 1997). Fish contained inside needed to be able to withstand a slow current of water in order to survive and thrive. FIPR systems incorporate airlift pumps for both aeration and water flow. Another important part of FIPR construction and a major advantage is a surface cover to protect fish from bird predation and to provide shade (Chappell, 2009; Hanson, 2009; Masser and Lazur, 1997).

FIPR systems utilize the benefits of raceway, cage and pond production systems. They allow for stocking densities and production levels similar to raceways but require much less water, since the outflow of FIPR water is into the pond and is re-circulated through this water body and is eventually re-flowed through the FIPR. Some FIPR systems also incorporate waste removal at the end of the raceway, where traditional cages and raceways usually have no waste collection (Chappell, 2009; Brown, 2010). When the water leaves the FIPR structure it goes back into the pond where the natural de-nitrification process can occur and water quality can be improved and maintained naturally, without the added costs of filtration. There are other managerial benefits to FIPR systems. Since all the fish are in an enclosed space, feeding to satiation is much more feasible and fish are more likely to have access to feed compared to pond systems where fish are more dispersed (Chappell, 2009). Early disease recognition and treatment is also easier since fish are more visible and contained (Masser and Lazur, 1997; Yoo, Masser and Hawcroft, 1995).

Studies show that FIPR systems have better water quality than the surrounding pond's surface water in terms of dissolved oxygen, temperature and consistency (Hartleb, 2004; Masser and Lazur, 1997; Morrison et al., 1995). Hartleb (2004) found that water in the FIPR system was consistently a few degrees lower than in the supporting pond's surface water. Water temperature is especially important in the southeastern U.S. where fish are subject to extremely high water temperatures nearing 30°C in summer. The airlift pumps provide oxygenated water at all times, supplying water that is higher in oxygen than the water before it was pumped through the FIPR system (Masser and Lazur, 1997). Higher dissolved oxygen levels and more consistent water temperatures that are optimal for specific fish species can result in more efficiency, higher production and higher net returns.

Another benefit of the FIPR system is that they can be used in ponds that would be otherwise unsuitable for fish production and harvest. Where production ponds must be shallow so they might be seined for partial harvesting, FIPR systems can be placed in deeper ponds and harvesting can be done with a seine inside the system structure or with a crane that removes the whole unit (D'Abramo and Frinsko, 2008). Deeper ponds contain lower water temperatures in their depths and may be preferred for growing some species of fish such as hybrid striped bass (D'Abramo and Frinsko, 2008; Hodson, 1989; Volkman, Kohler and Kohler, 2004). Another advantage of FIPR systems is that farmers can diversify their species produced in a single pond by putting different species in each raceway, or stocking each raceway at different times to diversify cash flows (Chappell, 2009; Odom, 2009).

Beside the biological benefits, there are numerous economic benefits as well. After the first season of Brown's research in a fixed in-pond raceway system they were able to harvest nearly 19,000 pounds of fish per acre (Brown, Chappell and Hanson 2009; Brown, 2010). It is important to adjust stocking rates according to the size of the pond supporting the FIPR and Masser (1994) recommended stocking no more than 14,800 fish/ha of pond (Masser and Lazur, 1997).

There are drawbacks to the FIPR system as well. The initial costs of building a FIPR system can be high depending on the materials used; and fixed FIPR system can be very expensive if built with concrete, but many less expensive materials can also be used that decrease this initial cost. Also, fish stocked very densely combined with any problem with the airlift pump system could be catastrophic for the farmer and should be addressed beforehand by including back-up pumps and emergency power generation as part of the standard FIPR equipment and machinery needs of system. The time window to prevent a great loss is much shorter in more intensive production systems than in less intensive pond systems and risk mitigation strategies are critical.

A similar type of in-pond raceway system, called the fixed in-pond raceway system, functions on the same principals as the floating raceways except it is permanently built into the bottom of the pond with concrete or plastic walls. There is a considerably higher construction cost associated with building a fixed IPR compared to a FIPR system. The air lift pumps and resulting water flows for the fixed IPR systems are powerful enough to circulate water through the entire pond. In a west Alabama fixed IPR research project a pond was drained and six raceways were built on a concrete pad with cement block walls. There was a baffle to direct water down the length of the six acre pond around the length of the bend, and then back to the paddlewheels at the front opening of the fixed IPR system (Brown, Chappell & Hanson 2009). The initial trial of this fixed IPR system showed promise, producing a high weight of catfish and two other co-culture species, tilapia and paddlefish.

Another species that shows potential for culture in the FIPR is the hybrid striped bass (HSB) or sunshine bass (Fullner, Gottschalk and Pfeifer, 2007; Hanson, 2009; Hodson and Hayes, 1989). HSB are produced by fertilizing eggs from white bass, *Morone chrysops*, with sperm of striped bass, *M. saxatilis.* The white bass is a freshwater species found in the Mississippi basin and other gulf coast states and can reach a weight of 1.81- 2.27 kg. The striped bass is an anadromous species occurring along the Atlantic and Gulf Coasts of the U.S. but have been successfully introduced into lakes and reservoirs throughout the U.S. and along the Pacific coast and can reach up to 31.75 kg. Since striped bass spawn in fresh water, some introduced populations have been able to reproduce in landlocked bodies of water despite being isolated from the ocean. Aquaculture of sunshine bass has been increasing over the past few years because of a general decline of the striped bass fishing industry and because of the hybrid's vigorous growth and its success in lakes and reservoirs as a game fish (Hodson and Hayes, 1989). HSB have a wide tolerance of environmental conditions. Their optimal growth temperatures are between 25 and 27°C but can survive temperatures between 4 and 33°C. They can also survive in salinities up to 25 ppt. In production ponds, HSB usually reach a harvest weight of 0.680 to 1.13 kg in 18 to 24 months.

Traditionally, hybrid striped bass were produced using a three-phase system. In Phase I or the nursery phase, eggs are hatched and raised to 30-45 day old fingerlings where each fingerling weighs approximately 1 gram. These fingerlings are then removed and stocked for Phase II in ponds from 30,000 to 44,000 per hectare. When these animals reach 125 to 225 grams they are graded and restocked into the final Phase III grow-out ponds at densities between 7,000 and 11,000 per hectare and grown to market size which is usually around 900 grams (D'Abramo, L. R., et. al., 2002; D'Abramo and Frinsko, 2008; Hodson and Hayes, 1989). Based on a survival of 80%, farmers can expect yields between 7,200 and 7,800 kg/ha.

Research in the last 10 years has led to a more streamlined method of HSB production called "direct stock" (D'Abramo and Frinsko, 2008; D'Abramo et al., 2002). The direct stock method eliminates the Phase II component of the three phase system and stocks larger, graded fingerlings directly into the grow-out pond. D'Abramo's protocol states that fingerlings should be stocked after they reach 3 grams in the initial phase. The larger and more uniform the fingerlings are when they are stocked led to larger and more uniform market sized fish (D'Abramo, et. al, 2002; Chappell, 2009).

One disadvantage of HSB is that they are cannibalistic, especially with larger fish cannibalizing smaller fingerlings. Therefore, it is important to effectively size grade the fish before stocking them for grow-out so that they are similarly sized and do not cannibalize each other. Cannibalism can also be prevented by feeding fish to satiation. Another disadvantage of farming HSB compared to other warm water fish, such as channel catfish, in southeastern states is that they are less tolerant of high water temperatures and require higher dissolved oxygen levels.

Water flowing through the FIPR is oxygenated with airlift pumps and uses water from approximately one meter below the water surface, so it is both cooler in temperature and higher in oxygen than the surface pond water. This can provide a favorable environment for HSB even during the hot summer months of the year. Alternatives to growing HSB in FIPR systems until harvest size are the possibility of stocker production in the FIPR system until they are past their most vulnerable stage and then grown out in ponds, or even stocked in reservoirs for recreational fishing. A study in Europe described HSB as an excellent fish for culture in pond circulation systems, saying they over wintered with low losses, and withstood handling pressures well (Fullner, Gottschalk and Pfeifer, 2007). HSB could also be raised from fingerling to market size in a FIPR system.

Stella® Bio-economic Modeling System

Field research of a FIPR system for a specific species can be costly and time consuming. However, an alternative modeling method can be used to simulate preliminary growth studies and economic analyses. Models can help users understand complex biological systems and enable the user to assess relationships between variables in the system. They also enable the user to optimize the output or flow through the modeled system. Costanza (1998) reported that a group of "novice" modelers were able to build their own models in a short period of time and able to answer a wide range of ecological and economic questions about the systems they had been studying (Costanza and Gottlieb, 1998). Modeling can also be used as a tool to direct research efforts in the field toward more relevant research areas, saving time and reducing costs of multiple field trials.

The program chosen for this project is called Stella®, made by ISEE Systems. Stella is a dynamic modeling program that uses an icon-based graphic interface to build models. HSB and channel catfish have been raised in FIPR system trials in West Alabama, providing some baseline data for bio-economic model construction. The resulting Stella bio-economic model will help identify parameters needing additional research as well as determine which factors are most influential on FIPR feasibility. This bio-economic modeling template could be used as a beginning point for modeling the production of other fish species.

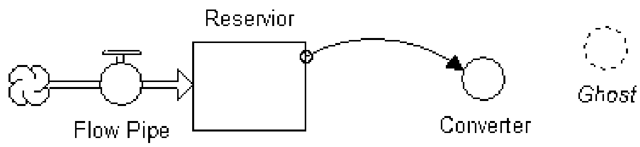
Baseline parameters and bio-economic model assumptions were derived from the scientific literature, and expert opinions of researchers and producers. The bio-economic model tracked the growth of HSB from initial stocking size to harvest and removed animals from the system at a mortality rate typical of HSB systems in West Alabama. Using the programmed parameters and assumptions, the bio-economic model calculated variable costs and fixed costs.

It also calculated receipts and net returns based on sales of harvested HSB minus production and fixed costs. The bio-economic model calculated results as often as the user decided; i.e. provide results for any time period desired. The bio-economic model could be set to calculate a certain number of time periods, and these sets of data were called “runs”. For example, the bio-economic model can be set to run for a year with the time step equaling one day, the total “run” would equal 365 days. Stella will then track the changes in a tabular form and in a graphical form which allows the user to see the results immediately.

The bio-economic model contains variable parameters that can be adjusted by the user. This allows the user to make adjustments to the bio-economic model’s specifications and immediately see the resulting implications. For example, the feed price is one adjustable factor. The price of feed for HSB in the FIPR system is $1.00/kg for 48% protein feed. The price per kg of feed influences the total cost of feed and therefore net returns. The user can see and record these dependent variable values. Then the user may leave every parameter the same and adjust the feed price to another level, say $2.00/kg, and run the bio-economic model again. Now the costs will increase and profits will decrease over time and the user can see the magnitude of the change instantly.

Like the Microsoft Excel spreadsheet software, the user develops the equations and relationships between components of the bio-economic model. Unlike Excel, Stella can calculate the equations repetitively to simulate and track changes over time. Stella also uses graphics to illustrate different types of functions, and each graphic contains a number, equation or graph depending on what the user programs it to have. As the bio-economic model is built, a map is formed of the functions and their relationships. Below is an example of the basic Stella graphic types:

Figure 1. Basic Stella bio-economic model components.



The *Converter* can be a number or equation and can be connected to make different relationships, much like a formula in an Excel software cell. Arrows connects the *Converter* to the *Flow Pipe*. The *Flow Pipe* is used to insert numbers into a *Reservoir.* Stella recalculates the equations in the *Converter* with each time step, which can be daily, weekly, monthly, etc., and recalculates for the duration of the bio-economic model run, which can be any chosen length of time. The *Reservoir* collects and stores the numbers over the entire length of the bio-economic model, where the other Stella elements simply recalculate. Red arrows point from a converter or reservoir to another converter or flow pipe, and they indicate that the equation in the origin is used in the graphic the arrow is pointing to.   A *Ghost* is used to copy any of the tools and paste them somewhere else in the system, mostly to keep the map more organized. They always have dotted outlines and indicate that only that part of the bio-economic model and the formula in it is copied. More specific Stella bio-economic model elements will be provided and discussed in the methods section.

Objectives

The overall goal of this study was to develop a bio-economic computer model depicting HSB production in floating in-pond raceways. The bio-economic model includes biological relationships between the culture environment, HSB characteristics and the economic setting to measure outcomes such as production, receipts, costs and net returns. Biological relationships of the culture environment include water temperature and its effect on HSB growth; species characteristics include not only the temperature dependent growth rates, but also the mortality associated with stocking densities and crop duration. The economic setting includes uncertainty, such as the risk of unexpected death events, input/output prices and initial stocking weight-date effects on harvest quantity and net returns. Development of a bio-economic model with these relationships will be useful as a research and decision making tool for researchers and producers, and can be adapted for other species.

Data from the literature, a FIPR system field trial in west Alabama and expert opinion was used in the computer software STELLA® to model biological production, costs, receipts and net returns for HSB in a FIPR system. The objectives and hypotheses set for the bio-economic model development were to:

I. Determine the importance of knowing the shape of a density dependent mortality curve. It was hypothesized that that the shape of the density dependent mortality curve would significantly affect production and net returns. Secondly, maximized production would not always correspond to maximized net returns. Specifically, this bio-economic modeling objective was to determine the effect of the relationship between mortality and stocking density on production and net returns by varying the HSB stocking density in the FIPR system at set intervals of 300, 400, 500, 600 and 700 fish/ m^3 using fixed, linear and exponential mortality relationships on fish biomass production and net returns above all costs.

II. Evaluate the effects of stochastic mortality events, on production and net returns. It was hypothesized that decreasing the magnitude of stochastic loss events from 50% to 10% would greatly improve production and net return and increase the chance of positive net return. Additionally, HSB FIPR crops with loss events occurring later in the grow-out period should experience lower net returns due to higher accumulated variable costs, than crops with loss events occurring earlier in the grow-out period. This bio-economic modeling objective sought to assess the economic consequences of stochastic loss events in FIPR systems, and determine the economic benefits realized from decreasing both the magnitude and frequency of stochastic loss events. This objective developed a component of the bio-economic model to generate stochastic loss events with varying frequencies of loss (1%, 10%, 20% and 40% through any given grow-out period) and two magnitudes (50% and 10% loss of current crop abundance). Effects were measured in terms of production biomass and net returns.

III. Examine the influence of initial stocking size and initial stocking date on crop duration, production and net returns in the HSB FIPR system. Growth rate is dependent on seasonal water temperatures typical of the southeastern United States. Since water temperature directly affects growth rates, the choice of fingerling size stocked at a particular time can be an important aspect in determining the profitability of HSB FIPR systems. It was hypothesized that larger fingerlings (7") stocked any month of the year should reach market size in less time than smaller fingerlings (6”, 5”, 4” or 3”) stocked in the same month and resulting production and net returns should be greater than for smaller fingerlings. Secondly, stocking larger fingerlings early in the year (January through April) would result in greater crop production and net returns because they would reach market size before the winter.

IV. Develop a method to analyze long-term HSB FIPR production planning to maximize net return potential from the bio-economic model. It was hypothesized that the largest fingerling size available (7”) would be the best choice to stock in any month of the year in order to maximize net return over an extended multi-year, multi-crop production scenario (five years).

General Methods

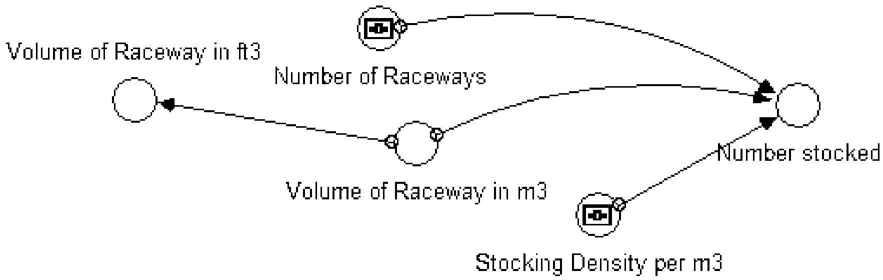
The bio-economic model was designed to represent a grow-out facility for HSB after being stocked with fingerlings purchased from an outside source. Mortality, biomass, crop value, feed costs, etc. were all calculated in weekly time steps. The time steps for the bio-economic model were weeks and therefore, results were produced on a weekly basis.

Stocking and Stocking Density

Stocking density can be adjusted for any given bio-economic model objective by using a slider bar. The range of values for *Stocking Density* is from 0.5 to 700 fish/m^3 based on the scientific literature search and expert opinion. The *Number Stocked* converter multiplies the number chosen on the stocking slider bar with the number of raceways used (one in all cases in this thesis) and multiplies by the volume of each raceway (65 m^3 in all cases in this thesis) (Figure 2 and Equation 1). This allows the user to choose the approximate size of the farm by choosing the appropriate number of raceways. The FIPR volume is set at 65 m^3 based on the volume of prototype raceways in West Alabama. *Volume of Raceway in ft^3* converts metric to English units, thus the bio-economic model can be readily understood by producers.

Equation 1: Number stocked
Number stocked = (Volume of Raceway in m^3)(Stocking Density per m^3)**
(Number of Raceways)

Figure 2. Stella stocking components.



The *Number Stocked* converter controls the inflow of animals to the grow-out reservoir. The week of first stocking is set by *Stocking Week* which can be adjusted by a slider bar. When time in the bio-economic model equals *Stocking Wee*k then *Number Stocked* is added to the FIPR reservoir (Equation 2 and Figure 3). When *Harvest* occurs and the *FIPR Reservoir* empties, restocking occurs after a set *Restocking Delay* period passes (which is controlled by the bio-economic model user). The Restocking Delay simulates the # weeks required for a producer to obtain and restock fingerlings (Equation 3).

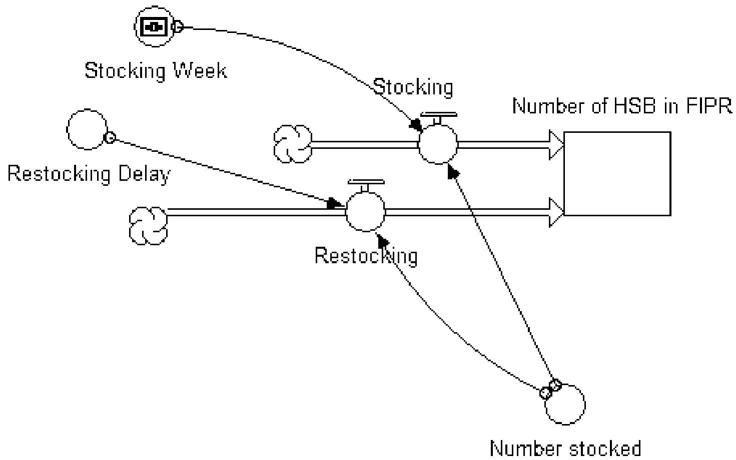
Equation 2: Stocking

If TIME = Stocking Week – 1 OR Stocking Week=0 AND TIME = 0 THEN Number stocked ELSE 0

Equation 3: Restocking

IF TIME < or = Restocking Delay THEN 0 ELSE IF Time= Restocking Delay + Restock Time THEN Number Stocked ELSE 0

Figure 3. Stocking and restocking the HSB reservoir components.



Weekly Growth Rate

Weekly growth is the most important component in the Stella model because it directly or indirectly influences all of the other model components. There are three main model converters that control the HSB growth and they are: *Growth Added to Previous Size*, *Average Weekly Water Temperature* and *Temperature Growth Adjustment.* Although growth rates vary among weeks, depending on water temperature and fish size, all fish within a crop grow at the same rate during any given week. The *Temperature Growth Adjustment* can be switched off by the user with the *Temperature Growth Switch* (Equation 4). The *Growth Added to Previous Size* is a graphical converter that sets the maximum amount of biomass (grams) that can be added to each HSB in the current week based on a converter, *Previous Size Grams,* that was the size of the HSB in the FIPR from the previous week (Figure 4). Essentially, the *Growth Added to Previous Size* converter is the maximum amount of weekly growth that is expected to occur under optimal conditions for any given sized animal.

Optimal water temperature for HSB growth has been determined to be between 23 and 25°C (Hodson, 1989), with growth rates decreasing as temperatures exceed or fall below the optimal temperature range. The *Average Weekly Water Temperature* converter defines the model's weekly water temperatures based on average weekly water temperatures from records for a fixed in-pond raceway system experiment in West Alabama (Figure 5) (Brown, 2010).   . Since fish growth is greatly influenced by water temperature, the Temperature Growth Adjustment converter designates the percentage of realized optimal growth within a temperature range of 9 to 35° C, (Figure 5). When water temperature is optimal, between 23-25° C for HSB, the *Temperature Growth Adjustment* converter produces 1, or 100% of optimal growth. At suboptimal temperatures, the converter produces a value less than one which designates the percentage of maximum growth (*Growth Added to Previous Size*) that will occur at that temperature (Figure 5 and Figure 7).

The *Actual Growth Kg* converter then uses the *Temperature Growth Adjustment* to determine the actual growth to add to each HSB,   For example, water temperatures in June exceed the optimal temperature range for growth. Therefore, if a fish weighs 200 g and water temperature is 30 C, the Actual Growth will be *Growth Added to Previous Size* (18.5 grams) * 85% (Temperature Growth Adjustment) / 1000 (conversion from grams to kg) = 0.016 kg (Figure 4, Figure 5 and Figure 6). The data produced by *Actual Growth* is fed into to the *Biomass added* reservoir flow pipe.   With each weekly time step the *Biomass Added* flow pipe multiplies *Actual Growth* by *Number of HSB in FIPR* to calculate the weekly increase in biomass. The *Biomass in kg* reservoir also has an initial function to account for the initial stocking weight of the fish (Equation 4).

Figure 4. Assumed relationship between maximum weight gained per week and fingerling size.

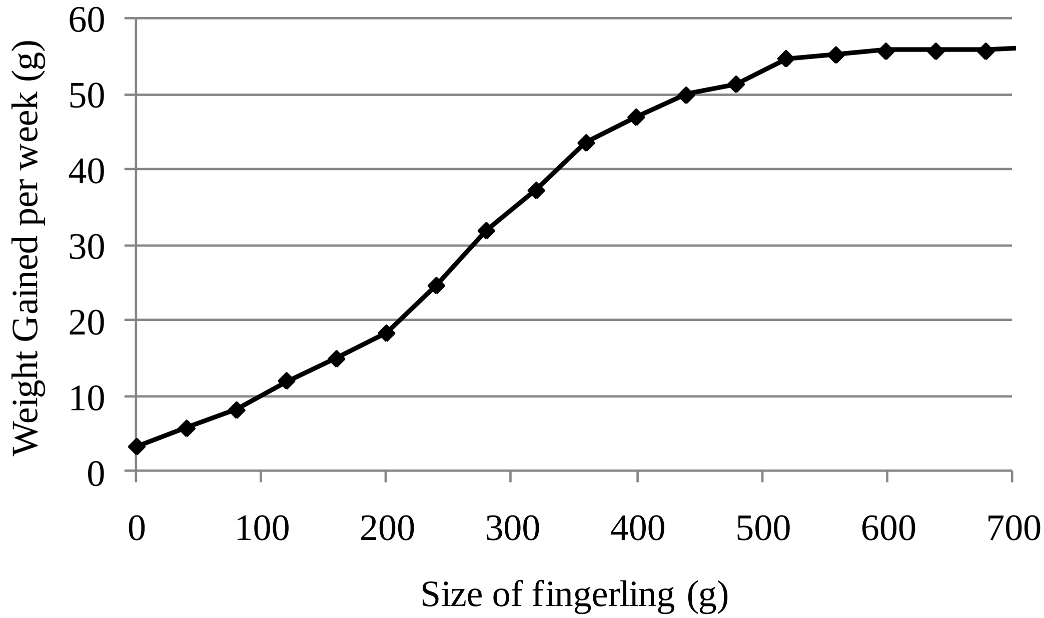


Figure 5. Monthly water temperature and percentage of realized growth.

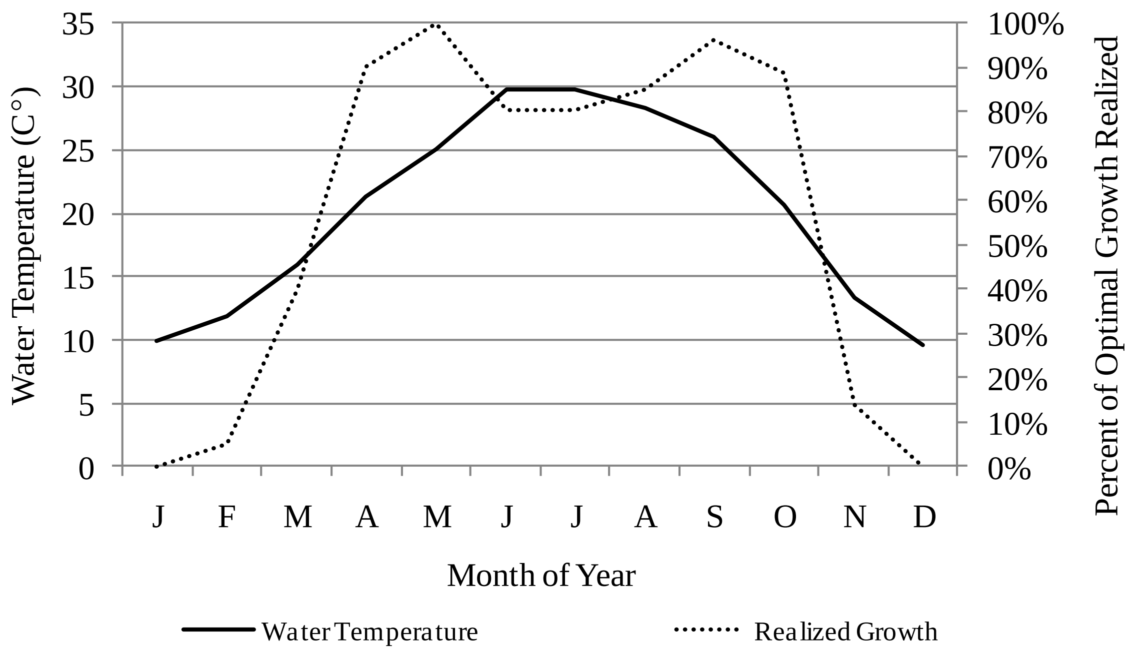


Figure 6. Relationship between water temperature and maximum (or optimal) growth rate.

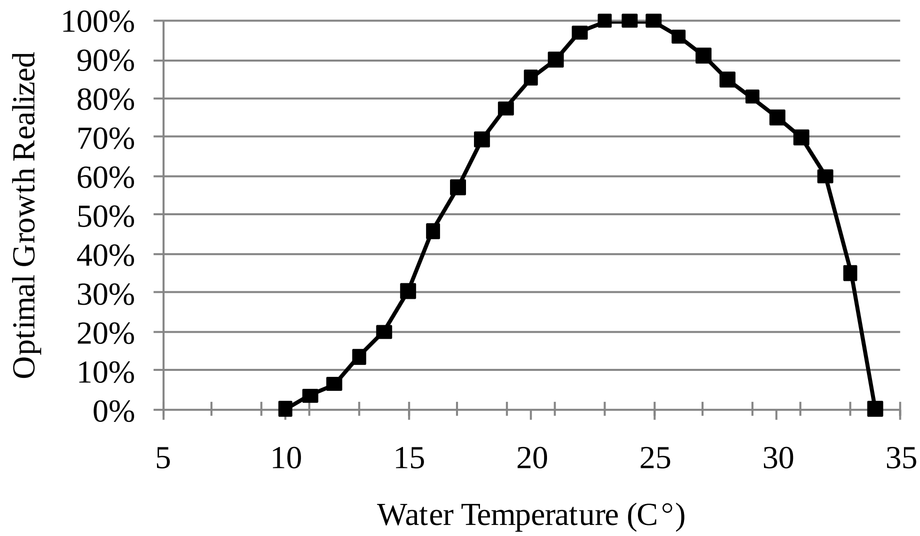
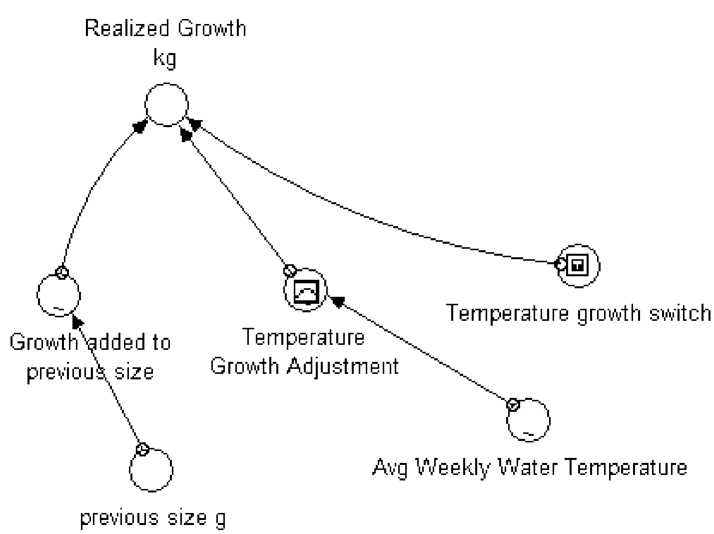


Figure 7. Growth and temperature adjustment component.



Equation 4: Realized Growth.

*IF Batch Biomass in kg > 0 AND Temperature growth switch = 1 THEN Growth added to previous size * Temperature Growth Adjustment/1000 ELSE IF Batch Biomass in kg > 0 THEN Growth added to previous size/1000 ELSE 0*

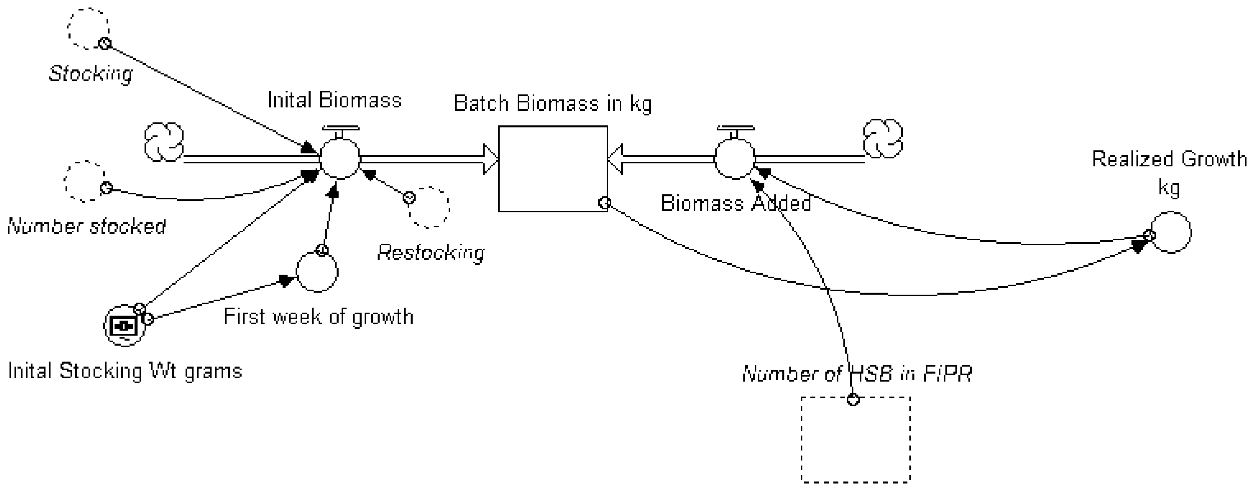
Biomass Production

The biomass components of the Stella bio-economic model determine the production of the FIPR system. The *Initial Biomass* flow pipe delivers biomass into the *Batch Biomass in Kg* reservoir. When *Stocking* or *Restocking* occurs the flow pipe calculates the amount of biomass to insert based on the number of fingerlings stocked and the initial weight of the fingerlings. The user control page has a slider bar where the *Initial Stocking Weight in Grams* can be selected. The initial week's growth is determined by the *First week of growth* converter. After the first week of growth, biomass is continually added based on the growth from the *Realized Growth Kg* converter through the B*iomass Added* flow pipe (Equation 5 and Table 7).

Equation 5: Biomass added.

*IF Number of HSB in FIPR > 0 THEN Actual Growth * Number of HSB in FIPR ELSE 0*

Figure 8. Initial and subsequent biomass production.



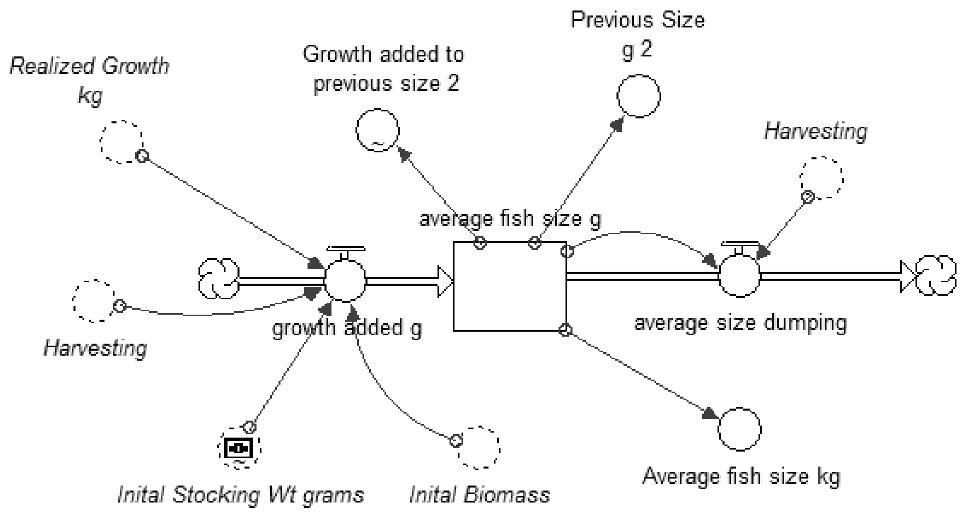
Average Fish Size

The *Average Fish Size g* reservoir accumulates the average realized growth per fish (Equation 6). When a harvest occurs, the *Average Size Dumping* out flow pipe removes the data stored in the reservoir and the process begins again with the next stocking (Figure 9).

Equation 6: Growth added in grams for average fish size.

*IF Initial Biomass > 0 THEN Initial Stocking Wt grams ELSE IF Harvesting > 0 THEN 0 ELSE Realized Growth kg *1000*

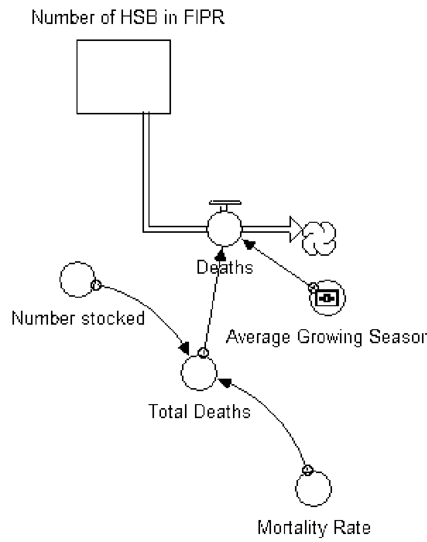
Figure 9. Average fish size component.



Fish Lost to Mortality

The mortality rate for the FIPR system is controlled by the *Mortality Rate* converter. *Mortality Rate* contains a graphical function related to *Stocking Rate.* The *Total Deaths* converter multiplies the *Number of Animals Stocked* by the *Mortality Rate* to calculate the cumulative number of fish that will die and be removed from the system over the course of the grow-out period. Since the literature gives little indication of when HSB mortality is more likely to occur, the bio-economic model distributes mortality evenly across the grow-out period by taking the total deaths and dividing them by the number of weeks in the grow-out of a batch. The user must assign a value for the number of weeks of grow-out using the *Average Growing Season* slider before running the bio-economic model. For example, if 1000 fish are stocked, the grow-out period is 50 weeks long and the mortality rate is 10%, then two fish will be lost per week for a total of 100 fish lost, or 10% of 1000 fish stocked. The *Deaths* flow pipe then removes that number of fish every week from the *Number of HSB* in the FIPR system (Figure 10).

Figure 10. Components of mortality and its relationship to stocking density.



Market Sized Harvest

The Stella bio-economic model automatically harvests the crop from the HSB reservoir when the *Average Fish Size* reaches or exceeds a user selected target weight (0.681 kg) per fish (Figure 11). When the *Average Fish Size* equals or exceeds the target weight, fish are moved from the *Number of HSB in FIPR* reservoir to the *Harvest* reservoir. When a harvest occurs, the *Biomass* reservoir drops to zero to show a harvest event. A similar mechanism is used to show a harvest in the *Batch Biomass* reservoir, when the *Average Fish Size* reaches or exceeds the selected target weight, then the *Batch Reservoir* is emptied by the *Biomass Lost* flow pipe (Figure 12).

Figure 11. Stella harvest of HSB reservoir.

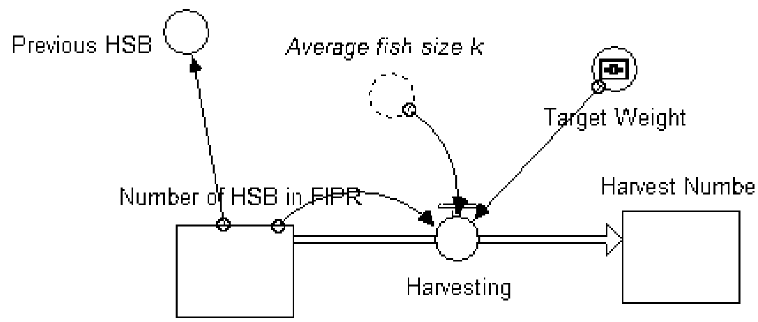
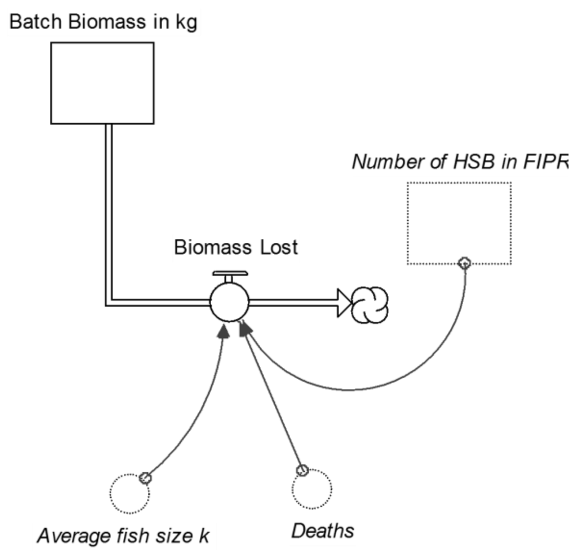


Figure 12. Stella biomass lost component.

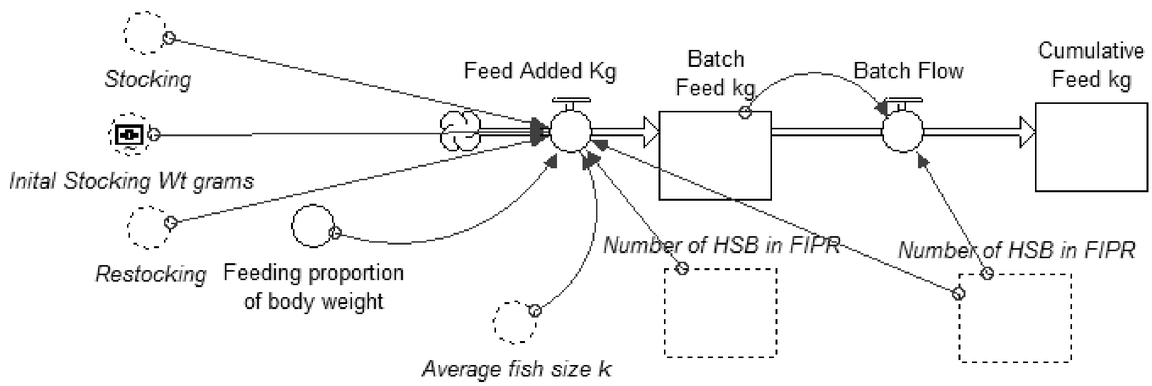


Feed Required

The amount of feed required in a production cycle is calculated based on a daily percentage of body weight, 1.5% per day, and the converter *Temperature Growth Adjustment* which varies the amount of required feed depending on the water temperature in the same manner as before (Figure 13 and Equation 7). Used feed accumulates in a reservoir over the course of the grow-out period. *Feed Required* is only calculated when there are fish in the reservoir and not during the restocking delay period (Equation 7).

Equation 7: Feed required
Feed Required = IF Number of HSB in FIPR = 0 THEN 0 ELSE IF time = 0 THEN Initial Stocking Wt grams/1000 ELSE Biomass in kg/Number of HSB in FIPR

Figure 13 Stella cumulative feed required



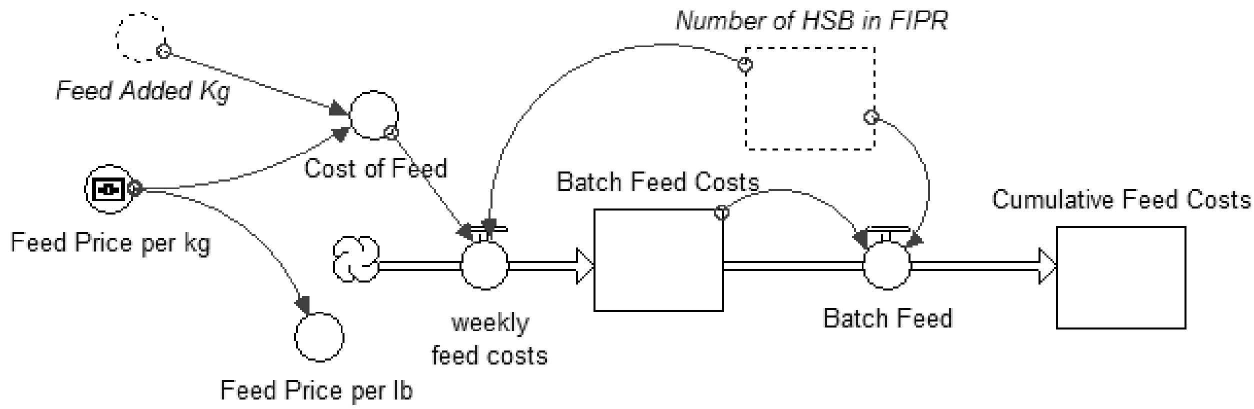
Feed Costs

Feed costs are calculated for each individual crop and accumulated for multiple crops over time. The *Feed Price per Kg* is selected manually in the interface menu (Equation 8). The *Cost of Feed* converter functions as the equation for the *Weekly Feed* in-flow pipe (Equation 13). *Batch Feed Costs* are not calculated during the restocking delay period (Figure 14).

Equation 8: Cost of feed

*Cost of Feed = Feed Price per Kg * Feed Required.*

Figure 14. Feed cost component.



Fingerling Costs

The price for each fingerling is automatically adjusted for size categories as the user selects the fingerling size to stock. Each fingerling size in inches corresponds to weight in grams which corresponds to a specific fingerling price. There is a *Crop Fingerling Costs* reservoir to track the cost of fingerlings for each stocking event and a cumulative reservoir, *CF Costs,* to accumulate all fingerling costs across multiple crops (Figure 15). Fingerling costs are calculated only at stocking or restocking. Fingerlings are purchased from off-farm commercial hatcheries and therefore there is a fixed shipping cost that is also calculated in this section and added into the total costs of production.

Equation 9: Total cost of fingerlings:

Total Cost of Fingerlings = If Number stocked = Stocking OR Number stocked = Restocking THEN Total Cost of Fingerlings ELSE 0

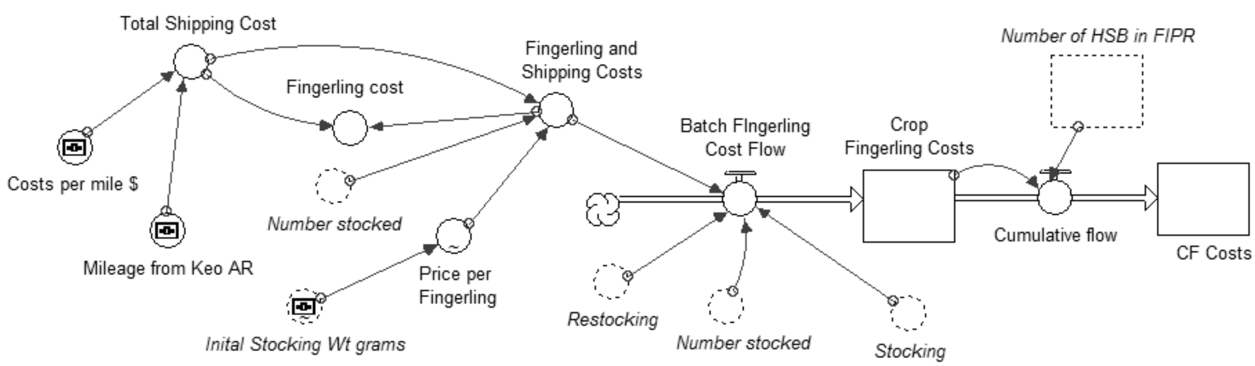
Equation 10: Fingerling cost

Fingerling Cost = If time = 0 then Total Cost of Fingerlings else 0

Equation 11: Fingerling shipping cost

*Total Shipping Cost = Mileage from Keo AR * Costs per mile $*

Figure 15. Fingerling costs component.



Electricity Costs

Electricity costs are estimated based on the number of raceways, the size of the pump and the price of electricity per kilowatt hour. Each raceway uses a 1.5 horsepower airlift pump which runs 24 hours a day. By estimating the number of kilowatt hours the airlift pump uses per week, the electricity usage can be calculated (Equation 12). Electricity costs per kilowatt hour (kWh) can vary, so that parameter is adjustable with a slider bar. Electricity costs accumulate and are stored a reservoir (Figure 16). Electricity costs are only calculated during grow-out and not during the restocking delay period. Both batch and cumulative electricity costs are calculated.

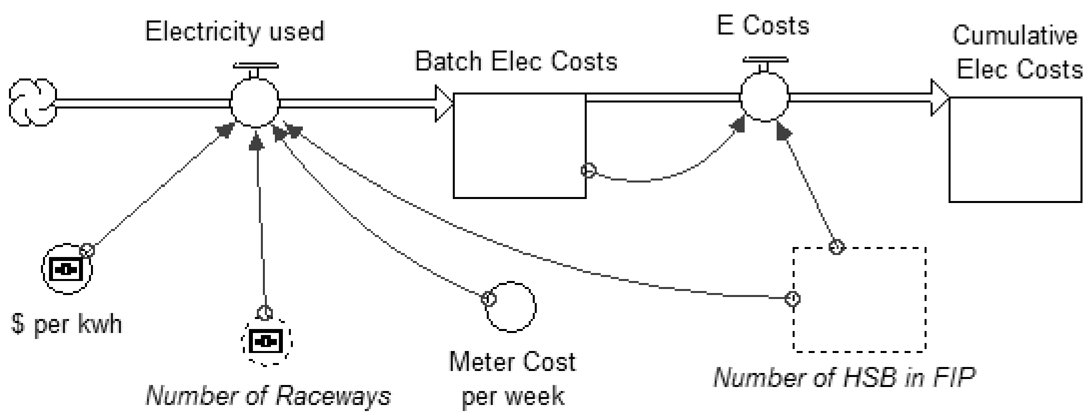
Equation 12: Electricity used

*Electricity Used = Number of raceways * Cost of Electricity per kWh* 188 kWh.*

1 HP = .746 kilowatts

*1.5 HP Motor * .746 kilowatts * 24 hrs. a day * 7 days = 188 kWh/week per motor*

Figure 16. Electricity cost component.



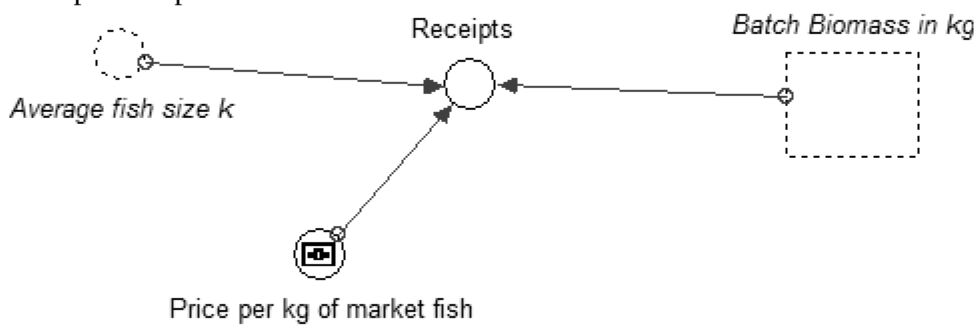
Receipts at Harvest

Receipts are the funds received from the sales of the HSB harvested. When the HSB reach market size the *Receipts* converter multiplies the kilograms of biomass in the biomass reservoir to the predetermined price per kg of fish (Figure 17 and Equation 13). Because of the constraints of the *Receipts* converter, the crop only has worth when the HSB reach a size of ≥ 0.680 kg (1.5 lb).

Equation 13. Receipts calculation.

*IF Average fish size kg > .680 OR Average fish size kg = .680 THEN Batch Biomass in kg * Price per kg of market fish ELSE 0.*

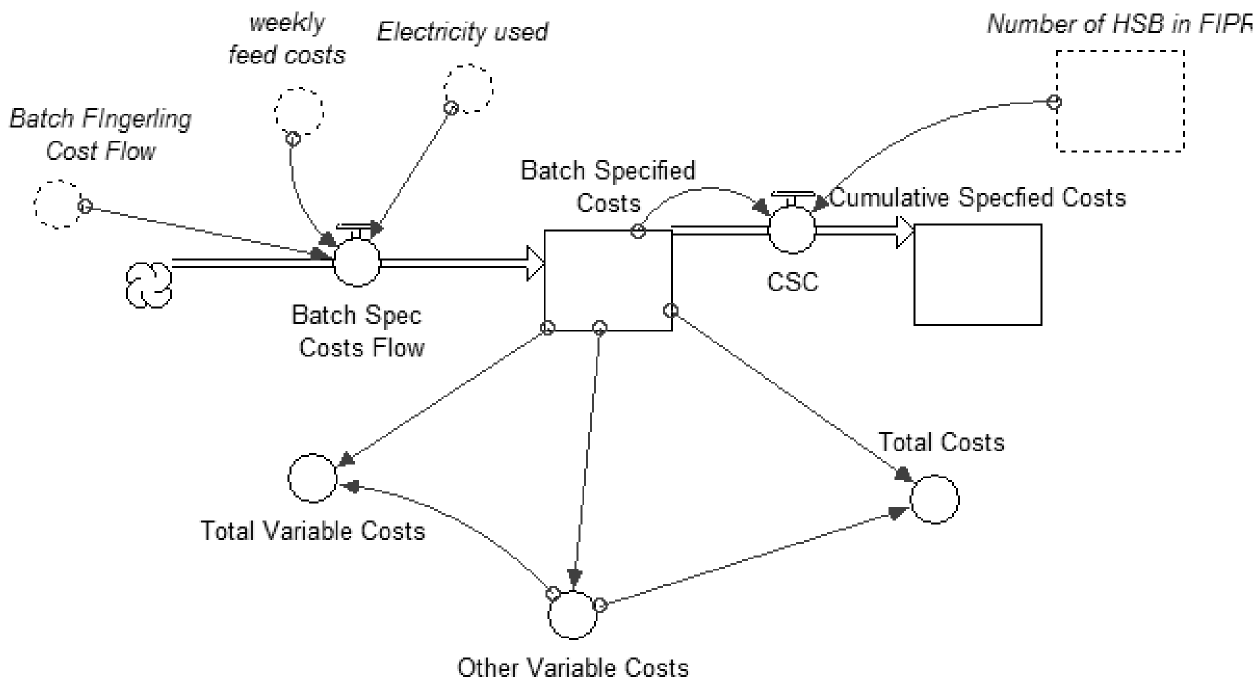
Figure 17. Receipts component.



Costs and Net Return

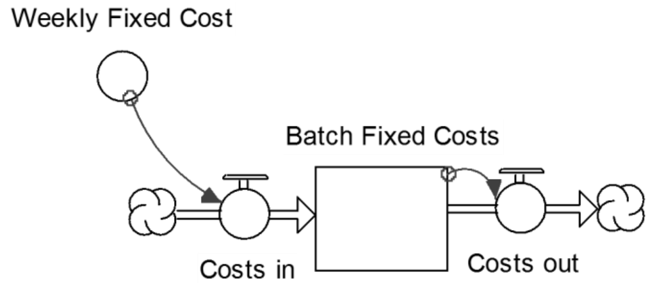
Three specified variable costs are calculated by the bio-economic model based on the assumptions made for each run: feed, fingerlings and electricity, as already discussed. These costs are stored together in the reservoir called, *Batch Specified Costs* and accumulated over time in *Cumulative Specified Costs.* Additional variable costs for elements not specifically described in the model, such as chemicals, fuel, labor, maintenance, etc., are calculated based on economic analyses of hybrid striped bass production (D'Abramo et al., 2002 and D'Abramo and Frinkso, 2008). Their studies indicated that the additional variable costs were approximately 43% of the total variable costs. The converter, *Other Variable Costs* multiplies the accumulated *Batch Specified Costs* by 3/7. *Total Variable Costs* sums the *Batch Specified Costs* and the *Other Variable Costs*.

Figure 18. Stella cost components.



Fixed costs are typically accessed on a yearly basis, but since some HSB FIPR crops require more than a year to reach harvest size and since the bio-economic model calculates on a weekly time step, the fixed costs are charged weekly at a rate of $81 per month. See the detailed depreciation schedule (Table 1 and Table 2). A reservoir is used, *Batch Fixed Cost*, to accumulate fixed cost over the grow-out period. When harvest occurs, *Batch Fixed Cost* empties and the process begins again (Figure 19).

Figure 19. Stella fixed cost component.



Total costs are calculated in the *Total Costs* converter where *Batch Specified Costs* and *Batch Fixed Costs* are added together. The *Net Return* component is a converter which takes the value produced from *Receipts* and subtracts *Total Costs* to calculate profits made above all costs (Figure 20).

Figure 20. Stella receipts, total costs and net return components.

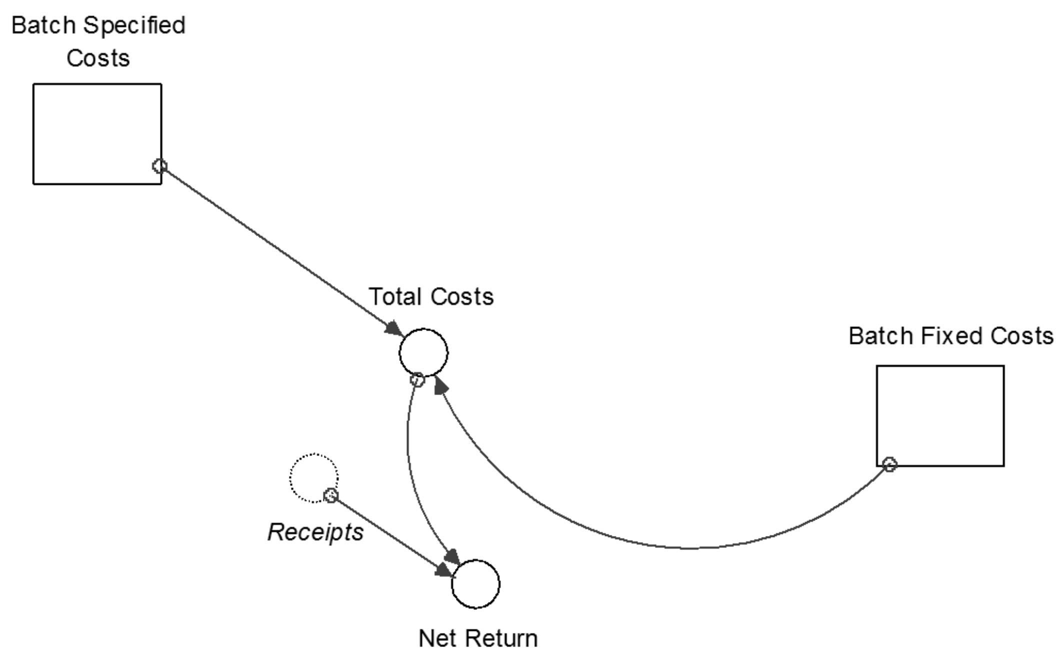


Table 1. Depreciation schedule for HSB FIPR system land, equipment, and machinery investments required for one 3.2 ha (8 acre) pond in West Alabama.

Item	Unit	Cost/unit	Number	Percent Use in FIPR	Cost	Useful Life, Years	Salvage Value	Annual Depreciation	Interest on Investment	Repairs as a % of new cost (%)	Annual repairs & maintenance ($)
A. Capital cost											
Land	ha	750	3.9		NA						
Pond construction	ha	2,471	3.2	100%	8,000	15	1,000	467	450	10	53
Gravel		667	1	100%	667		0		33		
Well (450 gpm, 25-hp electric motor)		25,000	1	20%	5,000	20	100	245	255	25	63
OFFICE BUILDING 20' x 40'	sq ft	40	800	5%	1,600	20	50	78	83	10	8
Shop	ea	30,000	1	5%	1,500	20	250	63	88	10	8
Shop tools and equipment	ea	5,000	1	5%	250	10	25	23	14	10	3
Subtotal (excluding land)					**17,017**		**1,425**	**874**	**922**		**134**
B. Equipment											
Floating In-Pond Raceway (incl. Airlift pump)	ea	20,000	1	100%	20,000	10	2,500	1,750	1,125	10	200
Harvest Net	ea	500	1	100%	500	5	0	100	25	10	10
Dock, floating	ea	800	1	100%	800	8	0	100	40	5	5
Trucks, 3/4 ton, used	ea	16,000	1	10%	1,600	6	250	225	93	6	16
Tractors, 45-65 hp, used	ea	20,000	1	10%	2,000	6	250	292	113	10	33
Boom attachment for harvesting	ea	10,000	1	10%	1,000	7	5	142	50	11	16
PTO aerators, emergency aeration	ea	3,500	1	17%	583	10	25	56	30	10	6
Electric aerators, 10 hp	ea	3,500	1	100%	3,500	5	500	600	200	10	70
Bush hog/mower	ea	4,500	1	5%	225	5	75	30	15	20	9
Feed bin not used because bags only	ea	5,000	1	0%	0	20	0	0	0	10	0
DO meter and accessories	ea	2,000	1	10%	200	10	0	20	10	50	10
Computer	ea	1,500	1	5%	75	5	0	15	4	10	2
Subtotal					**30,483**		**3,605**	**3,330**	**1,704**		**376**
TOTAL					**47,500**		**5,030**	**4,204**	**2,627**		**510**

Table 2. Annual fixed costs (interest payments and depreciation).

Loan Repayment for Capital Items	Cost	Useful Life (Years)	Salvage Value ($)	
Cumulative interest =	22,959	20	**1,148**	
Cumulative principal pmt=	17,017	20	**851**	
Average annual P&I =			**1,999**	
Loan Repayment for Equipment				
Cumulative interest =	13,347	7	**1,907**	
Cumulative principal pymt=	30,483	7	**4,355**	
Total 1st yr P&I =			**6,261**	
Interest and Depreciation			**Annual Depreciation**	
Annual Interest payment =			**3,055**	for 300 surface acres
Depreciation for Year 1 =			**4,204**	per acre
Depreciation + Interest for Year 1 =			**7,258**	per ha
			24	per 4.047 ha (10 acres)
			60	
			242	

Results

The results portion is separated into four sections, each pertaining to an individual objective. Each section includes the specific methods, results and a discussion pertaining to the particular objective. A summary of all four objectives follows the results portion.

Objective 1

Determine the importance of knowing the shape of a density dependent mortality curve relating cumulative mortality to initial stocking density.

Hypotheses:

1) Production and net return patterns will differ between the fixed, linear and exponential mortality curves even when cumulative mortality at the lowest and highest stocking densities is held constant.
2) Maximum net returns will not always correspond to maximum production.

Objective 1 Methods

A bio-economic model was developed to assess the relationship between stocking density, final production, and net returns. From the literature, the expected cumulative mortality for pond systems producing HSB ranges from 0-25%, i.e. 0-25% of fish stocked will be lost to one of many potential perils, including disease, water quality, cannibalism, bird predation, etc. during a crop's production cycle (D'Abramo et. al., 1994; Kelly and Kohler, 1996; Kemeh and Brown, 2001). It was assumed that FIPR systems would have a relatively low cumulative mortality rate due to increased control over water quality, fish inventory and feeding compared to pond systems. Therefore, the baseline cumulative mortality was set at 10% (i.e. 10% of stocked HSB die over the course of a production run).

At some point, an increase in the stocking density of a FIPR system will increase the cumulative mortality above 10% due to crowding and carrying capacity limitation of the raceway environment. However, the relationship between cumulative mortality and stocking density has not been empirically determined for FIPRs. This objective uses the Stella program to biologically and economically evaluate whether changing the shape of the density dependent mortality curve results in significant differences in production and net receipts.

One density independent (fixed) and two density dependent (linear, exponential) mortality curve components were added to the bio-economic model and used to simulate the relationship between cumulative mortality and stocking density (Figure 21). Each mortality curve component in the bio-economic model can be turned on (and the others turned off) with a special switch function located on the bio-economic model user interface page. Each switch causes the specified percentage of stocked fish to be removed (i.e. die) from the HSB reservoir over the course of a grow-out period based on the type of mortality curve switch that was switched on. The density independent curve was held constant at 10% cumulative mortality across all stocking densities (Figure 22 and Table 4). The density dependent curves each yielded a 10% cumulative mortality at the lowest stocking density (300 fish / m3) and a 50% cumulative mortality at the highest stocking density (700 fish / m3). However, they differed in the trajectory between the lowest and highest mortality rates (Figure 22 and Table 4).

Since there was no prior research found that indicated when during a grow-out period mortality actually occurred, fish, were removed weekly as a function of grow-out period length and assumed total mortality. For example, if total mortality was 10% and the length of grow-out period was 40 weeks, then 0.25% (10% ⁄ 40 weeks) of the total number of fingerlings stocked was removed each week. Thus, weekly mortality added up to the desired cumulative mortality at the end of the production season.

When discussing a bio-economic model it is important to define the parameter values and assumptions as their control and influence plays an important role in determining the outcome of the simulation. Parameters held constant in the Stella bio-economic model for this experiment can be found in Table 3. Under these bio-economic model parameters fingerlings grew to the final harvest size in 36 weeks. See general methods section for detailed description of other bio-economic model assumptions, including the bio-economic model growth components (Figure 4 and Figure 6). The number of HSB stocked in the FIPR for each stocking density and the cost to stock are in Table 5.

Table 3. Bio-economic parameters for Objective 1.

Parameter	Value
FIPR Water Volume	65 m^3
Stocking date	1-Feb
Initial fingerling weight	63 g
Initial fingerling length	17.9 cm
Fingerling price	$0.70
Harvest size	681 g
Market price	$7.16/kg
Feed price	$1.00/kg
Electricity cost	$0.07/kWh
Fixed costs	$81/week
Variable costs	3/7 of specified costs

The bio-economic model generated data for each of three mortality curves at five stocking densities for one grow out period (initial stocking to market size) per model run (15 total runs). Data resulting from each run included biomass produced, variable costs of production, fixed costs, receipts and net returns (receipts minus variable and fixed costs). Cumulative production and net returns were compared between mortality curves. Receipts, variable costs and fixed costs were compiled into detailed enterprise budgets (Appendix Table 21 through Table 25).

Figure 21. Basic Stella model components including three mortality curve choices.

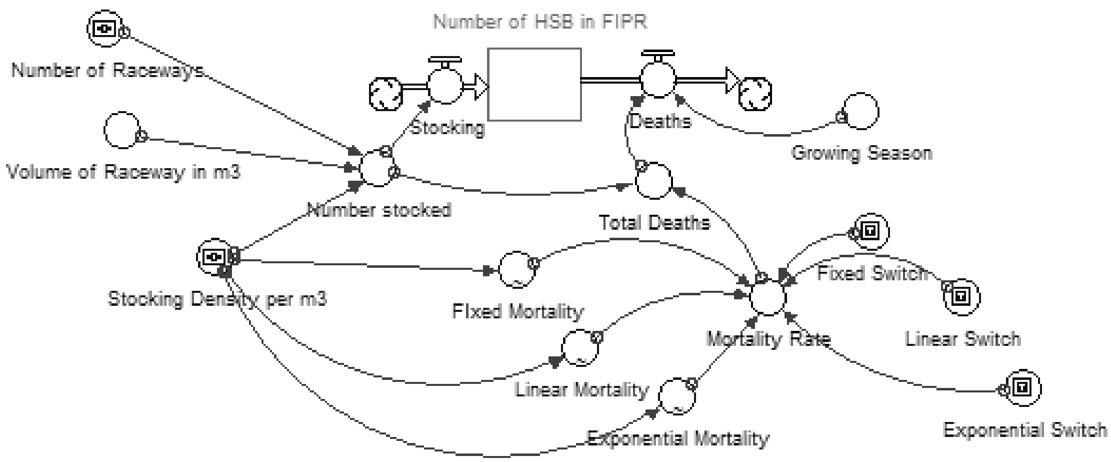


Table 4. Cumulative mortalities for each mortality curve and stocking density.

Stocking density (fish/m3)	Mortality Curve: Fixed	Linear	Exponential
300	10%	10%	10%
400	10%	20%	15%
500	10%	30%	22%
600	10%	40%	33%
700	10%	50%	50%

Figure 22. Relationship between cumulative mortality and stocking density under density independent and density dependent scenarios.

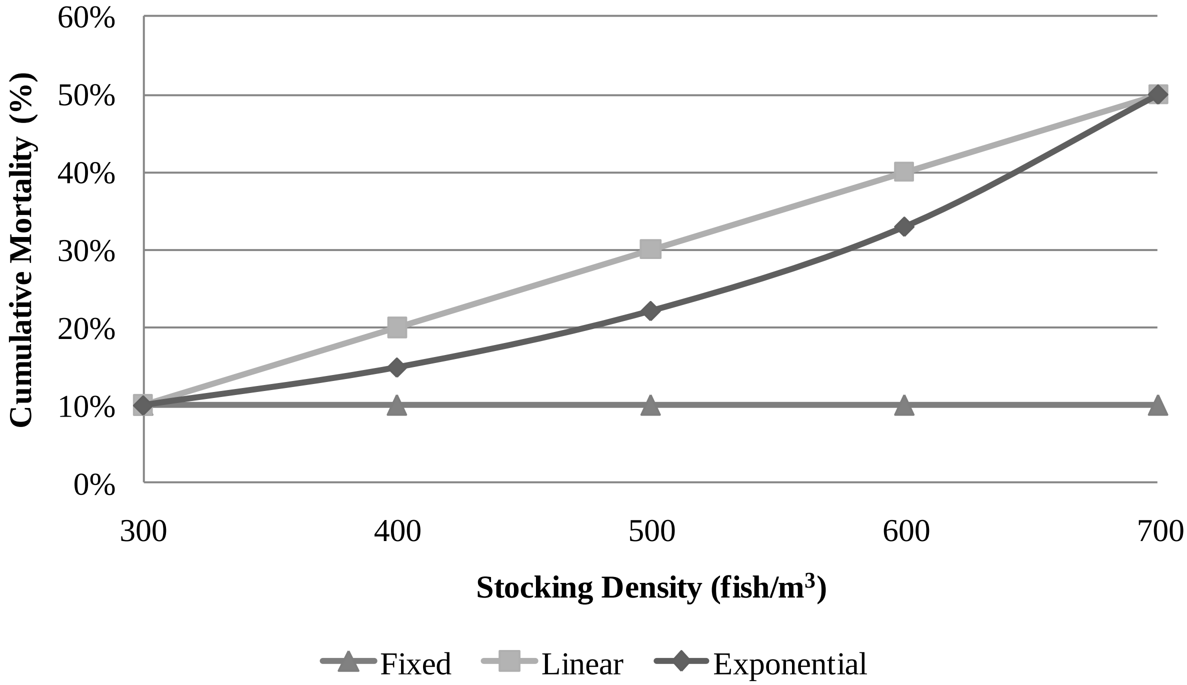


Table 5. Hybrid striped bass stocking density, total number of fish stocked and total fingerling cost per FIPR raceway system.

Stocking density (fish/m3)	Number of Fish stocked	Price for Fingerlings ($)
300	19,500	$13,650
400	26,000	$18,200
500	32,500	$22,750
600	39,000	$27,300
700	45,500	$31,850

Objective 1 Results

Final biomass produced for each mortality curve and stocking density combination is shown in Figure 23 and Table 6. Final biomass was highest when the fixed mortality curve was applied and increased linearly with increasing stocking density (Figure 23 and Table 6). Final biomass also increased with increasing stocking density when the linear mortality curve was applied, but the rate of increase slowed at higher stocking densities. When the exponential mortality curve was applied, final biomass increased as stocking density increased from 300 to 600 fish / m3, but subsequently decreased as stocking density increased further to 700 fish / m3.

Net returns for each mortality curve and stocking density combination are presented in Figure 24 and Table 6). The fixed mortality curve yielded the highest net returns overall, with net returns increasing linearly as stocking density increased (Figure 24 and Table 6). The linear and exponential mortality curves yielded increasing net returns from 300 to 500 fish/m^3 but decreasing net returns as stocking density increased further to 700 fish/m^3 (Figure 24 and Table 6). Total costs increased with stocking density for all mortality curves. Variable costs, fixed costs and total costs for each stocking density and mortality curve are summarized in Table 7. Detailed enterprise budgets for each stocking density and mortality curve combination are provided in Table 21 through Table 25 in the appendix.

Figure 23. Relationship between stocking density and final biomass for three mortality curves.

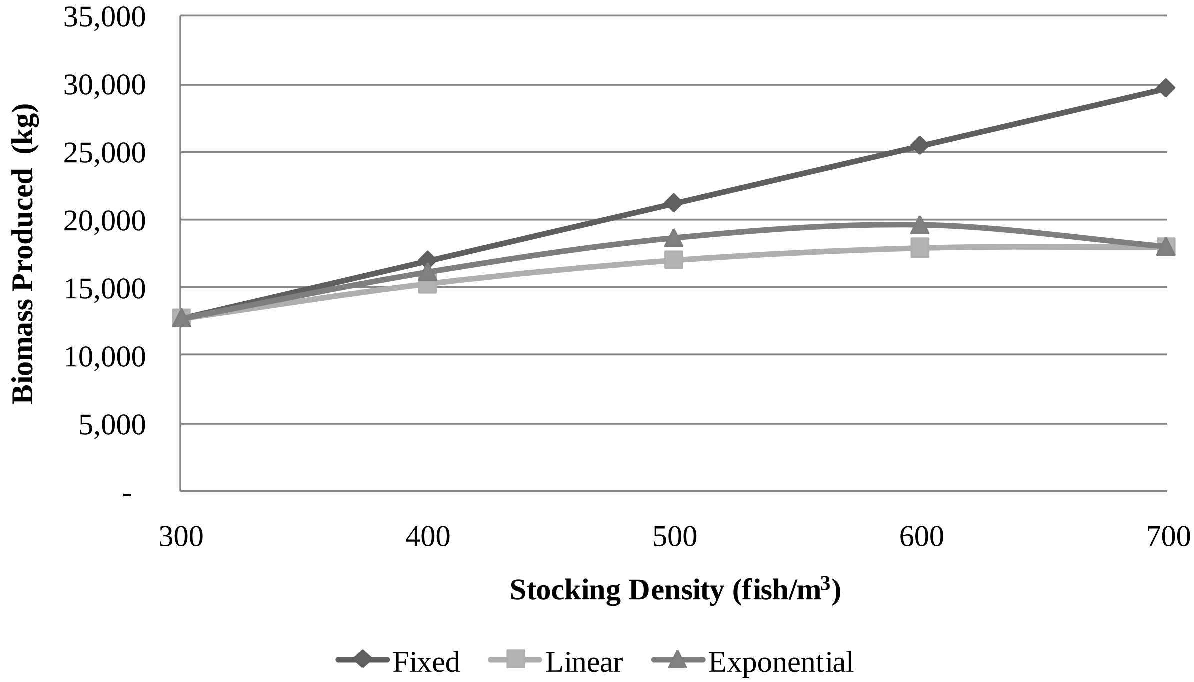


Table 6. Comparison of harvested biomass and net returns for each mortality curve and stocking density.

	Fixed		Linear		Exponential	
Fish/m3	Biomass (kg)	Net Return ($)	Biomass (kg)	Net Return ($)	Biomass (kg)	Net Return ($)
300	12,726	42,111	12,726	42,111	12,725	42,111
400	16,968	58,112	15,301	48,309	16,147	53,285
500	21,210	74,113	17,043	49,605	18,667	59,155
600	25,452	90,114	17,951	45,999	19,634	55,892
700	29,694	106,115	18,026	37,491	18,026	37,491

Figure 24. Relationship between stocking density and net returns for three mortality curves.

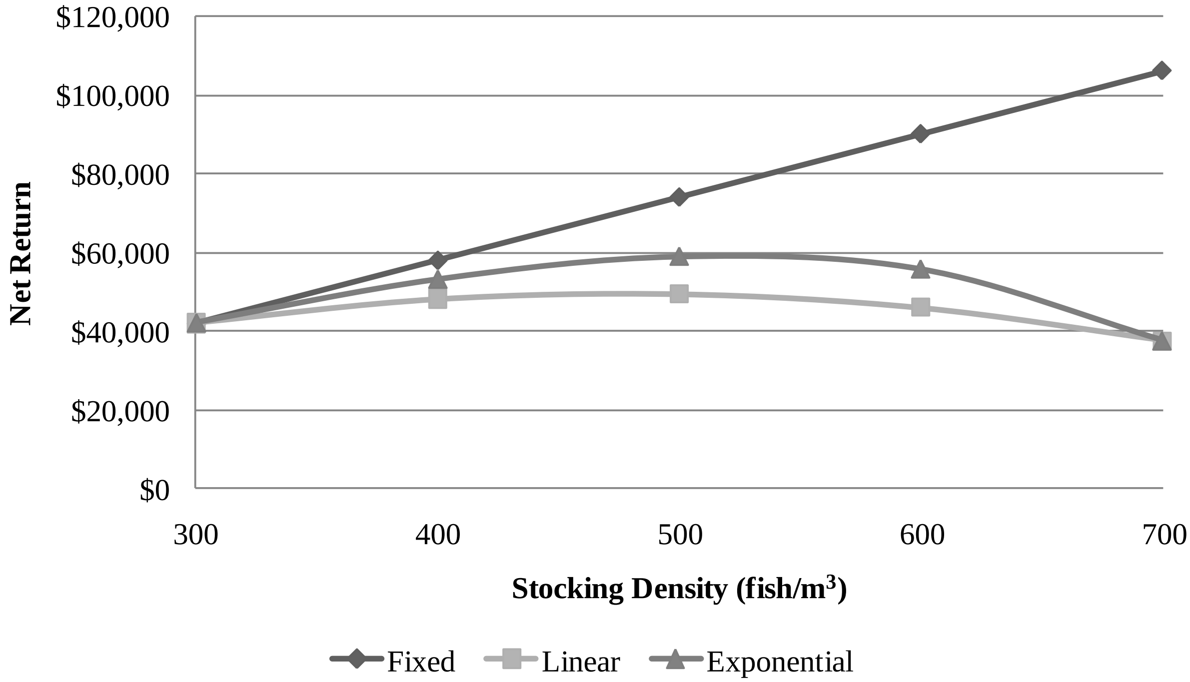


Table 7. Comparison of costs for each mortality curve.

	Variable Costs ($)			Fixed Costs ($)			Total Costs ($)		
Fish/m^3	Fixed	Linear	Exponential	Fixed	Linear	Exponential	Fixed	Linear	Exponential
300	45,136	45,136	45,136	3,872	3,872	3,872	49,008	49,008	49,008
400	59,508	57,377	58,458	3,872	3,872	3,872	63,380	61,249	62,330
500	73,880	68,552	70,628	3,872	3,872	3,872	77,752	72,424	74,500
600	88,251	78,662	80,813	3,872	3,872	3,872	92,124	82,534	84,685
700	102,623	87,706	87,706	3,872	3,872	3,872	106,496	91,579	91,579

Objective 1 Discussion

The relationship between stocking density and mortality curve type had important impacts on production and profitability. In the case of the fixed mortality curve, which is independent of stocking density, production and net returns increased as stocking rate increased indicating an optimal stocking density at 700 fish/m^3 (Table 6). Although this mortality curve would be ideal for producers, it is the least realistic of the three curve types because it implies that higher stocking rates have no effect on mortality in FIPR systems. The designer of the prototype FIPR system suggested that stocking densities higher than 500 fish/m^3 would produce a higher stress environment for HSB than lower stocking densities because of potentially lower water quality conditions and ultimately could result in a lower survival rate (Chappell, 2010). However, we do not know the exact stocking density in which density dependent mortality will begin to effect production and profitability. Increasing stocking density will eventually cause production and net returns to experience diminishing marginal returns; in other words production and net returns will increase as stocking density increases but at a decreasing rate until density dependent mortality effects actually reduce net return and profitability.

For the density-dependent linear mortality curve, biomass increased as stocking density increased but at decreasing rate (Figure 23). For example, when the stocking density was increased from 300 fish/m^3 to 400 fish/m^3 the biomass produced increased by 2,575 kg. But when the stocking density was increased from 600 fish/m^3 to 700 fish/m^3 the biomass produced increased by only 75 kg (Figure 23 and Table 6). Adding 100 kilograms of additional fingerlings does not guarantee >2,000 kilograms of increased production. The gain in production decreases with increasing stocking density. The decreasing rate of biomass production is due to the increasing mortality rate (Table 4). For the density-dependent exponential mortality curve, biomass did not always increase with increasing stocking density. Biomass production peaked at a stocking density of 600 fish/m^3 and then decreased at the 700 fish/m^3 stocking density. The biomass produced at the highest stocking density was the same for both the linear and exponential mortality curves because the mortality rate was set to 50% for both curves at 700 fish/m3.

The stocking density that maximized net return at harvest for both the linear and exponential mortality curves was 500 fish/m^3 (Figure 24 and Table 6). At stocking densities beyond 500 fish/m^3, the increased mortality rates greatly reduced receipts at harvest. The reduction in receipts was not matched with reductions in overall production costs (Appendix Table 21 through Table 25. In brief, the marginal costs of greater production inputs were greater than the marginal returns at the 600 and 700 fish/m^3 stocking rates. Although both the linear and exponential curves had maximized net returns at a stocking density of 500 fish/m^3 it should be noted that their net return values were different; the exponential curve had net returns approximately $10,000 more than the linear curve. This detail emphasizes the impact that the shape of the mortality curve can have on these FIPR systems, and how important it is to understand these curves.

Increased production did not always indicate increased net return for density dependent cumulative mortality curves. Large fish that died late in the production cycle had consumed a considerable quantity of feed and thus added considerable cost to the crop, but did not produce any sales receipts, only production costs. This explains why net returns began to decrease while biomass continued to increase from stocking 500 and 600 fish/m^3. When the stocking density of 700 fish/m^3 was modeled, both production and net returns decreased because the mortality rate was 50%.

Higher total costs for higher stocking densities are seen in Table 7 for all three mortality curves. As stocking density increased, variable costs increased mainly in the form of feed costs (Appendix Table 24 and Table 25). For the fixed mortality curve, the increase in stocking density and therefore feed costs was accompanied by increased receipts (Table 7) and increased net returns. For example, at a stocking density of 700 fish/m^3 and a fixed mortality curve, feed costs totaled \$37,574 and receipts were \$212,611 (Appendix Table 25). The net return above total costs was \$106,115. The ratio of receipts to feed costs was 5.63 (212,611 / 37,754). In other words, for every dollar spent on feed, \$5.63 was produced as receipts. This was not the case with the linear and exponential mortality curves. The ratio of feed costs to receipts for a stocking density of 700 fish/m^3 for linear and exponential mortality curves was 4.73. The extra feed cost did not produce the same ratio of receipts. The increased feed costs were not matched by the same increase in receipts and therefore, profitability was lower.

The results of this objective demonstrate that future field research is needed to determine which mortality curve best characterizes HSB in a FIPR systems across a realistic range in stocking densities. Data from field experiments could be used to adjust the Stella bio-economic model parameters to be more realistic and better suited as a tool for making production decisions. First, a field trial would need to establish the stocking density at which mortality begins to increase. For example, if mortality does not increase above 10% until fish are stocked at or above 700 fish/m^3 then the fixed mortality rate curve would be most accurate. But if density dependence kicked in at 300 fish/m3 and the linear mortality curve turned out to be accurate, then 500 fish/m^3 would be the optimal choice to maximize net returns, Figure 24. Field research needs to be conducted to give us a better understanding of when losses occur, i.e. what mortality curve best fits successively higher stocking rates. To determine this we would need to conduct field trial experiments at stocking densities used in this objective and measure cumulative mortality at each. With resulting production and mortality data we would be able to fit a density dependent mortality curve type to empirical data for each stocking density and incorporate these results into the developed bio-economic model.

Another area of future research might be to look at a different relationship altogether; one that relates stocking density to growth rate. In this analysis, the fish grew at the same rate at each stocking density and only mortality was increased or decreased. Instead of only analyzing the effect that stocking density has on mortality in this FIPR system, another study might consider the effect of stocking density on growth rate and, therefore, overall production and profitability. If field studies show that mortality is less affected than growth rate when increasing stocking densities in these systems, then management strategies for maximizing production and profitability may be quite different. It might be possible to obtain data on both objectives in one well run research and field trial effort.

Objective 2

Evaluate the effect on production and net returns of reducing the magnitude of catastrophic losses from 50% to 10% by purchasing risk mitigation equipment.

Hypotheses:

1) Decreasing magnitude of stochastic events from 50% to 10% will greatly improve production and net return and increase the chance of positive net returns.
2) Crops with loss events occurring later in the grow-out period will experience lower net returns due to higher accumulated variable costs, than crops with loss events occurring earlier in the grow-out period.

Objective 2 Methods

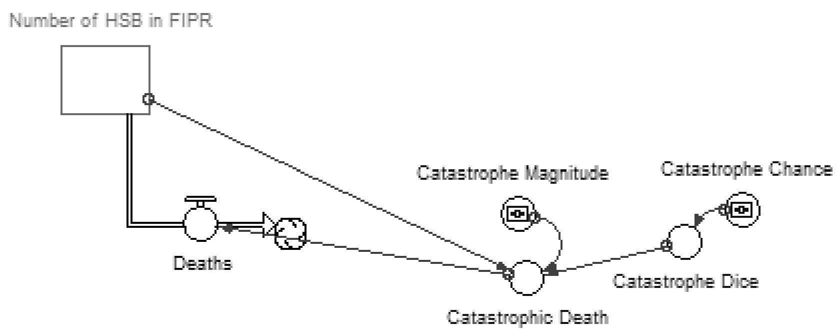
In this bio-economic modeling process, risk for FIPR system production is expressed in terms of fish lost through stochastic disaster events. Loss events are composed of two parts: 1) the frequency or probability of one or more loss events occurring; and 2) the magnitude of loss during each loss event. As the frequency and magnitude of stochastic loss events increase, it is expected that the average net return should decrease. For this objective, a bio-economic model component was developed to examine the effects of frequency and magnitude of unexpected loss events, i.e., beyond "natural" losses, on total production and net returns.

A review of the literature found no data for expected levels of risk or catastrophic loss for HSB FIPR systems. The prototype FIPR system in West Alabama experienced a high loss event due to unknown causes in one of its first field trial runs which prompted this portion of the bio-economic model to be developed. Generally, in fish production systems, there are many potential risk factors that can cause stochastic mortality events such as electrical outages, disease events, weather events and poor water quality. Densely stocked systems, such as in FIPR systems, require higher levels of management oversight to assure water quality is maintained and disease outbreaks are treated efficiently. Understanding potential risk factors and their effect on net return in FIPR systems is essential in assessing their economic feasibility. This objective does not focus on a specific cause of loss, but instead examines a range of risk factor values for a FIPR system,

The risk factors utilized in this objective were four different frequency of loss values, (40%, 20%, 10% and 1% chance of a loss event occurring during a grow-out period) and two different magnitudes of stochastic catastrophic events (50% and 10% loss of fish) (Table 8). Four frequency of loss values were chosen for this objective because a typical value for FIPR systems is unknown and also because expert opinion suggests that with time and experience, managers can often reduce risk in fish production systems. The 50% magnitude of loss scenarios represented a high loss event whereas the 10% scenarios represented a lower loss event for comparison. A total of eight scenarios were examined.

To assess these risk factor effects in FIPR systems, a stochastic component was added to the Stella bio-economic model to randomly initiate loss events. A Monte Carlo function that randomly produced a one or a zero to create a converter called *Catastrophe Dice* (Figure 25) was utilized. The *Catastrophe Chance* converter, linked to a slider bar on the user control page, allows the user to select the percent chance that a value of one, rather than zero, will be generated by the *Catastrophe Dice*, Figure 25. When *Catastrophe Dice* produces a one rather than a zero a catastrophic loss is initiated. The percent of fish lost during a catastrophic event is controlled by the *Catastrophe Magnitude* converter. *Catastrophic Death* multiplies the number of fish currently in the raceway by the percent loss (*Catastrophic Magnitude)* and adds the result to the death outflow (Figure 25).

Figure 25. Stella catastrophe components



Because the bio-economic model component used for this objective was stochastic, rather than deterministic, the model was run 500 times for the eight scenarios and net returns at harvest was calculated each time. The net return values from the 50% loss scenarios were either very high or very low rather than being normally distributed because any crop where a loss event occurred had a substantial loss in net returns. Crops with no loss event had a high uniform net return value. Therefore the average and standard deviation of the positive net return values and the average and standard deviation of the negative net return values were calculated separately for each scenario. Receipts, variable costs and fixed costs were compiled into detailed enterprise budgets for marginal analysis.

Table 8. Catastrophic loss variables for a 36 week grow out period.

% Chance of Disaster per grow out period	% Chance of Disaster per week	% Loss Occurring
40%	1.11%	50% or 10%
20%	0.56%	50% or 10%
10%	0.28%	50% or 10%
1%	0.03%	50% or 10%

Several parameters were held constant in the bio-economic model for this objective (Table 9.). Optimal growth occurred at water temperatures between 23-25°C and no growth occurred below 11°C or above 34°C (See Figure 4 and Figure 6 in general methods). Additional variable and fixed costs were added based on similar cost items for a 1.4 ha pond (see general methods for more detail). The crop was harvested when the average fish size reached or exceeded 0.681 kg (D'Abramo et. al., 2008). The bio-economic model parameters resulted in grow-out duration of 36 weeks from initial stocking to harvest at market size.

Table 9. Bio-economic parameters for Objective 2.

Parameter	Value
FIPR Water Volume	65 m^3
Stocking date	1-Feb
Initial fingerling weight	63 g
Initial fingerling length	17.9 cm
fingerling price	$0.70
Harvest size	681 g
Total Mortality	10%
Market price	$7.16/kg
Feed price	$1.00/kg
Electricity cost	$0.07/kWh
Fixed costs	$81/week
Variable costs	3/7 of specified costs

Objective 2 Results

Positive and negative net return averages and standard deviations were calculated from 500 model runs for each loss scenario (Table 10 and Table 12). For the 50% magnitude of loss scenarios, frequency of loss scenarios of either 40% or 20% were most likely to have negative net returns and had the lowest average negative net returns (Table 4). These same frequency loss levels had the lowest average positive net returns along with the highest standard deviations (Table 10). The scenarios with 10% and 1% frequency of loss had lower chances of negative net returns occurring and higher average positive net returns. For the scenario with 1% frequency of loss, there were no negative net returns; only three loss events occurred in the 500 runs which allowed for the highest average of positive net return and lowest standard deviation out of the four scenarios.

Table 10. Net returns and standard deviations for 50% magnitude of loss scenarios.

Frequency of Loss per Grow Out Period	Frequency of Loss per Week*	Chance of Negative Net Return	Average of Negative Net Return ($)	Standard Deviation of Negative Net Return ($)	Average of Positive Net Return ($)	Standard Deviation of Positive Net Return ($)
40%	1.11%	6%	-20,521	+/- 5,781	57,023	+/- 28,075
20%	0.56%	2%	-23,126	+/- 7,428	64,134	+/- 22,940
10%	0.28%	0.40%	-19,285	+/- 2,799	68,935	+/- 17,317
1%	0.03%	0.00%	-	-	73,866	+/- 3,899

*Since the grow out period is 36 weeks, each week has an equal chance of a stochastic loss occurring.

Net return values for the 50% magnitude of loss at 40% (40% / 36 weeks in grow out period = 1.11% per week) frequency of loss trials can be put into several category levels: 1) either very high returns, at exactly $74,113; or 2) low returns, between $14,000 and $0; or 3) very low returns, between -$17,000 and -$39,661 (Table 11). When no loss occurred, net returns were uniformly $74,113 but when one loss event occurred the average net return value was between $11,093 and $12,393 (Table 11). A 50% loss event could reduce net returns values to the $10,000 - $14,000 range. Lower net returns were associated with trials having multiple loss events and negative net returns were associated with trials that had both multiple loss events and loss events occurring in the latter half of the production cycle.

Table 11. Other net return values for 50% magnitude of loss.

	Frequency of Loss			
	40%	20%	10%	1%
Average positive net return values of 1 or more losses	11,093	11,549	11,215	12,393
Lowest postive net return value	2,227	5,049	2,227	12,358
Lowest negative net return value	-39,661	-38,067	-21,264	---

When the bio-economic model scenarios with a magnitude of loss of 10% rather than 50% were simulated, there were no scenarios that had a negative net return (Table 12). As the frequency of loss decreased, the average net returns increased. Compared to the net returns for the 50% magnitude of loss scenarios, the 10% magnitude of loss scenarios had a lower standard deviation (Table 12). Without a loss event occurring, net returns for the 10% magnitude of loss scenarios was $74,113. Net returns for 10% frequency of loss trials did not fall into the same high, low positive or negative categories that the 50% trials did (Table 13). The lowest net return value that occurred was $48,234.

Table 12. Net return for 10% magnitude loss scenarios.

Frequency of Loss	Frequency of Loss per Week*	Chance of Negative Net Return	Average of Negative Net Return	Standard Deviation of Negative Net Return	Average of Positive Net	Standard Deviation of Positive Net Return ($)
40%	1.11%	0%	---	---	69,411	+/- 7,212
20%	0.56%	0%	---	---	71,741	+/- 5,166
10%	0.28%	0%	---	---	72,948	+/- 4,063
1%	0.03%	0%	---	---	74,063	+/- 787

*Since the grow out period is 36 weeks, each week has an equal chance of a stochastic loss occurring.

Table 13. Other net return averages for grow-out periods with 10% magnitude of loss.

	Frequency of Loss			
	40%	20%	10%	1%
Average positive net return values of 1 or more losses	59,601	60,934	60,244	61,657
Lowest postive net return value	48,234	49,988	39,150	61,546
Lowest negative net return value	---	---	---	---

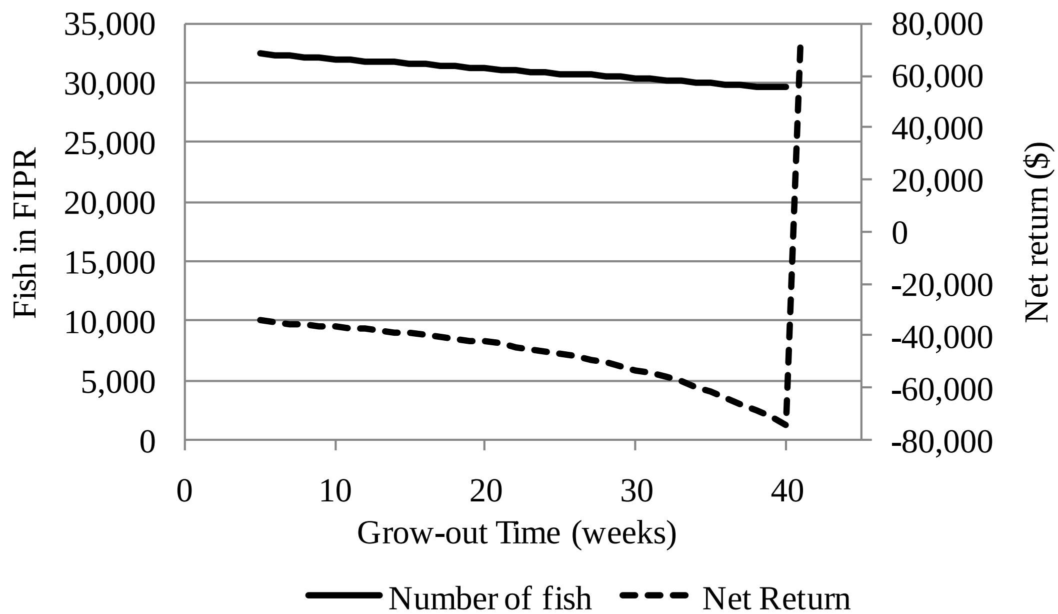
Objective 2 Discussion

Unanticipated loss events caused by electrical outages, disease outbreaks or managerial error are not uncommon in aquaculture production systems but the likelihood of these events occurring and their effect on production and net returns in FIPR systems are undocumented in the literature. By assessing a range of values for frequency of loss and magnitude of loss, inferences can be made into the effect of risk on production and net returns for FIPR systems. By comparing the results of the 50% magnitude of loss scenarios to the 10% magnitude of loss scenarios we can better understand the effects of risk mitigation strategies on costs and net returns.

It was hypothesized that the FIPR bio-economic model scenarios with the higher magnitudes and frequencies of loss (fish death) events would have greater variability and lower net returns than scenarios with lower magnitudes of loss per loss event and lower frequencies (probabilities) of loss events occurring. This hypothesis was proven correct. In general, a 50% magnitude of loss event was catastrophic for net returns. Although the chance of negative net returns was low, ranging from 0%-6%, trials with the least detrimental losses still experienced a decrease in net returns of approximately $61,000. Some crop trials had a negative net return of approximately -$40,000. Why the difference in net returns for just one crop with a 50% loss? In some trials, a loss event occurred more than once, causing a decrease in HSB numbers and therefore, receipts. When the fish were sold at harvest, net return was much lower due to the greatly decreased number of HSB in the FIPR. The timing of the catastrophic loss also had impact on the net returns. If the loss event occurred early in the grow-out period net returns were higher, conversely if the loss occurred near the end of the grow-out period, the net returns were much lower. The reason for this difference is in the variable costs, mainly feed. Fish that were lost to catastrophe had consumed feed from the time they were stocked. Therefore, when they were removed from the system (loss event mortality) before they could be sold, those costs were unrecoverable. When a loss event occurred near the end of a grow-out period, all the feed that had been consumed by the HSB was lost. Figure 26 illustrates a crop scenario where no loss event occurs. In Figure 27, the loss event occurred early in grow-out period and the final net return was approximately $12,000. Feed costs were reduced in this case as there were fewer fish to feed from an earlier stage of the production cycle. In Figure 28, the loss event occurred in the middle of the grow-out period and the net returns were approximately $10,600. In Figure 29, the loss event occurred near the end of the grow-out period and the net returns were approximately $7,000. Negative net returns occurred when there were two or more loss events in one grow-out period.

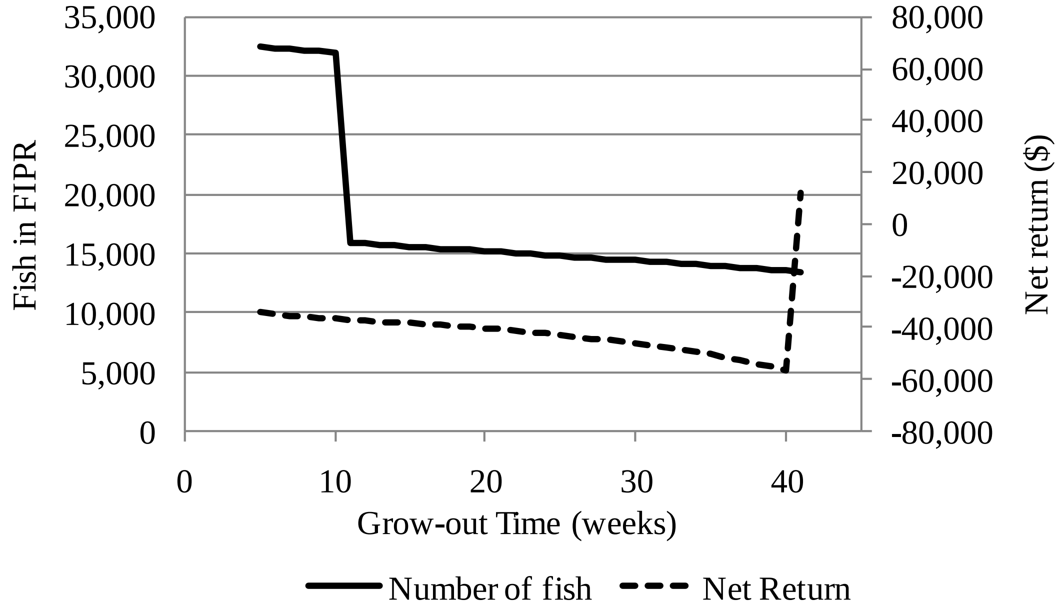
Receipts were much greater, almost double, for the 10% magnitude of loss scenarios compared to the 50% magnitude of loss scenarios, and when net returns are compared, the 10% loss scenarios are more than three times more profitable. The increase in net returns for the 10% magnitude of loss scenario came from increased survival and production over the 50% scenario rather than a difference in production costs. Cost of production for the two magnitude scenarios were similar, so the difference between the net return levels is derived from the improved survival and increased production. Detailed enterprise budgets comparing an early, middle and late occurrence of a loss event can be found in the Appendix Table 26 and Table 27. Production data comparing an early, middle and late occurrence of a loss event can be found in Appendix Table 28 and Table 29.

Figure 26. Number of fish in FIPR and Net Return over time, no loss event.[1]



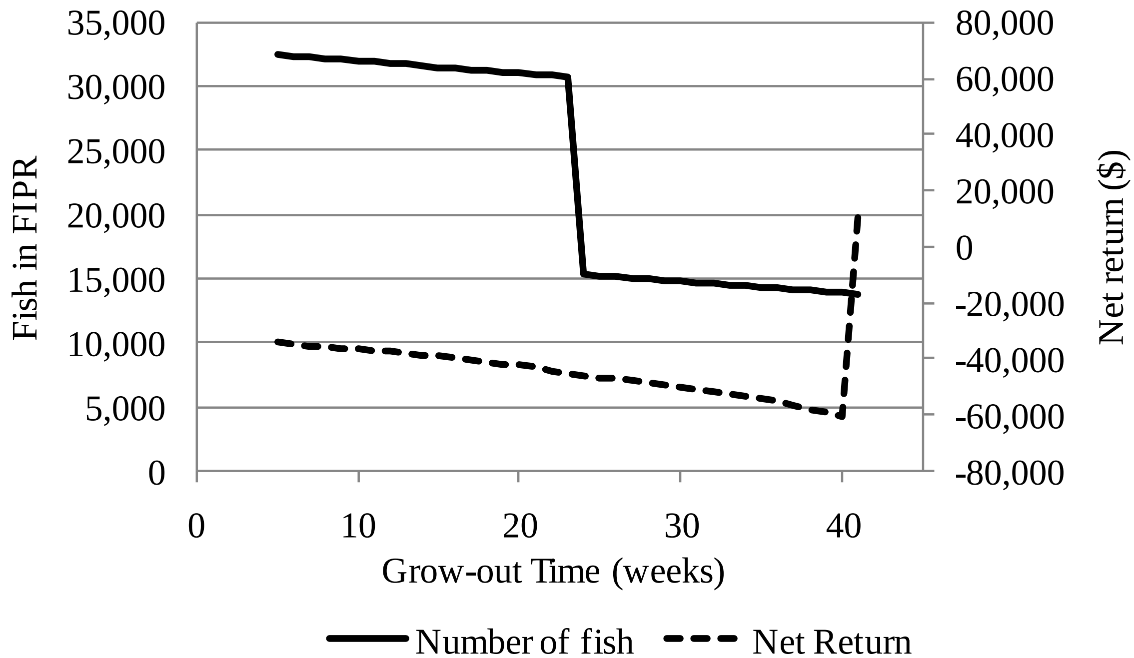
[1] Initial stocking occurred in week 5 of the simulation run.

Figure 27. Loss event of 50% magnitude occurring 5 weeks after stocking.[2]



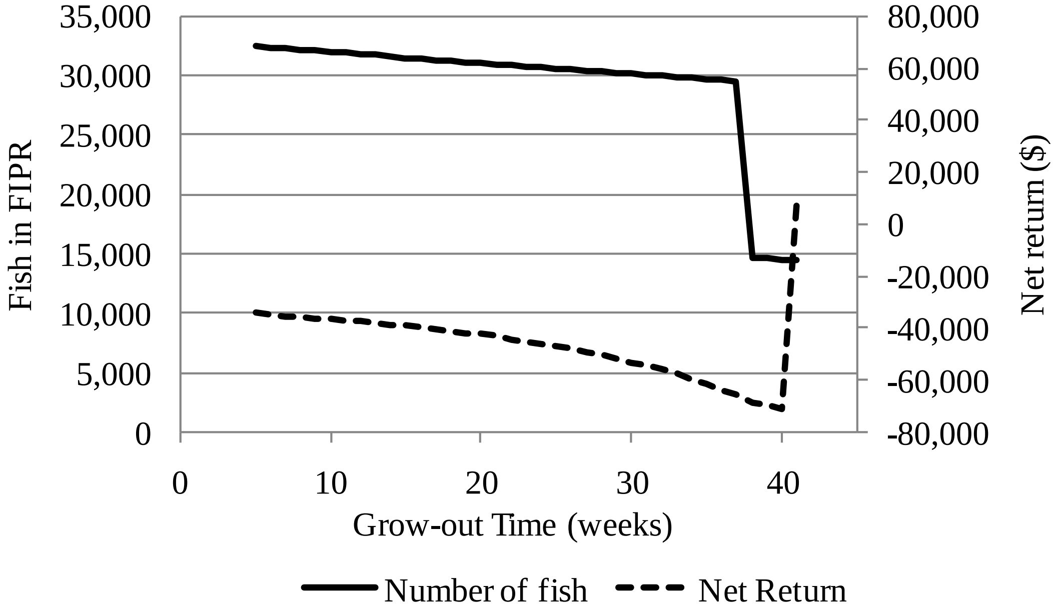
[2] Initial stocking occurred in week 5 of the simulation run.

Figure 28. Loss event of 50% magnitude occurring 19 weeks after stocking.3



3 Initial stocking occurred in week 5 of the simulation run.

Figure 29. Loss event of 50% magnitude occurring 32 weeks after stocking. [4]



4 Initial stocking occurred in week 5 of the simulation run.

A loss event at the 50% magnitude level caused the net return values to vary widely between trials, with no loss events at one end of the spectrum and trials with one or more loss events at the other end of the spectrum. The net return values were either a reoccurring maximum value when no loss event occurred, or a very low positive or negative net return value in the event of one or more loss events. The net return data was bifurcated rather than bell-shaped, with values either very high, or very low. The wide range of potential net returns with a high catastrophic loss indicates the importance of mitigating or reducing risk in FIPR systems before they happen. The lowest amount of risk possible is ideal but probably not realistic because there is always an element of uncertainty (risk) in fish production systems. Investing in risk mitigation equipment such as automatic emergency aeration systems or hiring more highly skilled workers can be expensive, but the benefits of reducing risk are difficult to ignore and may be worth the additional cost. The 10% magnitude of loss scenarios had a much smaller range of net return values and all of the net returns were positive. In the event of loss occurring, the reduction of net returns was much less than with the higher 50% magnitude of loss.

Results from the bio-economic model scenarios with the lower magnitudes and frequencies of loss had the lowest variability and highest net returns as hypothesized. Even with a 40% chance of loss, the lowest net return was $48,223, much higher than the lowest positive net return for 50% magnitude of loss scenarios (-$39,661), so the hypothesis was found to be valid. Also, it was hypothesized that HSB FIPR crops with loss events occurring later in the grow-out period will experience lower net returns due, to higher variable costs, than crops with loss events occurring earlier in the grow-out period. In fact it was found that crops with loss events occurring early in the grow-out period did experience higher net returns than crops experiencing loss events later in the grow-out period.

The results of this objective serve as an indicator of areas for future research in FIPR systems. Field research could examine both the frequency of unpredicted loss events occurring as well as measuring mortality levels from loss events to provide frequency and magnitude loss information that would make the bio-economic model more realistic and useable by producers. The results also serve as an indicator to the importance of understanding the risks associated with FIPR systems. If the frequency of loss events is likely to be high and the loss from an event is likely to be great, a producer may want to look at alternative, less risky production systems or, alternatively, if the frequency and magnitude of loss events can be reduced and managed by good producers then the FIPR system can provide high returns.

Objective 3

Examine the influence of initial stocking size and initial stocking date on crop duration, production and net returns in the HSB FIPR system under a water temperature-dependent growth regime.

Hypotheses:

1) Larger fingerlings will produce higher net returns than smaller fingerlings stocked in any given month because the larger fingerlings will reach market size in less time.
2) Net returns will be greater for larger fingerlings stocked early in the year as opposed to late in the year due to shortened grow-out period requirements.

Objective 3 Methods

This objective models the production and net returns stemming from specific HSB fingerling size and stocking date combinations to determine their influence on profitability of FIPR systems. For this objective several parameters were held constant, Table 14 Optimal growth occurred at water temperatures between 23°C and 25°C and no growth occurred below 11°C or above 34°C. (Refer to the general methods section that contains a description and graph of the growth rate relationship to water temperature over a 52 week period). Additional variable and fixed costs were added based on similar costs for a 1.4 ha pond. (See general methods section for detail). The crop was harvested when the fish size reached or exceeded 0.681 kg (D'Abramo et. al., 2008).

Table 14. Bio-economic parameters for Objective 3.

Parameter	Value
FIPR Water Volume	65 m^3
Harvest size	681 g
Total Mortality	10%
Market price	$7.16/kg
Feed price	$1.00/kg
Electricity cost	$0.07/kWh
Fixed costs	$81/week
Variable costs	3/7 of specified costs

Unlike the previous objectives where an additional bio-economic model component was added to account for mortality or risk, this objective used existing bio-economic model components. The fingerling size and stocking month parameters of the bio-economic model were varied to produce production and net return data for each scenario (Table 15). HSB fingerlings were purchased according to length, in inches, rather than by weight and the relative lengths for each weight are included into the cost and production components of the Stella bio-economic model (Table 15).

The first day of each month was used as the stocking date parameter for each scenario. The HSB fingerling sizes used were 3”, 4”, 5”, 6” and 7” and each size was stocked in each month from January through December. The bio-economic model calculated net returns for each size and month combination (total of 60 scenarios). Results were used to develop a table indicating production time (weeks until harvest size was reached) production quantity, and net returns at harvest. The cost to stock the FIPR with HSB fingerlings at a stocking density of 500 fish/m^3 varied with each fingerlings size (Table 15). Fingerling pricing was held constant at $0.10 per inch throughout the year with a shipping cost of $950 per order.

Table 15 Size and weight of HSB fingerlings, their prices and cost to stock the FIPR system used in Objective 3 scenarios (includes a constant $950 per order shipping cost).

Length (in)	Length (cm)	Weight (g)	$/fingerling	Cost to stock FIPR ($)
3	7.6	6	0.30	$10,700
4	10.2	14	0.40	$13,950
5	12.7	25	0.50	$17,200
6	15.2	43	0.60	$20,450
7	17.78	63	0.70	$23,700

Objective 3 Results

Grow-out duration, net returns at harvest and weekly net returns for each fingerling-size / stocking month combination are provided in Table 16. Because net return at harvest does not reflect the length of time required for receipts to be generated, the average net return per week was calculated in order to better compare scenarios. The net return per week value represents the profit earned per week of grow-out effort. In some instances, net returns were very high, but the length of time required was also high whereas other scenarios had slightly lower net return but half the grow-out time needed (Table 2). For example, 3” fingerlings stocked in July returned $77,117 in 64 weeks whereas 7” fingerlings stocked in February returned $74,113 in only 36 weeks.

As fingerling size increased the range of weeks required for grow-out for each stocking month of the year decreased (Table 17). Each fingerling size had initial stocking months with high profitability and months with low profitability (Table 16). For most months of the year the 7” fingerling was the most profitable choice in terms of net returns and time compared to the other fingerling sizes. They exhibited net returns above $60,000 when stocked in January – March or September-December, but had net returns below $30,000 when stocked in April or

May, (Table 16). The 6" fingerling size was generally the least profitable choice with only one stocking month of the year (September) having net returns over $60,000. The 4" fingerling size was also not as profitable as the 7" fingerling but did exhibit one highly profitable month, August, when the net returns were approximately $80,000 at harvest. The 3" fingerling was a highly profitable choice (net returns > $60,000) when stocked December through August excluding February. On average, the 3" fingerling had the highest net returns at $62,779, but also averaged the longest grow-out period lengths at 72 weeks (Table 16). In contrast, the 6" fingerling had the lowest net returns average ($36,095) but also a lower average grow-out period length (60 weeks). The 7" fingerling had the shortest grow-out period length (46 weeks) and highest average net returns per week of grow-out ($1,268). The fingerling size and stocking month with the highest average net return per week was the 7" fingerling when stocked in March and the lowest average net return per week combination was the 7" fingerling stocked one month later in April.

Biomass production results for each scenario are provided in Table 3 and ranged from a high of 21,210 kg for the 7" fingerling stocked in February to a low of 17,691 kg for the 3" fingerling stocked in November, Table 17. Production quantities varied between the scenarios because the bio-economic model harvests the HSB when they reach or exceed 0.681 kg each. In some scenarios the HSB were nearly 0.681 kg in one week then exceeded that weight in the following week and then were harvested. Those crops had higher biomass compared to crops where the fish size reached exactly 681 grams in a certain week and were not allowed the extra week of growth that other crops were given. To better compare the differences in total biomass produced from each scenario, the production per cycle, that is the weight produced divided by the number of weeks required for the HSB to reach harvest size was calculated, Table 3. This allows comparison between scenarios beginning with larger fingerlings needing less time to reach harvest size to smaller fingerlings needing more time to reach harvest. On average the initial 7” stocked fingerlings produced the highest weekly biomass at 452 kg per week, whereas the initially stocked 3” fingerling produced an average of 261 kg per week.

Table 16. Weeks of grow out, net returns and net return per week for varying fingerling length -stocking date combinations.

Month	3" Fingerling			4" Fingerling			5" Fingerling			6" Fingerling			7" Fingerling		
	wks of grow-out	Net Return ($)	Net Return per week ($)	wks of grow-out	Net Return ($)	Net Return per week ($)	wks of grow-out	Net Return ($)	Net Return per week ($)	wks of grow-out	Net Return ($)	Net Return per week ($)	wks of grow-out	Net Return ($)	Net Return per week ($)
J	74	60,117	812	72	53,648	745	69	34,964	507	66	15,562	236	40	69,049	1,726
F	69	59,703	865	67	53,466	798	65	43,591	671	61	16,284	267	36	74,113	2,059
M	66	63,689	965	63	52,227	829	61	43,110	707	57	16,514	290	32	73,450	2,295
A	64	64,557	1,009	61	56,854	932	59	52,490	890	55	27,400	498	51	6,289	123
M	65	68,907	1,060	63	65,993	1,048	59	56,154	952	55	46,078	838	52	29,904	575
J	65	74,656	1,149	63	69,301	1,100	60	61,307	1,022	56	55,694	995	51	42,938	842
J	64	77,117	1,205	62	71,826	1,158	60	69,228	1,154	56	59,148	1,056	47	46,579	991
A	66	71,939	1,090	62	80,025	1,291	59	71,534	1,212	55	59,322	1,079	52	55,756	1,072
S	86	40,168	467	83	17,425	210	60	67,196	1,120	55	68,037	1,237	47	60,864	1,295
O	85	52,386	616	83	39,707	478	81	25,627	316	61	47,368	777	52	67,424	1,297
N	82	57,305	699	80	49,794	622	78	38,469	493	74	10,401	141	49	68,663	1,401
D	79	62,806	795	76	49,677	654	74	38,860	525	70	11,334	162	45	69,099	1,536
AVG	72	62,779	894	70	54,995	822	65	50,211	797	60	36,095	631	46	55,344	1,268

Table 17. Production weight at harvest (kg) and production quantity per week of grow-out for each fingerling size and month scenario.

Month	3"		4"		5"		6"		7"	
	Production (kg)	Production per week	Production (kg)	Production per week	Production (kg)	Production per week	Production (kg)	Production per week	Production (kg)	Production per week
J	18,387	248	19,106	265	18,601	270	19,640	298	20,322	508
F	18,402	267	19,123	285	20,075	309	19,647	322	21,210	589
M	19,155	290	18,787	298	19,745	324	19,284	338	20,715	647
A	18,953	296	18,930	310	20,220	343	19,476	354	19,429	381
M	18,911	291	19,758	314	19,363	328	19,952	363	20,314	391
J	18,854	290	19,242	305	19,286	321	20,241	361	19,666	386
J	18,621	291	18,977	306	20,001	333	20,169	360	19,592	417
A	18,531	281	19,833	320	19,646	333	19,348	352	20,450	393
S	18,740	218	17,736	214	18,964	316	19,882	361	20,531	437
O	17,763	209	17,908	216	18,622	230	18,856	309	20,579	396
N	17,691	216	18,314	229	19,170	246	18,853	255	20,643	421
D	18,734	237	18,288	241	19,168	259	18,861	269	20,618	458
AVG	18,562	261	18,833	275	19,405	301	19,517	329	20,339	452

Objective 3 Discussion

There are several factors that affect grow-out times and net returns resulting from the different fingerling sizes and stocking months. The growth function is the backbone of the bio-economic model simulations because of the impact it has on production and ultimately profitability. In the bio-economic model, growth rate varies with water temperature and with average size of the HSB crop. January, February, November and December are the coldest months and thus least favorable for HSB growth (Figure 5). (See general methods section for detailed descriptions of growth functions).

The relationship between fingerling size and net returns changes dramatically between stocking months. While 7” fingerlings were the most profitable size for February stocking, they are the least profitable size for April stocking (Table 16 and Table 17). When stocked in February, the 7” fingerlings were harvested before the start of the winter period, and net returns were very high. Overwintering HSB in the FIPR system will often mean lowered net returns. HSB must be fed during the cold months of the year to maintain their prior weight. This lowers net returns because the costs of feeding the HSB through a winter period are not matched by increases in biomass value. When stocked April 1st, the 7” fingerlings almost reach harvest size before the cold winter period, but do not achieve the harvest weight threshold. When winter begins, the 7” fingerlings are approximately 600 grams and they must be fed to maintain their weight. The other fingerling sizes must be overwintered as well but they are smaller and require less feed to be maintained so are more profitable than the 7” fingerling when stocked in April (Figure 31). Therefore, the 3” fingerlings had the highest net return at harvest and the highest net return per week because they required the least amount of feed during the winter period (Table 16).

The 6” fingerling was often the worst choice of fingerling size for net returns (January, February, March, November and December). Compared to the other fingerling sizes, the six inch fingerlings are often largest when the winter period began, so those fish required more feed to be maintained; plus the cost to initially purchase 6” fingerlings added to overall operating costs compared to stocking costs for smaller fingerlings. The 7” fingerling costs more to purchase than the 6” fingerling but because it can reach market size faster, it often a more profitable choice.

Figure 30. Comparing five fingerling lengths at stocking to growth over time when stocked on February 1 (week 5) and harvested at ≥ 681 grams.

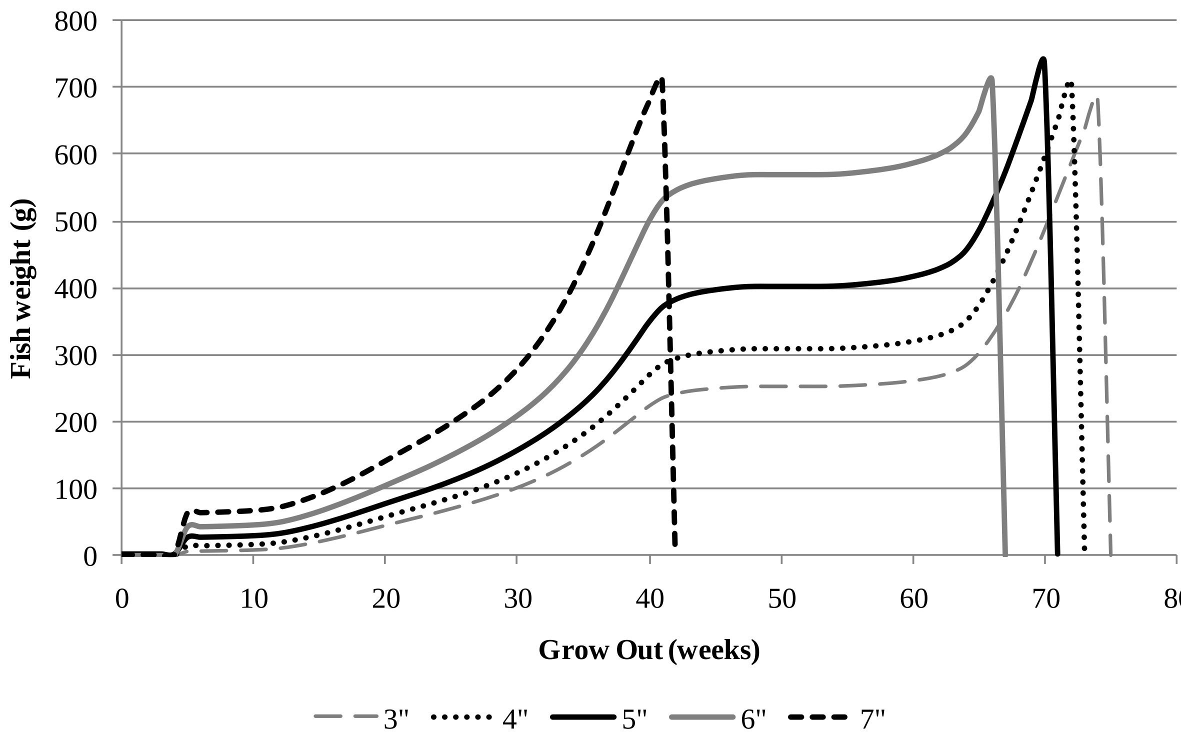
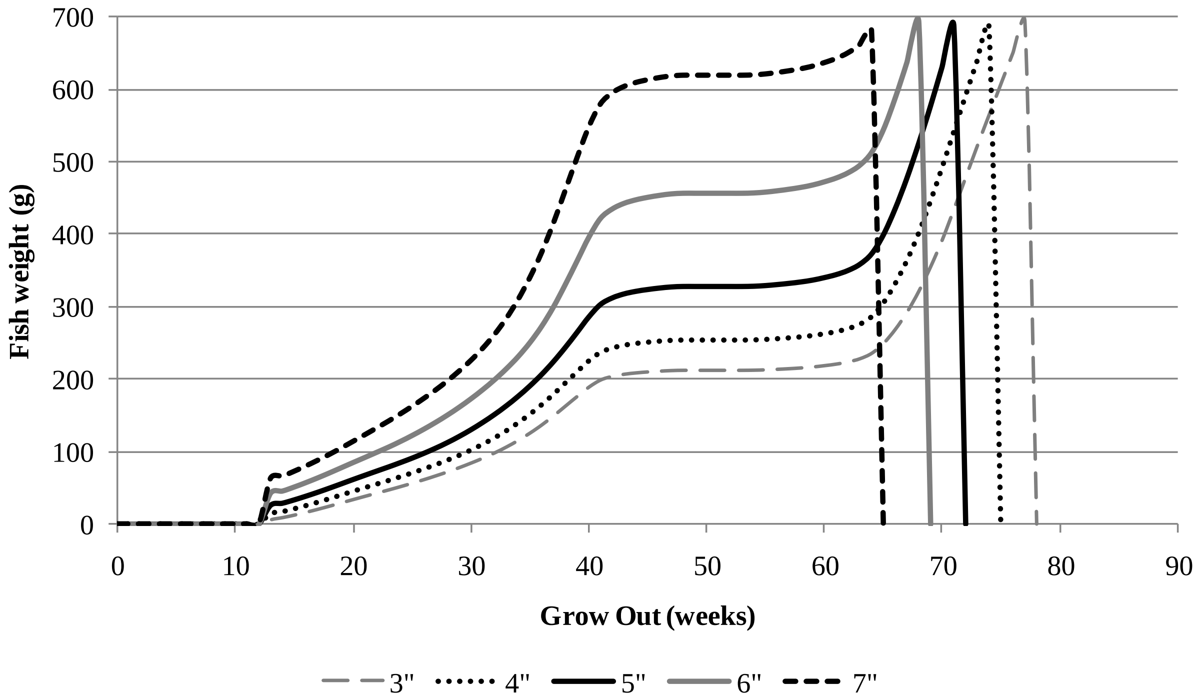


Figure 31. Comparing five fingerling lengths at stocking to growth over time when stocked on April 1 (week 513) and harvested at ≥ 681 grams.



Results showed a consistent trend with crops having smaller fish going into the overwintering period accumulating lower variable costs, primarily feed, during that period and were more profitable once grown out to harvest size. In cases where overwintering could be avoided all together, net returns were highest. Although the cost of purchasing 7” fingerlings was higher than the cost for smaller fingerlings, the net returns were also higher when the 7” fingerlings either did not need to go through the winter period or were overwintered when they were still relatively small.

The bio-economic model data demonstrates that water temperature and initial fingerling size strongly impact production and net returns. Field research is needed to more accurately determine the relationship between grow out time and temperature regimes. This information can then be used to adjust Stella bio-economic model parameters and improve the accuracy of growth, production and net return predictions. This objective assumed that purchased fingerlings can be accurately graded by inch categories and fish will grow to harvest size uniformly. Depending on the time of year, certain HSB fingerlings sizes may or may not be available for producers to purchase from hatcheries and producers may have to accept particular fingerling sizes that they had not anticipated receiving. In reality, fish purchased from producers can vary by age and size and the impacts of this variation should also be measured in field trials. Field trials using tightly graded fingerlings compared to ambient variation from the commercial hatchery would be meaningful and an important data addition for this bio-economic model and for the industry. The bio-economic model could be adjusted to include variability in growth due to variation in fingerling size to more accurately present HSB crops in the FIPR system.

The growth component of the bio-economic model has such strong effects on production and net returns that any field trials generating data pertaining to HSB growth in FIPR systems as it relates to temperature would be a tremendous asset to improving the accuracy of the model. If field trials demonstrated that other aspects of production, such as protein content of feed, or stocking density, or water quality had similarly strong impacts on fish growth, then the model could be adjusted to those results as well.

Objective 4

Demonstrate how the bio-economic model can be used by researchers and/or producers to make longer term production decisions. Specifically, choose stocking date and initial fingerling size combinations based on data obtained from objective three to produce the highest net return to obtain the highest net return over a five year planning horizon.

Hypothesis:

1) Stocking 7" fingerlings for each crop will allow more crops (and therefore more cumulative biomass) to be harvested in a five-year period than would be the case for crops stocked with fingerlings less than 7" in length.

<u>Objective 4 Methods</u>

With the variety of fingerling stocking sizes to choose from and the seasonal range in stocking dates, it is difficult to determine which combination will be the most profitable over a five year production period. This objective developed a method to use Objective 3 results to determine the most profitable five year production schedule. Profitability was measured through calculated net returns at harvest for all completed crops and accumulated costs for any unfinished crops for this time frame (Table 16). Stocking 7" fingerlings on March 1 was selected as the initial stocking scenario for the 5 year plan as it produced the highest weekly net returns in Objective 3. The dates of subsequent stockings were always chosen as the first day of the month following the date of the previous harvest and the fingerling size chosen for each subsequent stocking was based on which size would be most profitable when stocked on day, according to Objective 3 Table 16. Since the 5 year cycle started on March 1, the final day of the cycle was February 28.

According to the results of objective three, a crop with a start date of April 1 will be most profitable when stocked with 3" fingerlings. Therefore, this combination of stocking date and fingerling size was used to initiate a second 5-year production schedule for comparison to production schedule 1 (7" fingerlings stocked on March 1). For the subsequent crops, the optimal fingerling size choice was selected as in the first five year production schedule, where the fingerling with the highest net returns per week for the stocking date was stocked.

Several bio-economic model parameters were held constant for this objective (Table 18). Optimal growth occurred at water temperatures between 23°C and 25°C and no growth occurred below 11°C or above 34°C. (Refer to the general methods section for complete description of growth rates)).   Additional variable and fixed costs were added based on similar costs for a 1.4 ha pond. (See general methods section for detail). The crop was harvested when the fish size reached or exceeded 0.681 kg. Existing bio-economic model components were used and no additional components were developed to accomplish this objective.

Table 18. Bio-economic model parameters for Objective 4.

Parameter	Value
FIPR Water Volume	65 m^3
Harvest size	681 g
Total Mortality	10%
Market price	$7.16/kg
Feed price	$1.00/kg
Electricity cost	$0.07/kWh
Fixed costs	$81/week
Variable costs	3/7 of specified costs

Objective 4 Results

The crop number, stocking date (month), fingerling stocking size, weeks of grow-out, year stocked and year harvested, biomass produced, net returns per week and net returns for the five year production schedule incorporating only 7” fingerlings are provided in Table 19. After the first stocking on March 1, the stocking and harvesting fell into a cycle of September harvest, October restocking, October harvest and November restocking. The first crop stocked in March Year 1 was harvested in October Year 1. The second crop was stocked on November 1 Year 1 with the harvest occurring 49 weeks later at the end of September Year 2. The third stocking occurred October 1 Year 2 and was harvested 52 weeks later in October Year 3. The subsequent stocking was on the 1st day of the following month, November 1 Year 3, and this pattern of harvest and re-stocking repeated itself thereafter (Table 19). The sixth stocking occurred on November 1 in Year 5 and since the crop could not be harvested until October in Year 6, net returns were negative because costs had accumulated with no receipts (although biomass production had occurred).

Table 19. Five year production plan from the bio-economic model using the most profitable choice variables for HSB in a FIPR system beginning March 1 Year 1 and ending the last day of Year 5, Feb 28.

Crop #	Stocking Date	Fingerling Size	Weeks of grow out	Year Started	Year Harvested	Biomass Produced (kg)	Net Return per Week	Net Return ($)
1	1-Mar	7"	32	1	1	20,832	2,295	$73,450
2	1-Nov	7"	49	1	2	20,758	1,401	$68,663
3	1-Oct	7"	52	2	3	20,695	1,297	$67,424
4	1-Nov	7"	49	3	4	20,758	1,401	$68,663
5	1-Oct	7"	52	4	5	20,695	1,297	$67,424
6	1-Nov	7"	17	5	6	2,247	(2,476)	-$42,095
Total						105,986		$303,529

The data for the five year production plan beginning with a 3” fingerling in March Year 1 is provided in Table 20. For the first two crops, stocking 3” fingerlings had the highest net returns per week. For the three following stockings the 7” fingerlings had the highest net return values per week, and therefore were the size stocked in crops three through five. For the final stocking on September 1 Year 5, the crop would not be harvestable until Year 6, therefore the crop had a negative value at the end of the calendar Year 5 because crop costs had accumulated with no receipts.

Table 20. Five year production plan from the bio-economic model using the most profitable choice variables for HSB in a FIPR system FIPR system beginning April 1 Year 1 and ending the last day of Year 5, March 31.

Crop #	Stocking Date	Fingerling Size	Weeks of grow out	Year Started	Year Harvested	Biomass Produced (kg)	Net Return per Week	Net Return ($)
1	1-Apr	3"	64	1	2	20,306	1,009	$64,557
2	1-Jul	3"	64	2	3	19,950	1,205	$77,117
3	1-Oct	7”	52	3	4	21,284	1,297	$67,424
4	1-Sep	7”	47	4	5	20,984	1,295	$60,864
5	1-Sep	7”	30	5	6	4,019	(1,780)	-$53,399
Total						86,543		$216,563

The 7” stocking plan (Table 19) had a total of five harvested crops and one unfinished crop at the end of year five. Total net returns over the five year period was $303,529 and total biomass produced was 105,986 kg. The mixed-size stocking plan (Table 20) had four harvested crops and one unfinished crop at the end of year five. Total net return over the five year period was $16,563 and total biomass produced was 86,543 kg. The 7” stocking plan exceeded the mixed-size stocking plan in terms of net returns by $86,966 and in terms of biomass produced by 19,442 kg. For detailed enterprise budgets for each stocking plan, see Appendix Table 30 and Table 31.

Objective 4 Discussion

The purpose of this objective was to determine the most profitable production schedule for HSB FIPR systems using the developed Stella bio-economic model. However, it is recognized that many biological unknowns (educated guesses) are incorporated into this model so these specific results are not necessarily a production guide for producers to follow. This objective seeks to demonstrate one pragmatic way that the bio-economic model could be used to assist researchers and producers in making decisions about production. Knowledge of potentially higher net returns that could be achieved through choosing the most profitable fingerling size for a given restocking month is key to the development of a longer term production plan.

The hypothesis that stocking 7” fingerlings for each crop of a five year production schedule beginning March 1 would be the most profitable fingerling size choice due to their high potential net return values over a shorter grow-out period was found to be true. For the initial March 1 stocking, the 7” fingerling was the optimal choice for highest net returns, highest net return per week and for shortest grow-out period. And for each subsequent crop stocking month, the 7” fingerling continued to be the best choice to maximize net return values because the restocking months occurred in the months where the 7” fingerlings was more profitable than the other fingerling choices, according to the results from objective three.

The results demonstrate that the initial fingerling size stocked can have great influence on net returns and profitability because of the variation in time required for grow-out. For the first production plan, five total crops were able to be harvested in five years, with a sixth crop started, because of the shortened amount of time required to grow-out the 7” fingerlings to market size. The mixed-size production plan, which began by stocking 3” fingerlings, was only able to have four completed crops in a five year period. By adding an additional harvest to the production schedule by initially stocking 7” fingerlings, and by avoiding over-wintering periods when the HSB are near harvest size, net returns and production over a five-year period were greater, indicating that time required for species specific fish grow-out is one of the most influential factors on net returns and production in the development of longer term production plans.

The production plans developed for this objective are only two of many potential plans that could be tested with the bio-economic model. There are potentially many other plans that may increase net returns. The bio-economic model could also be used to make production decisions for unforeseen dynamics in HSB production. For example, if 7” fingerlings were not available to producers, or only certain sizes were available for restocking, the bio-economic model could be used to help make production decisions based on the fingerling size availability. Perhaps by waiting a few extra weeks for a different sized fingerling to be ready for purchase and stocking, a producer could increase his net return at harvest. The bio-economic model is a valuable tool that can help producers predict future returns for different stocking scenarios.

Further tests using the bio-economic model would be beneficial. Once the growth component of the bio-economic model is refined through additional replicated research and/or field trials, additional alternative long-term production plans could be analyzed for profitability and production. A profit and production maximization schedule based on empirical data could then be created to more accurately evaluate best strategies for stocking HSB in FIPR systems throughout the year.

Summary

This research was directed toward identifying the bio-economic factors affecting the feasibility of floating in-pond raceway systems using a Stella bio-economic modeling approach. The developed bio-economic model was used to investigate factors related to density dependent mortality, stochastic loss events, fingerling and stocking date relationships and production and net return over a five year production horizon.

In objective one, an important factor affecting the feasibility of the FIPR system was the relationship between stocking density and mortality. The shape of the mortality curve, either fixed, linear or exponential for increasing stocking density level, had a substantial impact on production and net return. It was assumed that mortality would increase when stocking density exceeded 300 fish/m^3 and continue to increase up to 700 fish/m^3. For the linear and exponential mortality curves, net returns were maximized at 500 fish/m^3 but production was maximized at 700 fish/m^3 and 600 fish/m^3 respectively. Maximized production did not always correspond to maximized net returns. Future research should focus on the stocking density where density dependent mortality begins to have an increased effect and the shape of the mortality curve as stocking density levels increase.

In objective two, the probability of a random catastrophic loss occurring was found to be as influential a factor as originally expected. By lowering the magnitude of a random disaster in the bio-economic model from 50% to 10% the feasibility of the FIPR system increased because at a 10% loss level average net returns were higher and the chance of negative net returns at harvest was eliminated. This showed the importance of mitigation equipment and the need for their inclusion as an integral part of the production system from the beginning of production planning, and not after a loss event occurs. The timing of the stochastic event was also found to be an influential factor. When an event occurred early in the grow out period, net returns were not as low as with crops with stochastic losses occurring later. It is difficult to predict the probability of high loss events occurring under any circumstances as they are relatively rare and stochastic in nature, but field trials of the FIPR system could give us data that may help narrow the range of possibility surrounding the frequency and magnitude of losses from various types of loss events. For example, the time HSB can survive in a FIPR system when the airlift pump flow is interrupted or the percentage of fish that are able to survive a disease outbreak when a timely and effective treatment is applied.

In objectives three and four, overwintering periods greatly affected net returns because of additional feed costs and, secondly, that fingerling size and stocking date combinations impacted the amount of economic loss for those overwintered fish. Fish overwintered at larger sizes were the most expensive to maintain, whereas fish overwintered at smaller sizes were the most cost effective. Over a five year period, by stocking larger fingerlings, the number of crops could be increased and resulting net returns were higher. Since the stocking month was varied (and therefore water temperatures fluctuated) between the scenarios, the results were greatly influenced by the bio-economic model's water temperature dependent growth rate assumptions.

Net return results are useful for comparing across objectives and to compare to other production systems. However, net returns are not the only indicators of feasibility; if high net returns can only be realized under very specific or highly improbable circumstances, the system may not truly be feasible. The results of this research indicate that high net returns can be realized under most of the circumstances examined except for the high magnitude of loss risk scenarios. A few well managed HSB FIPR field trials that closely examine and evaluate stocking density dependent mortality, magnitudes and probability of stochastic loss and the relationship between growth and water temperature would enable this bio-economic model to be a useful tool in making production decisions for HSB production in FIPR systems.

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Appendices

Table 21. Enterprise budget for one 65 m^3 FIPR system HSB crop stocked at 300 fish/m^3 stocking density in a 3.32 ha pond stocked on February 1 and harvested 36 weeks later.

	Mortality Curve Type		
Item	**Fixed**	**Linear**	**Exponential**
1. GROSS RECEIPTS	91,119	91,119	91,119
2. VARIABLE COSTS			
Fingerlings	14,761	14,761	14,761
Feed	16,180	16,180	16,180
Electricity	654	654	654
All Unspecified Costs: such as repairs and maintenance chemicals, fuel, labor, and interest on operating capital	13,541	13,541	13,541
TOTAL VARIABLE COST	**45,136**	**45,136**	**45,136**
3. INCOME ABOVE VARIABLE COSTS	**45,983**	**45,983**	**45,983**
4. FIXED COSTS			
Depreciation on capital items	605	605	605
Depreciation on machinery and equipment	2,305	2,305	2,305
Interest, taxes and insurance	962	962	962
TOTAL FIXED COSTS	**3,872**	**3,872**	**3,872**
5. TOTAL COST OF ALL SPECIFIED EXPENSES	**49,008**	**49,008**	**49,008**
6. NET RETURNS TO LAND			
Above variable costs	**45,983**	**45,983**	**45,983**
Above total costs	**42,111**	**42,111**	**42,111**
7. BREAKEVEN PRICE, $/kg			
Above variable costs	3.55	3.55	3.55
Above total costs	3.85	3.85	3.85
8. BREAKEVEN QUANTITY, kg			
Above variable costs	6,339	6,339	6,339
Above total costs	6,883	6,883	6,883

Table 22. Enterprise budget for one 65 m^3 FIPR system HSB crop stocked at 400 fish/m^3 stocking density in a 3.32 ha pond stocked on February 1 and harvested 36 weeks later.

	Mortality Curve Type		
Item	**Fixed**	**Linear**	**Exponential**
1. GROSS RECEIPTS	121,492	109,557	115,616
2. VARIABLE COSTS			
Fingerlings	19,428	19,428	19,428
Feed	21,574	20,082	20,839
Electricity	654	654	654
All Unspecified Costs: such as repairs and maintenance chemicals, fuel, labor, and interest on operating capital	17,852	17,213	17,538
TOTAL VARIABLE COST	**59,508**	**57,377**	**58,458**
3. INCOME ABOVE VARIABLE COSTS	**61,984**	**52,181**	**57,158**
4. FIXED COSTS			
Depreciation on capital items	605	605	605
Depreciation on machinery and equipment	2,305	2,305	2,305
Interest, taxes and insurance	962	962	962
TOTAL FIXED COSTS	**3,872**	**3,872**	**3,872**
5. TOTAL COST OF ALL SPECIFIED EXPENSES	**63,380**	**61,249**	**62,330**
6. NET RETURNS TO LAND			
Above variable costs	**61,984**	**52,181**	**57,158**
Above total costs	**58,112**	**48,309**	**53,285**
7. BREAKEVEN PRICE, $/kg			
Above variable costs	3.51	3.75	3.62
Above total costs	3.74	4.00	3.86
8. BREAKEVEN QUANTITY, kg			
Above variable costs	8,358	8,059	8,210
Above total costs	8,902	8,602	8,754

Table 23. Enterprise budget for one 65 m3 FIPR system HSB crop stocked at 500 fish/m3 stocking density in a 3.32 ha pond stocked on February 1 and harvested 36 weeks later.

	Mortality Curve Type		
Item	**Fixed**	**Linear**	**Exponential**
1. GROSS RECEIPTS	151,865	122,029	133,655
2. VARIABLE COSTS			
Fingerlings	24,095	24,095	24,095
Feed	26,967	23,238	24,691
Electricity	654	654	654
All Unspecified Costs: such as repairs and maintenance chemicals, fuel, labor, and interest on operating capital	22,164	20,566	21,188
TOTAL VARIABLE COST	**73,880**	**68,552**	**70,628**
3. INCOME ABOVE VARIABLE COSTS	**77,985**	**53,477**	**63,027**
4. FIXED COSTS			
Depreciation on capital items	605	605	605
Depreciation on machinery and equipment	2,305	2,305	2,305
Interest, taxes and insurance	962	962	962
TOTAL FIXED COSTS	**3,872**	**3,872**	**3,872**
5. TOTAL COST OF ALL SPECIFIED EXPENSES	**77,752**	**72,424**	**74,500**
6. NET RETURNS TO LAND			
Above variable costs	**77,985**	**53,477**	**63,027**
Above total costs	**74,113**	**49,605**	**59,155**
7. BREAKEVEN PRICE, $/kg			
Above variable costs	3.48	4.02	3.78
Above total costs	3.67	4.25	3.99
8. BREAKEVEN QUANTITY, kg			
Above variable costs	10,376	9,628	9,920
Above total costs	10,920	10,172	10,463

Table 24. Enterprise budget for one 65 m^3 FIPR system HSB crop stocked at 600 fish/m^3 stocking density in a 3.32 ha pond stocked on February 1 and harvested 36 weeks later.

	Mortality Curve Type		
Item	**Fixed**	**Linear**	**Exponential**
1. GROSS RECEIPTS	182,238	128,533	140,576
2. VARIABLE COSTS			
Fingerlings	28,762	28,762	28,762
Feed	32,360	25,648	27,153
Electricity	654	654	654
All Unspecified Costs: such as repairs and maintenance chemicals, fuel, labor, and interest on operating capital	26,475	23,599	24,244
TOTAL VARIABLE COST	**88,251**	**78,662**	**80,813**
3. INCOME ABOVE VARIABLE COSTS	**93,986**	**49,871**	**59,764**
4. FIXED COSTS			
Depreciation on capital items	605	605	605
Depreciation on machinery and equipment	2,305	2,305	2,305
Interest, taxes and insurance	962	962	962
TOTAL FIXED COSTS	**3,872**	**3,872**	**3,872**
5. TOTAL COST OF ALL SPECIFIED EXPENSES	**92,124**	**82,534**	**84,685**
6. NET RETURNS TO LAND			
Above variable costs	**93,986**	**49,871**	**59,764**
Above total costs	**90,114**	**45,999**	**55,892**
7. BREAKEVEN PRICE, $/kg			
Above variable costs	3.47	4.38	4.12
Above total costs	3.62	4.60	4.31
8. BREAKEVEN QUANTITY, kg			
Above variable costs	12,395	11,048	11,350
Above total costs	12,939	11,592	11,894

Table 25. Enterprise budget for one 65 m^3 FIPR system HSB crop stocked at 700 fish/m^3 stocking density in a 3.32 ha pond stocked on February 1 and harvested 36 weeks later.

	Mortality Curve Type		
Item	**Fixed**	**Linear**	**Exponential**
1. GROSS RECEIPTS	212,611	129,069	129,069
2. VARIABLE COSTS			
Fingerlings	33,429	33,429	33,429
Feed	37,754	27,312	27,312
Electricity	654	654	654
All Unspecified Costs: such as repairs and maintenance chemicals, fuel, labor, and interest on operating capital	30,787	26,312	26,312
TOTAL VARIABLE COST	**102,623**	**87,706**	**87,706**
3. INCOME ABOVE VARIABLE COSTS	**109,987**	**41,363**	**41,363**
4. FIXED COSTS			
Depreciation on capital items	605	605	605
Depreciation on machinery and equipment	2,305	2,305	2,305
Interest, taxes and insurance	962	962	962
TOTAL FIXED COSTS	**3,872**	**3,872**	**3,872**
4. TOTAL COST OF ALL SPECIFIED EXPENSES	**106,496**	**91,579**	**91,579**
6. NET RETURNS TO LAND			
Above variable costs	**109,987**	**41,363**	**41,363**
Above total costs	**106,115**	**37,491**	**37,491**
7. BREAKEVEN PRICE, $/kg			
Above variable costs	3.46	4.87	4.87
Above total costs	3.59	5.08	5.08
8. BREAKEVEN QUANTITY, kg			
Above variable costs	14,413	12,318	12,318
Above total costs	14,957	12,862	12,862

Table 26. Enterprise budget for one FIPR system HSB crop initially stocked at 500 fish/m3 in a 3.32 ha pond stocked on Feb 1 and harvested 36 weeks later. Catastrophic loss event occurring at indicated week with 50% of HSB removed at loss week.

	Week of Loss			
Item	**Early (5 wks)**	**Middle (18 wks)**	**Late (32 wks)**	**No Loss**
1. GROSS RECEIPTS	70,438	72,984	80,362	151,865
2. VARIABLE COSTS				
Fingerlings	24,095	24,095	24,095	24,095
Feed	13,438	16,215	23,730	26,967
Electricity	654	654	654	654
All Unspecified Costs: such as repairs and maintenance chemicals, fuel, labor, and interest on operating capital	16,366	17,556	20,777	22,164
TOTAL VARIABLE COST	**54,552**	**58,520**	**69,255**	**73,880**
3. INCOME ABOVE VARIABLE COSTS	**15,886**	**14,465**	**11,107**	**77,985**
4. FIXED COSTS				
Depreciation on capital items	605	605	605	605
Depreciation on machinery and equipment	2,305	2,305	2,305	2,305
Interest, taxes and insurance	962	962	962	962
TOTAL FIXED COSTS	**3,872**	**3,872**	**3,872**	**3,872**
5. TOTAL COST OF ALL SPECIFIED EXPENSES	**58,424**	**62,392**	**73,127**	**77,752**
6. NET RETURNS TO LAND				
Above variable costs	**15,886**	**14,465**	**11,107**	**77,985**
Above total costs	**12,013**	**10,593**	**7,235**	**74,113**
7. BREAKEVEN PRICE, $/kg				
Above variable costs	5.55	5.74	6.17	3.48
Above total costs	5.94	6.12	6.52	3.67
8. BREAKEVEN QUANTITY, kg				
Above variable costs	7,662	8,219	9,727	10,376
Above total costs	8,206	8,763	10,271	10,920

Table 27. Enterprise budget for one FIPR system HSB crop initially stocked at 500 fish/m^3 in a 3.32 ha pond stocked on Feb 1 and harvested 36 weeks later. Catastrophic loss event occurring at indicated week with 10% of HSB removed at loss week.

	Week of Loss			
Item	**Early (1 wks)**	**Middle (19 wks)**	**Late (31 wks)**	**No Loss**
1. GROSS RECEIPTS	133,736	134,824	136,157	151,865
2. VARIABLE COSTS				
Fingerlings	24,095	24,095	24,095	24,095
Feed	23,937	24,719	25,982	26,967
Electricity	654	654	654	654
All Unspecified Costs: such as repairs and maintenance chemicals, fuel, labor, and interest on operating capital	20,865	21,200	21,742	22,164
TOTAL VARIABLE COST	**69,551**	**70,668**	**72,472**	**73,880**
3. INCOME ABOVE VARIABLE COSTS	**64,185**	**64,156**	**63,685**	**77,985**
4. FIXED COSTS				
Depreciation on capital items	605	605	605	605
Depreciation on machinery and equipment	2,305	2,305	2,305	2,305
Interest, taxes and insurance	962	962	962	962
TOTAL FIXED COSTS	**3,872**	**3,872**	**3,872**	**3,872**
5. TOTAL COST OF ALL SPECIFIED EXPENSES	**73,423**	**74,540**	**76,344**	**77,752**
6. NET RETURNS TO LAND				
Above variable costs	**64,185**	**64,156**	**63,685**	**77,985**
Above total costs	**60,313**	**60,284**	**59,813**	**74,113**
7. BREAKEVEN PRICE, $/kg				
Above variable costs	3.72	3.75	3.81	3.48
Above total costs	3.93	3.96	4.01	3.67
8. BREAKEVEN QUANTITY, kg				
Above variable costs	9,768	9,925	10,179	10,376
Above total costs	10,312	10,469	10,723	10,920

Table 28. Production, receipts, total costs and net return for 50% magnitude of loss scenarios.

		Week of Loss			
		Early (5 wks)	Middle (18 wks)	Late (32 wks)	No Loss
Production	(kg)	9,893	10,251	11,287	21,329
Reciepts	($)	70,438	72,984	80,362	151,865
Total Costs	($)	58,424	62,392	73,127	77,752
Net Return	($)	12,013	10,593	7,235	74,113

Table 29. Production, receipts, total costs and net return for 10% magnitude of loss scenarios.

		Week of Loss			
		Early (5 wks)	Middle (18 wks)	Late (32 wks)	No Loss
Production	(kg)	18,783	18,936	19,123	21,329
Reciepts	($)	133,736	134,824	136,157	151,865
Total Costs	($)	73,423	74,540	76,344	77,752
Net Return	($)	60,313	60,284	59,813	74,113

Table 30. Enterprise budget for a five year production strategy stocking only 7" fingerlings in one 65 m^3 FIPR system HSB crop stocked at 500 fish/m^3 stocking density in a 3.32 ha pond and first stocking on March 1.

	Crop Number and Start Date						
Item	**#1 Mar**	**#2 Nov**	**#3 Oct**	**#4 Nov**	**#5 Oct**	**#6 Nov**	**SUM**
1. GROSS RECEIPTS	148,322	151,564	152,393	151,564	152,393	0	756,236
2. VARIABLE COSTS							
Fingerlings	24,095	24,095	24,095	24,095	24,095	24,095	144,570
Feed	25,325	29,356	30,524	29,356	30,524	3,557	148,643
Electricity	581	890	944	890	944	291	4,540
All Unspecified Costs: such as repairs and maintena	21,429	23,289	23,813	23,289	23,813	11,975	127,609
chemicals, fuel, labor, and interest on operating capital							
TOTAL VARIABLE COST	**71,430**	**77,630**	**79,377**	**77,630**	**79,377**	**39,918**	**425,362**
3. INCOME ABOVE VARIABLE COSTS	**76,892**	**73,933**	**73,017**	**73,933**	**73,017**	**-39,918**	**330,874**
4. FIXED COSTS							
Depreciation on capital items	544	833	884	833	884	136	4,114
Depreciation on machinery and equipment	2,048	3,136	3,328	3,136	3,328	512	15,488
Interest, taxes and insurance	850	1,301	1,381	1,301	1,381	1,073	7,287
TOTAL FIXED COSTS	**3,442**	**5,270**	**5,593**	**5,270**	**5,593**	**1,721**	**26,889**
5. TOTAL COST OF ALL SPECIFIED EXPENSES	**74,872**	**82,901**	**84,970**	**82,901**	**84,970**	**41,639**	**452,251**
6. NET RETURNS TO LAND							
Above variable costs	**76,892**	**73,933**	**73,017**	**73,933**	**73,017**	**-39,918**	**330,874**
Above total costs	**73,450**	**68,663**	**67,424**	**68,663**	**67,424**	**-41,639**	**303,985**
7. BREAKEVEN PRICE, $/kg							
Above variable costs	3.33	3.33	3.33	3.33	15.06	0.58	
Above total costs	3.49	3.56	3.57	3.56	16.12	0.61	
8. BREAKEVEN QUANTITY, kg							
Above variable costs	10,032	10,903	11,148	10,903	11,148	5,606	59,742
Above total costs	10,516	11,643	11,934	11,643	11,934	5,848	63,518

Table 31. Enterprise budget for a five year production strategy initially stocking a 3” fingerling (Years 1 and 2) and subsequently stocking a 7” fingerling (Years 3, 4 and 5) in one 65 m^3 FIPR system HSB crop stocked at 500 fish/m^3 stocking density in a 3.32 ha pond and first stocking on April 1.

Item	#1 Apr	#2 July	#3 Oct	#4 Sep	#5 Sep	SUM
1. GROSS RECEIPTS	145,389	142,843	152,393	150,247	0	590,873
2. VARIABLE COSTS						
Fingerlings	9,990	9,990	24,095	24,095	24,095	92,265
Feed	40,612	30,038	30,524	33,614	8,575	143,363
Electricity	1,162	1,162	944	944	454	4,667
All Unspecified Costs: such as repairs and maintenance chemicals, fuel, labor, and interest on operating capital	22,185	17,653	23,813	25,137	14,196	102,983
TOTAL VARIABLE COST	**73,949**	**58,843**	**79,377**	**83,790**	**47,320**	**343,278**
3. INCOME ABOVE VARIABLE COSTS	**71,440**	**84,000**	**73,017**	**66,457**	**-47,320**	**247,594**
4. FIXED COSTS						
Depreciation on capital items	1,088	1,088	833	799	272	4,080
Depreciation on machinery and equipment	4,096	4,096	3,136	3,008	1,024	15,360
Interest, taxes and insurance	1,700	1,700	1,624	1,786	1,393	8,202
TOTAL FIXED COSTS	**6,884**	**6,884**	**5,593**	**5,593**	**2,689**	27,642
5. TOTAL COST OF ALL SPECIFIED EXPENSES	**80,833**	**65,727**	**84,970**	**89,383**	**50,009**	**370,921**
6. NET RETURNS TO LAND						
Above variable costs	**71,440**	**84,000**	**73,017**	**66,457**	**-47,320**	**247,594**
Above total costs	**64,557**	**77,117**	**67,424**	**60,864**	**-50,009**	**219,952**
7. BREAKEVEN PRICE, $/kg						
Above variable costs	3.33	3.33	3.33	3.33	8.46	
Above total costs	3.64	3.72	3.57	3.56	8.94	
8. BREAKEVEN QUANTITY, kg						
Above variable costs	10,386	8,264	11,148	11,768	6,646	48,213
Above total costs	11,353	9,231	11,934	12,554	7,024	52,096