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Two Bioeconomic Studies on Haddock Culture: Live Feed and Juvenile Production

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TWO BIOECONOMIC STUDIES ON HADDOCK CULTURE:

LIVE FEED AND JUVENILE PRODUCTION

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An Abstract of the Thesis Presented
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The State of Maine is reliant upon its natural resources. Wild catches of marine finfish, especially ground fish such as cod and haddock, are declining. In addition, several new restrictions have been placed on the culture of Atlantic salmon due to its listing under the Endangered Species Act. These issues serve as an impetus to explore the development of alternative species for cold-water marine aquaculture.

This research focuses on early haddock culture. The two areas where haddock culture varies from production of other species are the need for live feeds and proximity to seawater. Unlike salmon, haddock spend their entire life in seawater. Due to their small size at hatching, haddock must be fed rotifers and Artemia (live feeds). These factors distinguish the rearing of haddock from salmon.

The objective of this research was to develop an ex-ante estimate of the cost of producing juvenile haddock. A static budget was developed and then the stochastic factors affecting production were identified and quantified. The model was re-estimated using Monte Carlo simulation techniques to account for the uncertainty and risk of the

stochastic factors. Risk efficient technology choices were identified from the simulation. This was accomplished by dividing the thesis into two distinct papers: live feed production and juvenile production.

Different strategies of rearing the live feed organisms were analyzed. It was found that using yeast was more cost effective than using green water for enrichment. A breakeven analysis was done to analyze the relationship between the increased risk of a rotifer crash and the decreased cost of continuously rearing systems. The third area of live feeds production that was considered was the unpredictability of Artemia cyst prices. It was found that a doubling of Artemia cyst prices lead to a 5% increase in the total live feeds cost.

The second portion of the thesis looks at juvenile feeding technologies. Biological literature suggests that a reduction in the number of days juvenile haddock are fed live feeds will reduce the total costs of production. Including both the biological risk of mortality and the cost of producing live feeds, it was found that reducing the number of days on live feeds did not lead to a reduction in total costs.

Overall, it was found that juvenile haddock could be produced at under $1.60, 85% of the time. Reducing the number of days on live feeds did not result in a decline of total costs. The final step of the research involved sensitivity and policy analysis to determine where future research is needed. The price of Artemia cysts, the interest rate, and an increase to two production cycles per year were analyzed to determine the impact on per-fish costs. The largest cost reduction was seen when production increased to two cycles per year. This cost reduction is due to the large capital costs associated with the system.

DEDICATION

This thesis is dedicated to my husband, Ryan.

ACKNOWLEDGEMENTS

I would like to thank Dr. Timothy Dalton, who has given me the necessary guidance in order to complete my thesis. I also owe a great deal to Dr. Linda Kling who helped me become interested in the economics of aquaculture. I would also like to take this opportunity to thank Jacqueline Hunter and Neil Greenberg, who have both given me lots of information and ideas on aquaculture and live feeds production.

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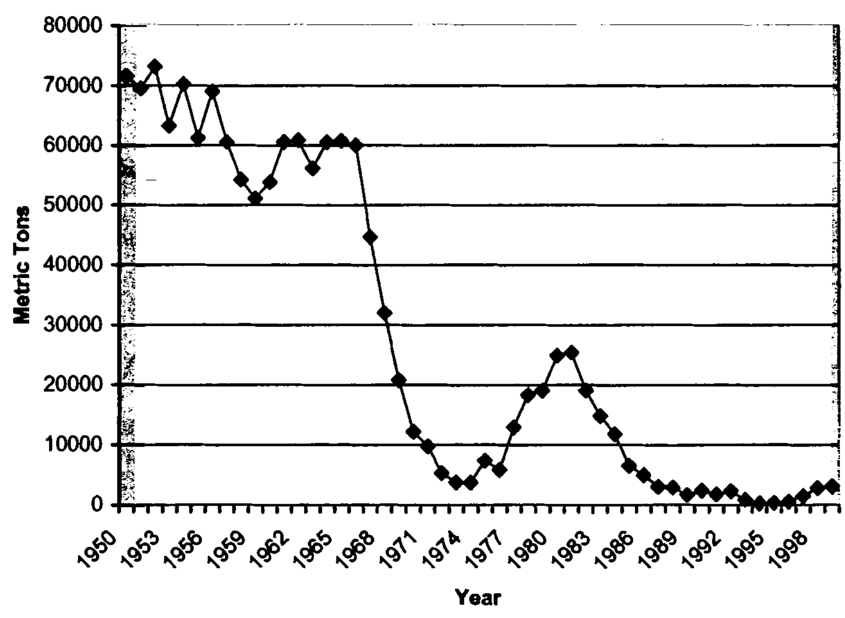
Chapter 1
INTRODUCTION AND JUSTIFICATION

The health of the ocean's fishery is a concern shared by biologists, fishermen, and marine governing agencies. The concern has been growing lately, as many fear the demise of several species of commercially important fish. The wild populations of ground fish, including cod, haddock, and flounder, have dwindled to levels near extinction. This has lead to fishing moratoriums and other restrictions since the early 1990s. The decline in population is due to many factors, including over fishing and the destruction of habitat and breeding grounds. Increased demand for fish as a protein source has encouraged the fishing industry to improve their technologies in order to catch

Figure 1.1: Haddock Catch from 1950-2000 in New England (in metric tons)

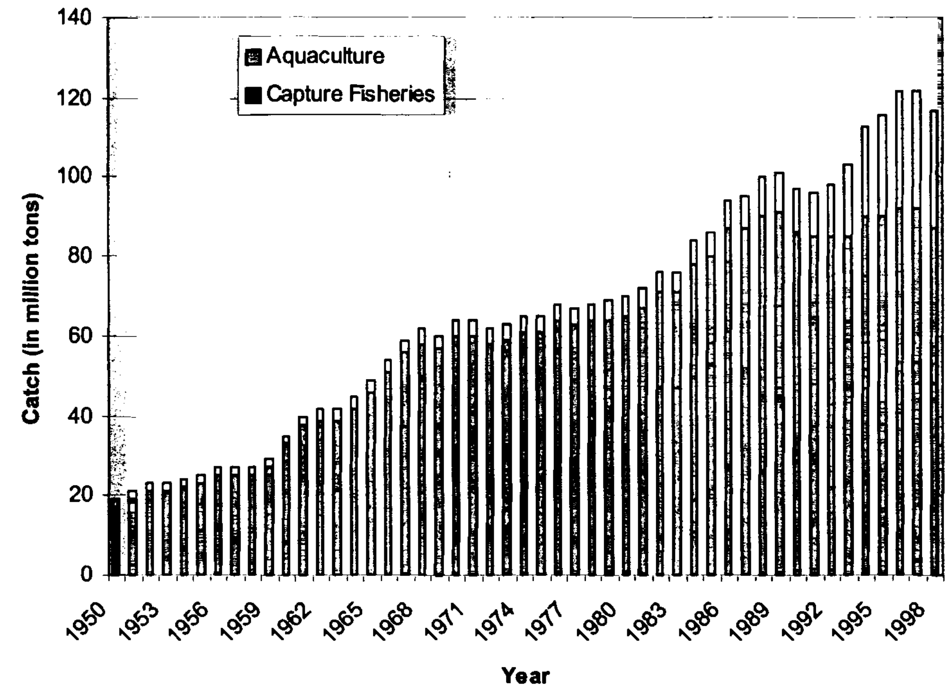


Source: National Marine Fisheries Service, 2001 more and more fish. Bigger, faster boats, the introduction of sonar and fish tracking devices, and improved nets and gear have all helped to enable the exploitation of many species of fish. Figure 1.1 depicts the quantity of haddock caught over time, and it is clear that the catch has dropped significantly since 1950.

By contrast, aquaculture has been growing at 11% per year over the past ten years, and is poised to take over cattle ranching in terms of pounds produced by 2010 (Brown, 2000). Figure 1.2 depicts aquaculture's increasingly important role. As population grows and the demand for seafood increases, the natural fisheries are not going to be able to meet the wants. Aquaculture can help in meeting the demand for seafood products.

The amount of fish caught in natural fisheries has been increasing since 1950. The higher catches are due to advancements in technology, not the increase in fish stocks. Biologists believe that many natural stocks are at all time lows. In many parts of the world, catch limits have been placed on many fisheries. In nine of the nineteen world fishing zones monitored by the Food and Agriculture Organization of The United Nations (FAO, 2000), fish catches are above the limit of sustainable yield (Meadows, 1992). Over 60% of the world's fish species are seriously threatened or on the verge of collapse. Almost all commercially important species are threatened. It is estimated that it would take at least five to twenty years for these populations to rebound to "healthy" levels, even if all fishing efforts were to stop (Meadow, 1992).

Figure 1.2: World Capture and Aquaculture Production, 1950-1998



Source: FAO, 2000

Fish have high protein levels with balanced amino acids, many essential vitamins and minerals, and provide the least expensive source of animal protein (Edwards, 1997). It is hoped that aquaculture will be able to produce a healthy and reliable protein source. There are 220 different species of finfish, shellfish, and crustaceans commercially farmed in the world. Fifteen species dominate production, and more than a third of all farmed fish is comprised of five species of carp (Brown, 2000). Since the early 1980's aquaculture is increasing (Figure 1.2) in order to meet some of the demand that cannot be met by traditional fishing means. Aquaculture has two main forms, extensive and intensive.

Extensive aquaculture has been practiced for thousands of years, especially in areas of China, Thailand, and Bangladesh. Extensive aquaculture involves growing fish in earthen ponds. Fish are usually caught from lakes or other sources as small juveniles. The fish are then placed in the ponds, where they remain until they are big enough to be harvested. Nothing, in terms of food or medication, is added to the ponds. The fish feed on plankton in the water or on plants growing in the pond. The number of fish in the ponds must remain low, so that there is enough food for all of them. The growth rates are not especially high, but this type of farming is very sustainable. It is also very cost effective for the farmer. There is also a semi-intensive type of aquaculture. This is exactly like the extensive aquaculture, except that fertilizers are added to the water to promote plant growth. The increase in plant growth allows for a larger number of fish to be grown in the same volume of water. Production can be increased by 25-40%, just by the addition of fertilizer to increase plant growth.

Many of the areas that once practiced extensive aquaculture are now moving to more intensive production, in order to increase output. The aquaculture in more prosperous nations, such as Norway, Canada, and the United States starts as the intensive type. In these areas, the majority of production is for export or for consumption in other regions of the country. In early times, the extensive culture was done in order to provide food for individual families and small communities. Intensive aquaculture involves large initial investments, in equipment, buildings, and construction. This type of aquaculture is usually done in tanks, raceways, oceanic net pens, or large constructed ponds.

There are usually three phases of the operation. The first phase consists of housing the broodstock, or parents. This phase produces the eggs, which are then sold to the second phase, which is the rearing of the juveniles. The eggs are incubated until they hatch; the fish then are fed until they reach the juvenile phase. Depending on species, this phase can occur in tanks or ponds. Once they reach the juvenile stage, they are sold to grow-out operations. In the grow-out operations the fish are put into large ponds, oceanic net pens, or large tanks. The fish get most or all of their nutrition from added feeds. As a result, the stocking densities in these operations can be very high.

Intensive aquaculture can produce up to six times more fish in the same volume of water as that which can be produced in extensive aquaculture. The fish and their health are closely monitored. If bacterial infection occurs, antibiotics are often given. The fish are also vaccinated to protect them from a myriad of viral diseases. Vaccines are important because the high stocking densities lead to the fish being in close proximity, which increases the spread of disease. Intensive aquaculture operations often have genetic breeding programs in order to enhance the lines for large size and fast growth. Intensive aquaculture is more costly than extensive aquaculture, because of the infrastructure and labor needed for its success. However, production is much higher.

Aquaculture, the raising of aquatic organisms in captivity, plays a vital part in Maine's agricultural economy. With its vast coastline and multitude of lakes and rivers, fishing has historically played a large role in Maine's economy. In past decades, the aquaculture industry has been steadily increasing. In 2000, Maine's aquaculture industry harvested $70 million worth of seafood, and employed over 900 people (Maine State Planning Office, 2002).

Over 75% of Maine's aquaculture is located in Washington County. Washington County is larger in area than Rhode Island and Delaware together, yet only has a population of 32,000. The region contains 412 miles of rivers, traveling to the ocean. These rivers are important not only for industry, but also for breeding areas for many species, including the Atlantic salmon. Throughout its history, this region has been economically dependent upon natural resources, especially fish and lobster. The top employers include aquaculture operations, commercial fishing boats, and fish processing plants.

The recent listing of the wild Atlantic salmon under the Endangered Species Act (ESA) is expected to have many negative implications for Maine businesses. The Atlantic salmon aquaculture industry may be the most seriously affected (Wilson, 2000). Due to the production restrictions imposed under the ESA listing, many aquaculture operations may close down on move to other locations. The closures and movements are going to leave many aquaculture workers unemployed and many production sites unused. These economic changes will be significant since most of the affected region (Downeast Maine) currently exhibits relatively high unemployment rates and relatively low incomes. Washington County has one of the lowest per capita incomes in the state ($15,180 vs. state average of $19,488) (Maine State Planning Office, 2002). There are only eight businesses in the area that employ more than 100 people. The unemployment rate is also consistently one of the highest in the State, usually falling between 12 and 13 percent in the winter months (Maine State Planning Office, 2002).

The current status of the ground fish stocks is another motivating force behind this research. With declining natural populations and limits being placed on wild catches, the market demand will soon not be able to be met by fishing alone. Although all of the intricacies of the relationship between aquaculture and natural fisheries is not known, it is hoped that aquaculture may be able to lessen the pressure on the wild fish stocks, allowing them to attain healthy, sustainable levels.

A potential alternative to raising Atlantic salmon is to raise haddock. Commercial haddock production is in its early stages; research into the production and marketing of haddock is needed. In many ways, raising haddock is similar to Atlantic salmon aquaculture, but there are several significant differences. These differences arise in the feeding and early rearing techniques. Our research is going to look at the economic feasibility of alternative species production, namely haddock. This research is crucial to the state, because it could help to offset the financial hardships that will be faced by workers and communities that depend on salmon aquaculture.

Objectives and Organization

Research is needed to ensure that haddock production is a viable alternative to salmonid culture for commercial aquaculture. The goal of this research is to analyze the economic feasibility of the early stages of haddock aquaculture, and to determine the areas of production that need to be improved biologically in order to decrease costs. Although Atlantic salmon and haddock aquaculture are similar in many regards, there are also several significant differences. Most of these differences occur during the first few stages of production. The first objective is to develop cost effective methods for producing rotifers and Artemia, the live food organisms needed for haddock larvae at first feeding. The second objective is to improve the techniques of rearing haddock from egg to the juvenile stage, at which time they are ready to enter the netpens in the ocean. For ease of reading, this thesis will be split into two distinct papers.

The first section is to estimate the cost of producing the live feeds: rotifers and Artemia. The production costs of these live feeds represents a majority of the total operating cost of juvenile production. If brine shrimp hatching techniques can be improved and rotifer culture methods made less labor-intensive, then this could make larval haddock rearing less costly. It is necessary to consider the risk associated with the different production methods for live feeds.

The second section analyzes the production of juvenile haddock. This production will be in a land-based facility. Once the juvenile stage is reached, the fish are ready to be placed into oceanic net pens. It is important to determine which culture techniques will give the lowest cost, as well as considering the variability. It is also important to study new techniques of weaning the juvenile haddock onto microparticulate (MP) diets.

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Chapter 2
LIVE FEEDS PRODUCTION

Introduction and Justification

Female haddock are much more fecund than are female Atlantic salmon. Fecundity is a measure of reproductive capacity; in this case it refers to the number of eggs produced by the female. More eggs are produced, but the size of each egg is much smaller. As a result, the haddock fry (hatchlings) are much smaller at hatching and first feeding than are the salmon fry. Salmon fry are able to eat microparticulate (MP) diets at first feeding. Haddock, on the other hand, will not eat these formulated MP diets, and must be fed live foods. *Brachionus plicatilis* (rotifers) and *Artemia* (brine shrimp) are the two live feeds most commonly used in marine aquaculture.

Haddock feed on the yolk sac for the first few days after hatching. After three days (temperature-dependent), the larvae are fed exogenously. Rotifers are fed first, then brine shrimp, and then finally they are weaned onto the formulated MP diets.

The following sections will discuss the key economic differences in rearing live feeds. There are several different rotifer techniques, each varying in production levels and risk. Artemia are hatched and enriched, and there are not many variances of technique. In order to analyze the costs of the different scenarios, budgets will be created to look at the annual costs of producing the live feeds. There are two types of uncertainty in the model: economic and biological. These uncertainties are taken into the account using Monte Carlo simulation technique. This technique allows helps to determine the cost of the associated risk.

Literature Review

Rotifers

Rotifers are small marine organisms. *Brachionus plicatilis* was first developed as larval fish food in Japan in the 1950's. They are the most commonly used live feeds in hatcheries worldwide. Over 60 species of marine finfish are cultured globally using rotifers as live food (Treece and Davis, 2000).

There are several different methods used for rotifer culture. The earliest method of culture involved the daily transfer of rotifers to fresh tanks of water. While this method prevents the build-up of wastes in the tanks, it is labor intensive, and hence costly. This daily transfer method is not currently used in commercial aquaculture. Presently, the two most common types of systems used for rotifer culture are batch or continuous methods.

Batch culture involves a three to five day production cycle. On day 1, a culture of rotifers is placed into a clean tank. During the middle days of the cycle, fresh seawater is added to the tank. One the final day of the cycle (either day 3, 4, or 5, depending on cycle length) the tank is drained. From this drained tank, some of the rotifers are used for feed for the larval fish, and the remaining rotifers are placed into a clean tank to start a new cycle at day 1. Batch culture is the most reliable, but the least efficient in economic terms.

Continuous cultures are less costly than batch culture, but can be hard to maintain (Treece and Davis, 2000). Maintenance is difficult, because without frequent and complete water changes, wastes accumulate quickly in the tanks. In continuous cultures, the tanks run indefinitely, with some rotifers removed daily for feeding. In removing some rotifers, some water is also removed. Fresh seawater is then added to replace the drained water. Without complete water changes, wastes can accumulate, leading to chemical, bacterial, and fungal contamination. If the water quality parameters are not within the proper ranges, a "crash" can result. Crashes can have negative economic implications for the hatchery, because a large percentage of the rotifer population will die. This means that there will not be enough rotifers to feed the haddock fry and maintain a large enough population for the next cycle. In extreme cases, a crash or collapse of the rotifer population can result in a loss of an entire year's production of juvenile fish (De Araujo et. al., 2000).

The risk or probability of a crash must be considered when determining the method with which to culture rotifers for the facility. There is currently research being done to determine tests to look at the stress levels of rotifers in the culture. If the rotifers are stressed, then there is an increased likelihood of the tank crashing. De Araujo et.al. (2000) looked at the disadvantages and advantages of different methods to indicate stress levels. These methods include survival, egg ratio, ingestion rate, swimming activity, and enzyme inhibition. Using these methods may help to decrease the risk of crashes, by alerting the culturist to the problem while there is still time to take action to correct the problem. Using batch culture, it is estimated that there would be an average of two or three crashes during a typical four-month production cycle. However, the number of crashes is dependent upon the experience level of the culturist (Greenberg, 2002).

While being cultured in intensive systems (year-round, indoor facilities), the rotifers must be fed and enriched. Rotifers can either be cultured in green water (seawater containing algae), in which case they would use plankton and algae as the food source. Baker's yeast can also serve as the food source for rotifers, if they are not cultured in green water. Stottrup (2000) suggests feeding a mixed diet to the rotifers. A mixed diet consisting of both yeast and various algal species will lead to better productivity of the rotifers and they will be more nutritional for the fish. The only downside to using green water is the added cost. Green water must either be pumped in from the ocean, resulting in additional filtration and sterilization costs. Algae can also be cultured in the facility.[1] Enrichment is the process in which rotifers are "fed" emulsions of certain fatty acids and vitamins. While these components are not necessary for the rotifers themselves, the fry needs them. The rotifers serve as a vehicle to get the fatty acids and vitamins to the fish.

Artemia

Artemia, also called brine shrimp, are used for the second stage of live feeds production. Artemia are larger than rotifers, and the haddock switch to the brine shrimp once they have grown to approximately 8.5-9 mm. After approximately 21-28 days of rotifers, the larvae are introduced to the Artemia. During this switch from rotifers to Artemia, there is a co-feeding period of seven days. Artemia are purchased as dried cysts, and then decapsulated. There are different grades of cysts. There is a correlation between the quality/grade of the cysts and the hatch rate. Early analysis indicates that brine shrimp account for 40% of the feed costs, and 80% of the live feeds costs for marine larviculture (Le Ruyet, et.al, 1993).

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[1] Commercial sources of condensed algae and algae paste are also available. These sources are not included in the analysis.

The first step of Artemia decapsulation is to place the cysts in a bleach and sodium hydroxide solution. After the solution has weakened the outer layer of the cysts, the cysts are rinsed thoroughly with freshwater in order to remove all traces of solution. The bleached cysts are then placed in heated, aerated vessels containing seawater for 24 hours to hatch. After hatching, the Artemia napulii are enriched.

There are very few costs associated with the production of Artemia. There is not a lot of equipment or labor involved in the decapsulation of cysts. The main cost associated with the Artemia is the cost of the cysts. For this reason, the only way to reduce the cost of production is to reduce the amount of Artemia fed to the haddock fry.

Microparticulate Diets

Microparticulate (MP) diets are formulated diets produced by feed companies. They are commercially available, and are very inexpensive when compared to live feed costs on a per-day fish feeding basis. MP diets are available in many sizes, so they can accommodate the fry as they grow. Formulating a compound diet adequate for larvae is difficult, because the estimation of nutritional requirements of fish larvae cannot be conducted by traditional nutritional approaches (Cahu and Zambonino Infante, 2001). Cahu and Zambonino Infante also point out that nutritional requirements change rapidly as the fish grow, creating another problem for finding proper MP diets.

For this analysis, a feeding technology is used whereby the larvae are fed rotifers for approximately 28 days, Artemia for 25 days, and then weaned on to a MP diet for the remainder of the juvenile production cycle. When there is a weaning from one diet type to another, there is a seven-day co-feeding period. This co-feeding period helps to reduce stress to the fish. This paper will focus on finding the least costly live feeds regime, in terms of rotifer technologies and scale of production. The model will also include the expected cost of the crash risk of rotifers.

Data, Methods, and Key Assumptions

In order to derive the economic cost of live feeds production, costs must be estimated and a budget formed. These costs include capital and operating and maintenance (O&M) costs. Capital costs include items that are durable, and are expected to last for more than one year.

O&M costs consist of variable costs and annual fixed costs. Variable costs are those costs which change depending upon the amount of output produced. Common variable costs in the aquaculture industry include feed, labor, and electricity. Annual fixed costs include costs that occur each year, but do not vary depending on production. These include such things as leases, permits and licenses.

In order to determine the size of the tanks and the O&M costs, some assumptions must be made. Three alternative scenarios have been set up, each producing different levels of juvenile fish. The levels are 100,000, 200,000 and 400,000 fish (low, medium, high production levels). Due to the high mortality of haddock from egg to the weaned stage, the number of fish being fed is much higher at the beginning of production than at the end. In addition to the haddock production levels, alternative scenarios are being formed using the two different rotifer feed methodologies (yeast v. green water), as well as the two rotifer production technologies (batch v. continuous culture). Costs are examined in detail below. The live feeds model excludes haddock mortality. It assumes that the number of fish being fed at the beginning of the production cycle is the same as at the end of the cycle.

Capital Costs

There are five main centers of capital costs:

1) Building and Land;
2) Pumping, Filtering and Heating Equipment;
3) Generator;
4) Tanks;
5) Plumbing and Miscellaneous Equipment.

The facility and land requirements for a typical operation are based upon a facility recently purchased in the Franklin, Maine area. It is important that the land be located close enough to the coast so that seawater can be pumped into the facility. It is important to make sure that there is at least a few hundred feet of shore frontage. Frontage is needed to provide enough area for water intake.

The first cost center is the building and land. Building costs are estimated to be $120 per square foot (R.S. Means, 2001). This would provide for an industrial-type building with concrete floors, and would have areas for egg incubation, larval production, live feeds productions, and office space. The size of the building is dependent upon the level of production. As production increases, more space is needed. The low production level uses a 5000 square foot building. As production increases, the building size increases by 25%.

The second cost center includes the pumping, filtering, and heating portions. The intake pumps are located outside, right near the water. Only one pump is used at a time, but most operations would have a secondary pump in case of mechanical failure. Although the system is recirculating, it is important that water be brought in continually. Even in a recirculating system, 10-20% of the water is replaced daily. The incoming water from the ocean would be mechanically filtered. The water would also be filtered through an ozone generator to kill any potentially harmful microorganisms.

The water will flow from the holding tank into the live feeds production room. Since the water for the rotifers will need to be warmer than the water for the fish (around18-20°C), it will need to be heated. The water will have to be pumped through an inline heater, in order to get it to the desired temperature.

The third cost center is the generator. A 234-killowatt generator is another necessary component of the set-up. The generator is powerful enough to run the entire facility. This is very important in the event of a power failure.

The fourth cost center includes the tanks needed for the operation. After filtration, the water will be pumped into a holding tank. The holding tank will be raised, allowing the water to be gravity-fed throughout the different systems in the buildings. The raised tank will reduce costs, because the water will not have to be pumped again.

The rotifer setup includes tanks with drains, set on wooden platforms. The number of tanks is dependent on the number of rotifers needed, and the stocking density (type of system) used for production. The miscellaneous rotifer cost includes the initial starter culture of rotifers, piping to the tanks, mesh bags for draining the tanks, air stones, etc.

The equipment needed for Artemia production includes vessels used for the initial decapsulation (bleaching process). The decapsulated cysts would then be placed in the hatching vessels with spigots for easy draining. Plastic cylindrical tanks would be used to enrich the decapsulated Artemia. Miscellaneous Artemia cost includes air stones, piping, small aquarium heaters, etc.

In order to determine the number of tanks needed for each type of culture, it is necessary to know how many rotifers the fish will eat per day. While eating rotifers, each fish will be fed 834 rotifers per day (over four feedings per day). Each fish will consume an average of 250 Artemia per day. The table below shows the number of rotifers and Artemia needed per day for feeding for the different scenarios (Hamlin and Kling, 2001).

Table 2.1: Rotifer and Artemia Needed for Various Production Levels (in millions)

	# Rotifers/day	#Artemia/day
Low	83.4	25
Medium	166.8	50
High	333.6	100

Using batch culture, 350 rotifers/ml can be harvested every four days (Suantika, 2000). The production level will determine the size of the tanks used. The more rotifers needed, the larger the tank. For the continuous operation there is a lot more uncertainty on production levels. Between 100-950 rotifers/ml can be harvested every 3-7 days for continuous cultures (Suantika, 2000).

The stocking density in the Artemia vessels is not as critical, because they are only in there for a very short time. Also, since the first decapsulation process can be done in separate batches, only two of the initial decapsulation vessels are needed. Ten decapsulation vessels and ten enrichment vessels should be able to accommodate the Artemia needed for any of the three production levels.

The fifth cost center includes plumbing and miscellaneous capital needs. Plumbing includes all piping, valves, connections, etc. in the entire system. Miscellaneous live feeds costs include items that are needed for both rotifer and Artemia production. This would include a microscope needed to determine population levels of the cultures. Also included in this cost would be a heavy-duty blender needed to make enrichment emulsions, and water quality testing devices, such as an oxygen meter.

If the rotifers are fed an algal diet, the cost of growing algae must be included. The capital costs of algal culture would include lights, shelving units, glass beakers, etc. If the rotifers are only fed yeast, then the algal culture setup will not be needed. A complete listing of the capital requirements is detailed in Appendix A.

Operating and Maintenance Costs

Operating and maintenance (O&M) costs consist of variable costs and annual fixed costs. Variable costs are those costs which change depending upon the amount of output produced. Annual fixed costs include costs that occur each year, but do not vary depending on production. These include such things as leases, permits and licenses. There are five main cost centers of O&M costs:

1) Electricity;
2) Labor;
3) Artemia cysts and Enrichment and food for live feeds;
4) Consumables;

5) Licenses and permits.

The first center of O& M costs is electricity. Electricity is needed to run much of the equipment in the facility, including the pumps, filters, and lights. The electricity needs for the facility are estimated at 200 kilowatts per day, which is a weighted sum of peak and off-peak electricity usage. The peak electricity use is estimated to occur for 2 hours per day. The total electric costs for the production cycle are found by multiplying the total kilowatts needed by the cost per kilowatt-hour (Greenberg, 2002).

The second cost center of O&M costs is labor. For the live feeds production, two full time and one part time employee would be needed. The two full-time employees would be responsible for maintaining the rotifer cultures, decapsulating the Artemia cysts, and maintaining algal cultures (if green water is used). The part-time employee would work evenings and weekends, doing some culture maintenance and evening feedings/enrichments. Labor is not dependent upon production level. Although more rotifers and Artemia are being produced, larger tanks are used. However, it takes approximately the same amount of time to harvest and clean a large tank as it does a small tank, therefore no change in labor requirements (Hunter, 2002).

The third center of the O& M costs is the cost of the Artemia cysts. There are 250,000 cysts/gram. 454-gram cans can be purchased with a 90% hatch rate. For high quality cysts, the cost per can is approximately $40. However, due to the shortage of cysts, this price is very volatile and has increased significantly in the past decade. This price increase is expected to continue over time. At a low production level 0.25 cans of cysts are needed per day, 0.5 and one can are needed, respectively, for the medium and high production levels.

Another necessary cost associated with live food production is the cost of yeast and enrichment. If rotifers are not reared in green water than they are fed yeast. Enrichment is the process in which the rotifers and Artemia are "fed" emulsions. These emulsions are very high in certain fatty acids and vitamins. The live foods take up these emulsions and then they are passed to the fish, when the rotifers and brine shrimp are eaten.

Consumables, the fourth cost center, are another part of the operating costs. This section includes things such as chemical test kits used to check ammonia, nitrites, and other important water quality factors. Included in this category would be pH buffers and replacement parts for oxygen and pH meters. This section also covers other items that need to be frequently (at least a couple of times per year) replaced. It would cover things such as cleaners, disinfectants, solutions for the foot and hand baths, replacement UV bulbs for the UV filters, and replacement filters. Hand and foot baths are important to have at the entry to each area, to prevent disease transmission from one area to another. The yearly cost associated with these consumables is $2000.

The fifth cost center is licenses and leases. This would cover the costs of licenses needed for the operation. The cost is estimated at $100 per year (Greenberg, 2002). Also included in the O&M section is the interest on the working capital of the facility. This charge represents the opportunity cost of using the money for haddock production instead of another activity.

Risk and Uncertainty

Risk and uncertainty are having imperfect information and unknown consequences (Hardaker, 1997). Since there is currently no commercial production of haddock, this analysis is an ex ante assessment of production costs. This type of assessment is based on estimates, which creates many uncertainties, both biological and economic.

Economic Risks

Since commercial marine aquaculture is still in development, there is a lot of uncertainty in economic models. Many of the variables and inputs are based on estimates from other cultured species or from experimental data. In order to accommodate this uncertainty in the model, Monte Carlo techniques are used to simulate the alternate cost scenarios by varying the quantity and price of inputs. The economic uncertainties that the model is concerned with are electricity, labor, interest, and Artemia cyst price.

There are two parts of the electricity cost that are unknown. The first is the actual cost of the electricity from the supplier. Due to the deregulation of electricity in Maine there have been changes in price in the past few years, and this could alter the price in future years. The other unknown portion of the electricity costs is in calculating the actual electricity needs of the operation. There is no available data about the electricity demand from commercial marine hatcheries, so these figures for kilowatt hours needed are estimated based upon companies with labs and are adjusted for efficiency. Also, as aquaculture technology advances, much of the equipment will become more energy efficient. This trend has been seen in the past couple of decades. In the model, electricity prices were varied by ten percent above and below the estimate, to account for the price uncertainty. The full-time and part-time labor prices are also varied by ten percent over and under the expected wage rate.

The interest rate used in the analysis is a real interest rate, meaning it has been adjusted for inflation. The nominal rate used in the model is 8.0%, which is the average used for agricultural loans. There is variance in the inflation rate over time, which will affect the real interest rate, and is accounted for in the model.

The cost of Artemia cysts has increased dramatically in the past decade. The shortage and price increases are due to the fact that there is a limited supply of the cysts and demand has increased significantly due to the increase in aquaculture. With no good substitutes for the cysts, it is expected that the price will continue this upward trend. In the analysis, cyst prices of $40, $80, and $160 were used.

Table 2.2: The Distribution and Expected Value of Uncertain Parameters

	Distribution	Expected Value	Minimum	Maximum
Electricity Consumption	Triangular	89 kwhr/day	56 kwhr/day	110 kwhr/day
Electricity Price	Uniform	$0.13	$0.125	$0.135
Part-time Wage Rate	Varied by +/- 10%	$6.50	$5.85	$7.15
Full-time Wage Rate	Varied by +/- 10%	$8.50	$7.65	$9.35
Real Interest Rate	Extreme Value	4.46%	0.20%	7.16%

Biological Risks

In addition to economic risks, there are also several biological risks. For the live feeds model, the main biological risk is the likelihood of crashes in the rotifer systems.

These crashes are costly and can have devastating effects on fish production. The model will help determine the expected cost of a crash.

The two types of rotifer production systems, batch and continuous cultures, have different crash rates. It is expected that there will be 2-3 crashes during a typical 120-day culture period, using the batch culture method (Greenberg, 2002). The model is run with scenarios ranging from zero to four crashes during the production cycle.

Table 2.3: Number of Expected Rotifer System Crashes and the Associated Expected Probability

Number of Crashes	Expected Probability
0	77.27%
1	9.09%
2	6.82%
3	4.55%
4	2.27%

Results

Total Investment Costs

Investment costs are the costs associated with land, the building, and equipment described in the previous section. In this section, the investment costs are only for the live feeds portion. Some of the costs are needed for the live feeds lab as well as the rest of the operation (such as land, building, etc.). Approximately 10% of the space and water need is apportioned to the live feeds lab. Therefore the 10% of total cost is used as the cost of these shared items for this analysis. Investment costs will differ depending upon the level of production, as well as the type of rearing practice used (yeast vs. green water). The costs were estimated from discussions with individuals involved in the industry, as well as quotes from aquaculture supply companies. The total investment costs do not differ significantly for the different scenarios. Total investment costs for the live feeds portion of the operation are estimated between $81,200 for low production and $98,400 for high production. A list of the investment costs is located in Appendix A.

Table 2.4: Investment Costs for Live Feeds Using Different Production Techniques ($/facility)

	Green Water	Yeast
Low	$82,657	$81,157
Medium	$90,185	$88,685
High	$98,375	$96,875

Annual Ownership Costs

Annual ownership costs include the depreciation, interest, taxes, insurance and maintenance/upkeep for the capital costs. Depreciation is calculated using the annual equivalent capital recovery technique (Patterson et.al., 1996). Deprecation and interest are calculated:

$$D = B\ [i\ (1+i)^n/[(1+i)^n-1]]-V\ (i/[(1+i)^n-1]$$

Where D= Deprecation and interest charge

B = initial investment

V= salvage value

i = real interest rate

n = years of useful life of capital

The useful life estimates for the capital components are shown in Appendix A. The useful life depends on the type of equipment. Taxes and insurance are estimated to be 0.7% of the purchase price. Maintenance and upkeep charges are determined as a percentage of the purchase price. These percentages are shown in Appendix A, and vary depending on level of usage. For example, equipment that is used frequently and has many moving parts, such as pumps and filters, have a higher relative maintenance cost than tanks. Some capital costs increase as the production levels increases, for example the building size and the size of the rotifer tanks. Annual ownership costs range from $7,323 for low production, not using green water to $9,238 for high production using green water.

Table 2.5: Expected Annual Ownership Costs for Live Feeds Using Different Production Techniques ($/year)

	Green Water	Yeast
Low	$7,681	$7,323
Medium	$8,412	$8,054
High	$9,238	$8,880

Operating and Maintenance Costs

There are changes in the O&M costs, when comparing the alternative scenarios. Electricity, labor, and license costs are the same for the different production levels and scenarios. However, cyst costs, consumables, and yeast costs will vary depending on the level and scenarios. Yeast costs are less if green water is used. These costs range from $15,500 to $18,600.

Total Annual Costs

The total costs or the yearly budget adds the O&M costs and the yearly ownership costs for the live feeds operation. The total costs for the alternative scenarios are presented in Table 2.6. There is less than a 1% increase in the costs of using green water as the rotifer food source instead of yeast. The results indicate that the production of live feeds experiences economies of scale. Economies of scale are seen when costs increase at decreasing rates as production expands. O&M costs account for approximately 75% of total annual costs for all production levels.

Table 2.6: Median Total Annual Cost for the Six Live Feeds Production Scenarios ($/year)

	Low Production		Medium Production		High Production	
	Green Water	Yeast	Green Water	Yeast	Green Water	Yeast
Ownership	$7,681	$7,323	$8,412	$8,054	$9,238	$8,880
O&M	$15,479	$15,493	$16,560	$16,588	$18,467	$18,522
Total Annual Cost	$23,160	$22,816	$24,972	$24,642	$27,705	$27,402

Table 2.7 shows the summary statistics for the annual costs after including the biological and economic risks discussed above. 1500 iterations were run, using the Artemia price set at the current level of $40. The uncertainty in the model provides the ranges for estimated total annual costs. There is approximately a $4,000 difference between the maximum and minimum values. This difference is 17% of the expected total annual cost.

Table 2.7: Summary Cost Statistics for the Six Production Scenarios ($/year)

	Low Production		Medium Production		High Production	
	Green Water	Yeast	Green Water	Yeast	Green Water	Yeast
Minimum	19,464	19,182	21,027	20,759	23,482	23,242
Maximum	26,062	25,699	27,997	57,649	30,893	30,575
Mean	23,274	22,930	25,095	24,765	27,840	27,538
Median	23,310	22,968	25,140	24,817	27,900	27,597
St. Deviation	1,090	1,077	1,150	1,136	1,218	1,204
Skewness	-0.229	-0.219	-0.248	-0.239	-0.265	-0.257
Median Cost/fish	0.233	0.230	0.126	0.124	0.070	0.069

Due to the large uncertainty of Artemia cyst prices, the model was rerun using the high estimates of future cyst price. Table 2.8 shows the total annual median cost of production at the different price levels. The total costs of production are not sensitive to changes in cyst price. A ten percent increase in cyst costs will lead to a 0.5% increase in total annual costs at the high production level

Table 2.8: Total Median Costs for Rotifer and Artemia Production for the Six Production Levels, Varying Artemia Cyst Price ($/year)

	Artemia Cyst Price ($/454g can)		
	40	80	160
Low Production			
Green Water	23,310	23,649	24,326
Yeast	22,968	23,307	23,984
Medium Production			
Green Water	25,140	25,816	27,173
Yeast	24,817	25,494	26,847
High Production			
Green Water	27,900	29,253	31,962
Yeast	27,597	28,953	31,663

Alternative Production System

The continuous rotifer culture method is relatively new, and not currently used in commercial operations. As a result, there is not enough information about the crash likelihood for these systems. Because of the increased populations and decreased water changes, it is assumed that there will be more crashes in continuous operations, at the current level of technology. Due to the decreased labor input, the cost of running a continuous system is less than a batch culture system. It is assumed that 50% less labor will be needed for production of the rotifers. Breakeven analysis will be done in order to determine the point (in terms of number of crashes per cycle) at which continuous culture is more cost effective than batch culture. For the continuous culture model, an ex ante budget was formed which was identical to the batch budget, except for the labor costs. Three different crash situations were also analyzed: a minor crash, which takes two days to recover to normal production levels, a medium crash, with a recovery period of three days, and a major crash with a recovery period of four days. The following table summarizes the results of the model simulation. The cost penalty associated with a minor crash is estimated to be $440. The cost penalties for medium and severe crashes are $670 and $877, respectively.

Table 2.9: Breakeven Analysis of Continuous Culture Compared to Batch Culture ($/year)

	Cost Saving	#Minor	#Medium	#Major
Low Production				
Green Water	$3,500	8	5	3
Yeast	$3,500	8	5	3
Medium Production				
Green Water	$3,500	8	5	3
Yeast	$3,500	8	5	3
High Production				
Green Water	$3,500	8	5	3
Yeast	$3,500	7	5	3

The breakeven analysis shows that as long as there are fewer than eight minor, five medium or three major crashes during the production cycle, then continuous culture is more cost effective than batch culture. In the batch culture system, there was only a 2.27% probability of having four crashes in a cycle. Although biological research is still analyzing continuous culture system, it appears that it would be economically viable.

Conclusions

An important finding is the large economies of scale when comparing the different production levels. This is expected, because the hatchery phase of production is capital intensive. The live feeds cost per-fish decreases significantly as the production level increases. The live feeds cost per-fish decreases from $0.23 (producing 100,000 fish) to $0.07 (when producing 400,000 fish).

The analysis shows that green water is more costly to use as the rotifer food source than is yeast. However, this cost difference if very insignificant, at less than an

1% increase. It appears that as technology progresses, continuous rotifer culture will be more cost effective than batch rotifer culture. The annual cost of a continuous system is approximately 14% less than the cost of a batch system. Once the crash likelihood is reduced for this system, it will have a definite cost advantage.

The difference in the maximum and minimum estimates for annual costs accounts for the variance in the model. The variance comes from the biological and economic uncertainties and risks of production. There is an approximate disparity of $7,000 between the minimum and maximum estimates. As the biology and economics of haddock production improve, there will be less uncertainty, and therefore less variance between these values.

Cited biological literature suggests that the Artemia costs have a large impact on total costs. However, this is not the case. A ten percent increase in cyst costs will lead to a .5% increase in total annual costs at the high production level. In the past five years, the cyst prices have doubled. A doubling of cyst price from the current level will lead to an increase of total annual costs by 1.5% (for the low production level) to 5% (for the high production level). The total costs are highly insensitive to increases in the cyst price. The uncertainty in cyst price indicates an area that needs research in the future. While there are Artemia alternatives being researched, there are no economically viable alternative production techniques that will reduce the cost of Artemia use. The following chapter on juvenile production will look at the economics of alternative feeding strategies. Further analysis will help to determine the cost share of Artemia in the juvenile production budget. Some of the feeding strategies use no Artemia or far less than the traditional feeding strategy modeled in this paper. There is a definite tradeoff between the use of Artemia and the survival rate of the larval haddock. This cost tradeoff is studied in the next chapter.

The live feeds costs represent a large percentage of the total yearly operating budget for a hatchery producing haddock. Since live feeds are not needed for many other aquaculturally produced species, such as salmon, haddock production may be more costly than most other types of culture.

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Chapter 3
JUNVEILE PRODUCITON

Introduction

It is important to research the economic feasibility of production before beginning business ventures in the aquaculture of alternative species. Each species holds unique challenges in culture, so a model for Atlantic salmon or a freshwater species, will not hold for haddock. Although haddock aquaculture is in its early stages, it appears that it has potential for future commercial production.

Although Atlantic salmon and haddock aquaculture are similar in many regards, there are also some significant differences. Most of these differences occur during the early stages of production. Atlantic salmon are anadromous fish, which means that they hatch and live in fresh water for the first couple years of their life. After smoltification, the salmon are ready to move into saltwater. Haddock hatch and spend their entire life cycle in seawater. Another difference between haddock and salmon are the size at hatching; haddock are much smaller at hatching. This distinction means that haddock need special diets, and are not able to eat commercially produced diets. The third main difference between the two species is the survival rates in production. Salmon have much greater survival rates in cultured settings than do haddock.

Biological literature suggests that the production cost of live feeds represents the majority of the total costs of producing juvenile haddock (Le Ruyet, et.al, 1993). If brine shrimp usage can be made more efficient and rotifer culture techniques made less labor-intensive, larval haddock rearing would less costly (Lee and Ostrowski, 2001). It is also important to study new techniques of weaning the juvenile haddock onto microparticulate (MP) diets. Feed costs are currently estimated to be 40-60% of cost of salmon production, from egg to market size. Biologists estimate that these costs may be as high as 75% of total costs for haddock, because live feeds are so costly to produce (Le Ruyet, et.al, 1993). Since live feeds are not used in many commercially produced species, there has not been extensive economic analysis published.

The modeling of the juvenile production will determine if commercial haddock production is economically feasible. It can also find the economically optimal feeding technologies and analyze different production levels. The hypothesis is that reducing the number of days on live feeds will reduce the per-fish production cost. If it is found that haddock production is currently not feasible, the model will identify areas where research may decrease costs of production. The goal of the model is to find the minimum cost of rearing a juvenile haddock, and will determine the least costly feeding regime. Stochastic dominance techniques will be used to identify the preferred feed technology.

A budget for the production of juvenile haddock will be created for three different production levels: 100,000, 200,000, and 400,000 fish per year. These production levels represent the number of five-gram juveniles that will be placed into the netpens. As discussed later, the larval haddock have high mortality during the early stages of production (egg to five grams). These high mortality rates mean that the culturist must begin with many more fish than the target levels. There is much uncertainty and risk associated in these models.

Risk and uncertainty are having imperfect information and unknown consequences (Hardaker, 1997). Within the juvenile production model, there are many uncertainties, both biological and economic. The biological uncertainties result from the survivability of the haddock, as well as the uncertainty associated with live feeds production, discussed in chapter 2.

Literature Review

As aquaculture production increases, there has been an interest in diversifying the species that are reared. The downside of culturing alternative species is that there are several bottlenecks encountered in commercial production. These bottlenecks include low output levels and the lack of production efficiency (Shields, 2001). These problems are seen in the emerging culture of cold-water marine species including haddock.

The need for seawater in the hatchery stage greatly increases the cost of producing juvenile haddock. Haddock hatcheries would either need to be placed on the coast, where seawater could be pumped into the facility, or seawater would need to be made using artificial sea salts. Artificial seawater is extremely expensive to make. It is costly to purchase the salt, and it takes labor to make up the artificial seawater. Coastal property is usually more expensive than property located away from the ocean. These are important considerations when looking at haddock culture feasibility (Lee and Ostrowski, 2001).

Female haddock are much more fecund than are female Atlantic salmon. Fecundity is a measure of reproductive capacity; in this case it refers to the number of eggs produced by the female. Haddock produce more eggs, but the size of each egg is much smaller. This means that the haddock fry (hatchlings) are much smaller at hatching and first feeding than are the salmon fry. Salmon fry are able to eat microparticulate

(MP) diets at first feeding. Haddock, on the other hand, will not eat these formulated MP diets, and must be fed live foods. *Brachionus* (rotifers) and *Artemia* (brine shrimp) are the two live feeds most commonly used in marine aquaculture. These organisms must be produced by the aquaculture facility as well. Rotifers, a type of marine organism, are produced on a three-day cycle. It is important that enough rotifers are produced to meet the needs for fish feeding, as well as maintaining healthy populations of rotifers. Production can be difficult, because the populations can "crash" (rotifers will die) if there are changes in water quality parameters or if the bacterial/fungal load becomes too great (Suantika, 2000). A crash will reduce the food available for the haddock fry.

Brine shrimp are used for the second stage of live food production. Brine shrimp are larger than the rotifers, and the haddock are moved onto the brine shrimp once they have grown. Brine shrimp are decapsulated from dried cysts. The cysts can be costly to purchase, and the decpasulation process is time consuming. After live feeds, the haddock are weaned onto a MP diet. Since haddock production is in its early stages, no commercially formulated diet exists for juvenile as it does for salmon. There is research being done to determine optimal nutrient levels, particle size and other feed characteristics for a juvenile haddock diet (Hamlin and Kling, 2001).

Another problem in haddock production is the high mortality rates from egg to juvenile stages. Large-scale salmon production has been occurring for decades, and the husbandry techniques have been refined. Mortality rates are usually 10% or less from egg to smolt for salmon (Shields, 2001). In haddock production, 75% mortality rate is the lowest that has been achieved. It is common to lose more than 95% from egg to juvenile (Kling, 2002).

It will take approximately six months from egg until the juvenile is ready for transfer to the netpens. The production cycle begins with the spawning of the broodstock. Broodstock are sexually mature fish, capable of releasing viable gametes. There are two separate groups of broodstock, held in separate tanks. Currently, haddock broodstock are only releasing eggs once per year. However, it is hoped that in the future, that two cycles will be produced per year. Two cycles could be produced by using conditioning techniques (temperature and light control) to control when the fish spawn (Lee and Ostrowski, 2001). The broodstock will be held in 20-foot tanks. Each of these tanks will hold at least 50 parents. Each adult female will spawn approximately a million eggs[2] (Wroblewski et.al., 1999). Although one or two females could produce enough eggs for the operation, it is important to have a large group of parents, in order to increase genetic diversity for future selection and to prevent inbreeding.

After spawning, the eggs are fertilized. The fertilized eggs are then disinfected and placed into incubators. Disinfection is important to prevent or decrease the growth of microbes (fungus, bacteria, etc). As hatching approaches, the eggs are transferred to larval rearing tanks. After hatching, the yolk-sac fry feed on nutrients contained within the yolk sac. When this yolk sac is approximately two-thirds absorbed, it is important to introduce exogenous, live feeds to the fry. The haddock will live in the rearing tanks for approximately 180 days, until they are large enough to be transferred to oceanic netpens.

The basis for the modeling in this research is derived from previous aquaculture economic studies (Kazmierczak and Soto, 2001; Zucker and Anderson, 1999). The most significant difference between this haddock model and prior research is the production of

[2] Fecundity = 53.7*length^2.42 (Wroblewski et.al, 1999)

live feeds. This need for live feeds increases the costs of production of haddock. The cost of live feeds and the high mortality rates of haddock create differences from previous aquaculture models.

Data, Methods, and Key Assumptions

In order to derive the economic cost of juvenile production, costs must be estimated and a pro forma budget calculated. These costs include capital and operating and maintenance (O&M) costs. Capital costs include items that are durable, and are expected to last for more than one year.

Operating and maintenance costs consist of variable costs and annual fixed costs. Variable costs are those costs which change depending upon the amount of output produced. Common variable costs in the aquaculture industry include feed, labor, and electricity. Annual fixed costs include costs that occur each year, but do not vary depending on production. These include such things as leases, permits and licenses.

In order to determine the size of the tanks and the O&M costs, some assumptions must be made. Due to the high mortality of haddock from egg to the weaned stage, the number of fish is much higher at the beginning of production than at the end. The objective is to produce 100,000, 200,000, or 400,000 (low, medium, and high production levels) juvenile fish for grow-out in oceanic net pens. Cost estimates are contingent upon this constraint.

Capital Costs

The capital cost components described in this section are based on the design set-up by Neil Greenberg. Additional estimates were obtained from a salmon facility design by Patrick White (as seen in the preliminary manuscript for USDA facility, 2002). There are five main cost centers of capital investments:

1) Building and land;
2) Pumping, filtering and chilling equipment;
3) Broodstock and broodstock equipment;
4) Generator and alarm system;
5) Plumbing, lighting, tanks, incubators and miscellaneous equipment.

The first cost center is the building and land. Building costs are estimated to be $120 per square foot. This would provide for an industrial-type building, with areas for egg incubation, larval production, live feeds production, and office space (R.S. Means, 2001). The size of the building is dependent upon the level of production; the base model uses a 5000 square foot building. However, the size of the building will vary at different production levels and feeding technologies.

The second cost center includes the pumping, filtering, and chilling portions. The intake pumps are located outside, near the water. Only one pump is used at a time, but most operations would have a secondary pump in case of mechanical failure. Although the system is recirculating, it is important that water be brought in continually to provide for a 10-20% water replacement daily. Filtration includes both mechanical and biological. The incoming water will be heated or chilled before going into the tanks to keep constant temperatures (8°C for incubators and 12°C for larval tanks).

The third cost center covers the equipment needed for the broodstock setup. The broodstock are the parents, and will produce the fertilized eggs for the hatchery operation. Broodstock will be held in a 20-foot tank with lighting units overhead. Commercial fishermen will collect haddock broodstock. Haddock broodstock mortality is initially quite high at 20%, so additional fish will need to be included (Kling, 2002). This high mortality is only during the few months as they become acclimated to living in tanks.

The fourth cost center includes the generator and alarm system. The generator is powerful enough to run the entire facility in the event of a power failure. The alarm system is needed to alert people in order to prevent catastrophes. It will alarm the manager or employee of any problems in the facility.

After the broodstock spawn and the eggs are fertilized, they will then be put into incubators. During incubation, the lights are kept very dim and only a small amount of water flows into the incubators. It is important to check the eggs periodically and remove any dead eggs. This helps to reduce problems with fungal contamination.

As the eggs begin to hatch, they will be transferred into the larval grow out tanks. The fish will live in these tanks from the time they are yolk-sac larvae until they are ready to be transferred to the net pens. Assuming a stocking density of 4 fish per liter, table 3.1 shows the number of tanks needed for the three production levels. When the fish are small, the stocking density (fish/liter) can be much higher, as a result additional tanks will not be needed even though the number of fish are much higher at the beginning of production.

Table 3.1: Number of Tanks Needed for Three Production Levels

Production level	# Tanks
Low	5
Medium	10
High	20

The fifth cost center includes plumbing, lighting and miscellaneous capital needs. Plumbing includes all piping, valves, connections, etc. in the entire system. There will be a light over every tank. The lights in each system will be able to be controlled by a timer, so that the amount light received and the intensity of light can be controlled automatically. A miscellaneous charge is also included to cover any additional items that are needed such as testing equipment and automatic feeders for the tanks.

Operating and Maintenance Costs

Operating and maintenance costs consist of variable costs and annual fixed costs. Variable costs are those costs which change depending upon the amount of output produced. Annual fixed costs include costs that occur each year, but do not vary depending on production. These include such things as leases, permits and licenses. There are six main cost centers of O&M costs:

1) Live Feeds;
2) Electricity;
3) Labor;

4) Microparticulate Diet;
5) Consumables;
6) Lease and licenses.

The first cost center includes the live feeds costs. This center includes both the capital and O&M costs associated with producing rotifers and Artemia.[3] Later, five different feeding technologies are discussed. Each feeding technology uses different numbers of days on each type of feed. In the juvenile model, the total annual costs of live feeds production is endogenized. The number of days needed of each type of live feed is determined based on feeding regime. The cost of the live feeds is then determined for each of the feeding technologies.

The second center of O& M costs is electricity. Electricity is needed to run much of the equipment in the facility, including the pumps, filters, and lights. The electricity needs for the facility are estimated at 200 kilowatts per day, which is a weighted sum of peak and off-peak electricity usage. In the base model, the peak electricity use is estimated to occur for 2 hours per day.

The third cost center of O&M costs is labor. For the base model, it is estimated that there would need to be one full-time and one part-time employee to see to the juvenile production. However, labor needs would increase as more tanks are added. A salaried manager would also be hired. Another associated labor cost would be the fringe benefits to the manager and full-time employees. Fringe benefits would include unemployment compensation tax, social security, worker's compensation, and health insurance. These benefits are estimated as 25% of the salary.

[3] 10% of the total capital costs (land, building, etc.) is attributed to the live feeds portion of production.

The fourth cost center is the cost of the formulated diets. Diets are fed after the live feeds. The diet cost also includes the feed used for the broodstock. Broodstock diets usually have increased levels of vitamins and minerals, in order to produce viable eggs.

Consumables, the fifth cost center, includes items such as chemical test kits, pH buffers, and replacements parts for oxygen and pH meters. Also included in this section also covers other items that need to be frequently (at least a couple of times per year) replaced: cleaners, disinfectants, solutions for the foot and hand baths, replacement UV bulbs for the UV filters, and replacement filters.

The sixth cost center is licenses and leases. This would cover the costs of licenses needed for the operation. The cost is estimated at $100 per year (Greenberg, 2002).

As previously cited, biological literature suggests that live feeds represents approximately 75% of the total costs of producing juvenile haddock. Studies have been done to reduce this cost share by changing the number of days the fish are fed live feeds. Reducing the days on live feeds leads to higher mortality rates of the fish; this tradeoff is analyzed in an economic context.

Bioeconomic Risk and Uncertainty

Three different production goals of 100,000, 200,000 and 400,000 haddock will be analyzed. However, these end target production levels do not include mortality. The survivability is dependent upon the feeding technology used. The feeding technologies are summarized in the table 3.2. These technologies examine the number of days the fish are fed the different types of diet: rotifers, Artemia, and formulated MP diets. While MP diets are inexpensive, the survival rates are also low if weaning takes place early.

With a more traditional (42MP) system, where live feeds are fed for a longer period of time, survival is much higher, but so are costs. Hamlin and Kling looked at the survivability and growth of the fish on the different feeding technologies, but no economic analysis has been done.

Table 3.2 Feeding Periods of Four Different Feeding Technologies (start day after hatch-end day after hatch

	Rotifers	Artemia	Microparticulate
28MP	0-35		28-180
30MP	0-28	21-36	30-180
35MP	0-28	21-42	35-180
42MP	0-28	21-49	42-180

Source: Hamlin and Kling, 2001

At the end of the production cycle, there will be 100,000, 200,000, or 400,000 (depending upon production level) juvenile fish ready to be placed into the netpens. However, because of the high mortality rates, the number of fish being fed at each stage of the hatchery stage is much higher. The highest mortality occurs during the first few weeks of rearing. All feeding regimes have mortality rates of 83% during this initial phase. The mortality rates during the weaning period are dependent upon the feeding technology used. The expected mortality rates for the different feed technologies are listed in table 3.3. After weaning has occurred, the expected mortality rate is 3% for the remainder of the juvenile production cycle.

Table 3.3: Expected Mortality Rates During the Weaning Period, Using the Four Different Feeding Technologies

Feeding Technology	Survival Rate	Standard Error
28MP	2.8%	1.7%
30MP	35.1%	3.6%
35MP	50.7%	5.3%
42MP	64.5%	4.0%

Source: Hamlin and Kling, 2001

Table 3.4 shows the number of haddock being fed during the different stages of production for the alternative feeding technologies. At the end of the production cycle, 100,000 juvenile fish will be ready to go into the oceanic netpens[4]. However, due to the standard deviation of the survival rates, these numbers could vary by several hundred of thousand fish at the early production stages.

Table 3.4: Number of Fish Being Fed at Various Production Stages for the Low Production Level

	Egg to wean	Start wean	End wean
28MP	21,963,107	3,733,728	103,093
30MP	1,727,715	293,712	103,093
35MP	1,196,111	203,339	103,093
42MP	940,199	159,834	103,093

Other biologic uncertainties include the feed conversion ratio (FCR) and the risk associated with live feeds production discussed in chapter two. Since commercial marine aquaculture is still in development, there is a lot of uncertainty in economic models. Many of the variables and inputs are based on estimates from other cultured species or

[4] The number of fish being fed at the various production stages will be increased by two and four times, respectively, for the medium and high production levels.

from experimental data. There could be a lot of variance in some of the estimates. In order to accommodate this risk in the model, Monte Carlo techniques are used to compare the total costs and budget, based on varying inputs.

The economic uncertainties that the model is concerned with are electricity, labor, and the interest rate. An average cost per-fish per day for the different types of feed (rotifers, Artemia, MP) is determined, based on the cost estimated from the live feeds model presented in chapter 2. Costs were then determined for the alternative feeding strategies, based on the cost per-fish per day, the number of fish being fed at that stage, and the number of days. Table 3.5 shows the uncertain parameters and their expected values.

Table 3.5: Distribution and Expected Value of Uncertain Parameters

	Distribution	Expected Value	Minimum	Maximum
Electricity Consumption	Triangular	89 kwhr/day	56 kwhr/day	110kwhr/day
Electricity Price	Uniform	$0.13	$0.125	$0.135
Part-time Wage Rate	Varied by +/- 10%	$6.50	$5.85	$7.15
Full-time Wage Rate	Varied by +/- 10%	$8.50	$7.65	$9.35
Real Interest Rate	Extreme Value	4.46%	0.20%	7.16%
Crash	Discrete	0	0	4
FCR (during weaning)	Uniform	0.50	0.40	0.60
FCR (after weaning)	Uniform	1.00	0.90	1.10

Results

The model was simulated, estimating the cost of production for fifteen different scenarios. There were three production levels of juvenile haddock: low (100,000), medium (200,000), and high (400,000). Four feeding technologies were also examined: 28MP, 30MP, 35 MP, and 42MP.

Total Annual and Per-fish Costs of Production

The total investment cost components, which range from $765,848 (low production) to $983, 638 (high production), are detailed in Appendix B. Table 3.6 shows the total annual costs for the different feeding technologies and production levels. Table 3.7 depicts these costs on a per-fish basis. The total costs are increasing, but at a decreasing rate, which indicates economics of scale.

Table 3.6: Median Total Annual Costs of Production for Four Technologies and Three Levels of Production ($/year)

	28MP	30MP	35MP	42MP
Low	45,028,308	846,770	627,031	505,447
Medium	48,697,396	922,881	687,242	556,433
High	50,598,496	1,004,362	748,420	607,672

The 28MP feeding technology results in high costs, which would be infeasible for production. Eight of the twelve per-fish costs are over $3.00, which also makes these technologies and production levels infeasible. Therefore, the remainder of the paper will focus on the high production level, because it is the most cost effective, due to the economies of scale.

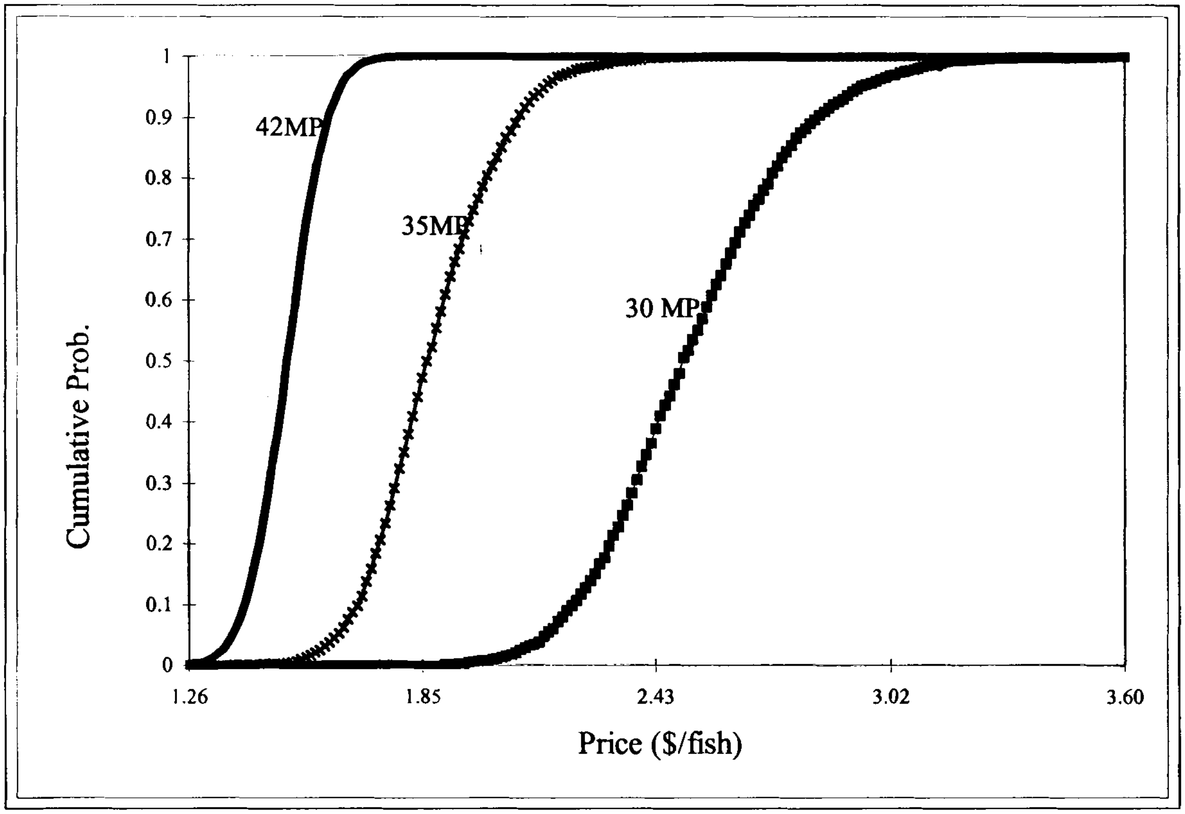
Table 3.7: Median Per-Fish Costs for the Various Production Levels and Feeding Technologies ($/fish)

	28MP	30MP	35MP	42MP
Low	$450.28	$8.47	$6.27	$5.05
Medium	$243.49	$4.61	$3.44	$2.78
High	$126.50	$2.51	$1.87	$1.52

Feeding regime four (42MP) is the least costly feed technology. However, it is important to look at the cumulative distributions. Figure 3.1 shows the cumulative distributions for feeding technologies two through five. Since feeding technology one (28MP) is so costly it is considered unfeasible, and is not included.

As discussed earlier, there are many sources of variability and uncertainty in the model. Cumulative distribution functions (CDFs) aid in determining the preferred technology in the presence of all this uncertainty. With first-degree stochastic dominance, the CDFs of one technology lies completely to the left of the other technology choices. The CDF indicates that this is the preferred technology choice, since it results in the lowest costs. However if two CDFs cross, then neither dominates the other in the first-degree sense. It situations such as these, further analysis must be done to determine which technology is preferred (Hardaker, 1997). In looking at the cumulative distributions of the per-fish costs, technology four (42MP) lies to the left of all of the other technologies and there are no crosses in the CDFs. Therefore, it can be concluded that 42MP is the risk-preferred technology.

Figure 3.1: Cumulative Distributions of Feeding Regimes Two through Four



42MP, or the fourth feeding regime is the preferred technology by first order stochastic dominance. 42MP also has the smallest standard deviation. The 90% confidence interval for the price per-fish using the 42MP feeding technology is $1.38 to $1.65. The price per-fish is less than $1.60, 85% of the time. The mean, minimum, maximum, and standard deviations of the per-fish costs at the high production level for feeding technologies one through four are presented in table 3.8.

Table 3.8: Mean, Minimum, Maximum, and Standard Deviation of Per-Fish Costs (High Production Level) ($/fish)

	Mean	Maximum	Minimum	Standard Deviation
28MP	$1,532	$102,205	$49.96	$10,311
30MP	$2.53	$3.59	$1.87	$0.24
35MP	$1.88	$2.57	$1.41	$0.16
42MP	$1.52	$1.79	$1.26	$0.08

Cost Structure

Table 3.9 presents the ex-ante budget estimates for the four feeding strategies at the high level of production. This is useful in determining which areas contribute the most to the total costs. Figure 3.2 breaks down the cost of production into a per-fish basis in order to illustrate the declining cost of live feeds as the number of days on live feeds increases. This is contrary to the hypothesized relationship and underscores the importance of the bioeconomic tradeoff between survivability and Artemia costs. The largest cost components in juvenile production are the live feeds, capital, labor and electricity.

The main costs of production are transformed to cost shares to indicate the relative importance of different cost components. Figure 3.3 shows the cost shares of the different components of the budget for the different feeding regimes. The cost shares for the 28MP technology are not included, because it is infeasible due to the high costs. Knowing which cost shares are the largest will help to steer future research and will also assist in policy formation Since the live feeds budget accounts for 56% to 72.6% of the total juvenile budget, the live feeds components have been further broken down in figure 3.4. Figure 3.3 and 3.4 both show cost shares as a percentage of total costs.

Figure 3.4 shows how each cost component contributes to the live feeds portion. The largest cost share within the live feeds component is the capital costs, accounting for 43.9% to 55.1% of the total live feed costs. The other two large cost components, labor and electricity, account for 36.3% and 11.9%, respectively for the preferred 42MP feeding technology. Artemia cysts make up only 3% of the total costs of live feed production.

When these two cost components, live feeds and juvenile, are combined, capital expense accounts for 42.8% of the total costs of producing a fish. Labor accounts for 32.1% of the total budget, and electricity represents 14.5%. Artemia cysts account for only 1.7% of the total budget, representing an insignificant cost share. These cost shares show which components have the largest impact on total costs. Changes in the price of capital, which contributes a large cost share, will significantly alter the total budget, whereas changes in the price of Artemia cysts will not.

Table 3.9: Total Annual Costs for the Different Feeding Technologies (High Production Level) ($/year)

	28MP	30MP	35MP	42MP
Ownership				
Land	2,694	2,694	2,694	2,694
Building	52,920	52,920	52,920	52,920
Equipment	54,658	54,658	54,658	54,658
Total ownership	110,272	110,272	110,272	110,272
O&M				
Electricity	47,340	47,340	47,340	47,340
Labor	71,479	71,479	71,479	71,479
Live Feeds	47,438,948	729,267	479,064	340,375
Diet (juvenile)	29,193	16,491	15,660	14,786
Diet (broodstock)	342	342	342	342
Consumables	1,920	1,920	1,920	1,920
Oxygen	12,000	12,000	12,000	12,000
License	80	80	80	80
Interest on O&M	1,877,969	39,026	29,122	23,616
Total O&M	49,479,271	917,945	657,007	511,938
Total Annual Cost	50,598,496	1,004,362	748,420	607,672

Figure 3.2: Cost Components Per-Fish ($)

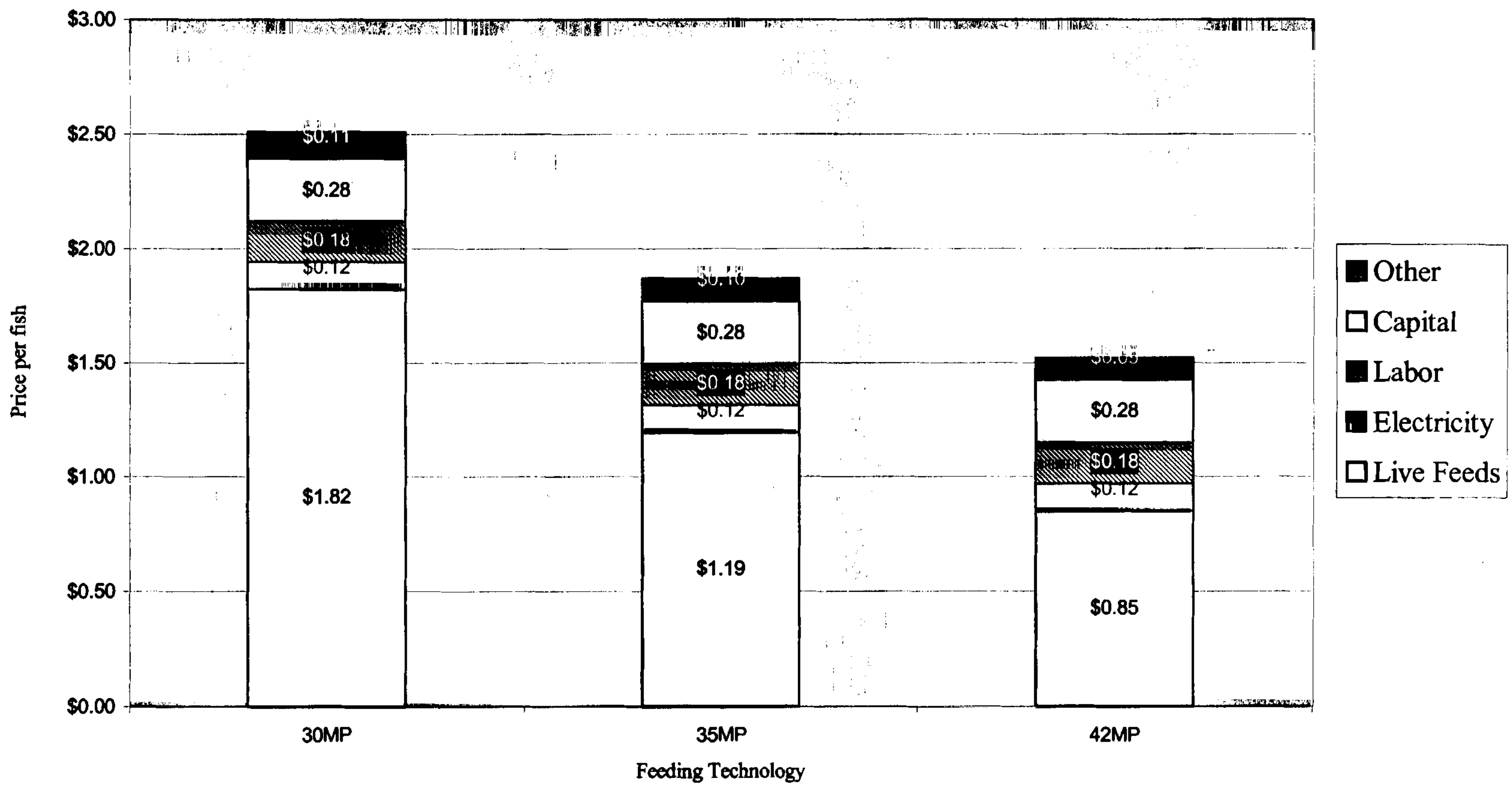


Figure 3.3: Cost Shares for Juvenile Production Under Different Feeding Regimes (% of total cost)

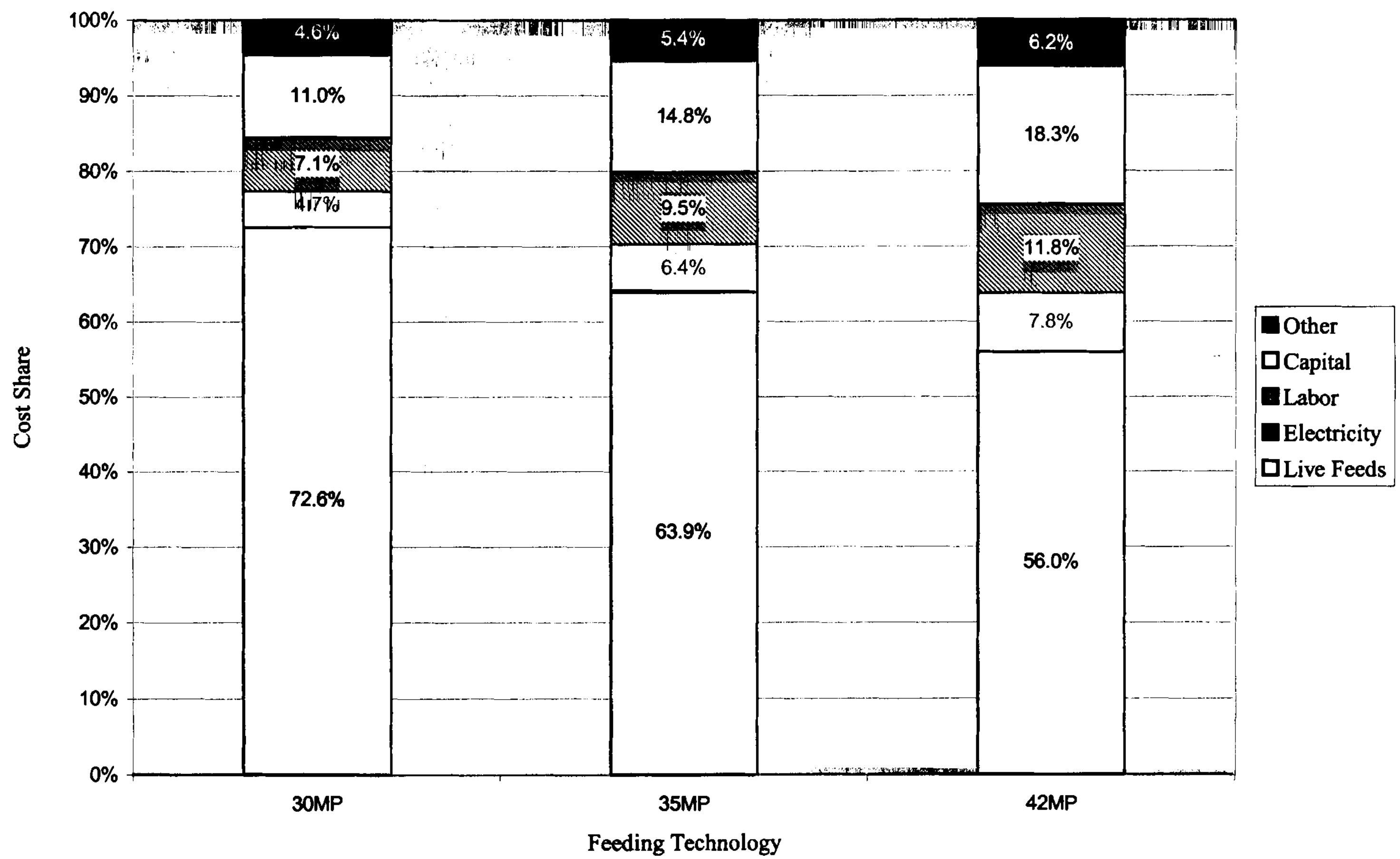
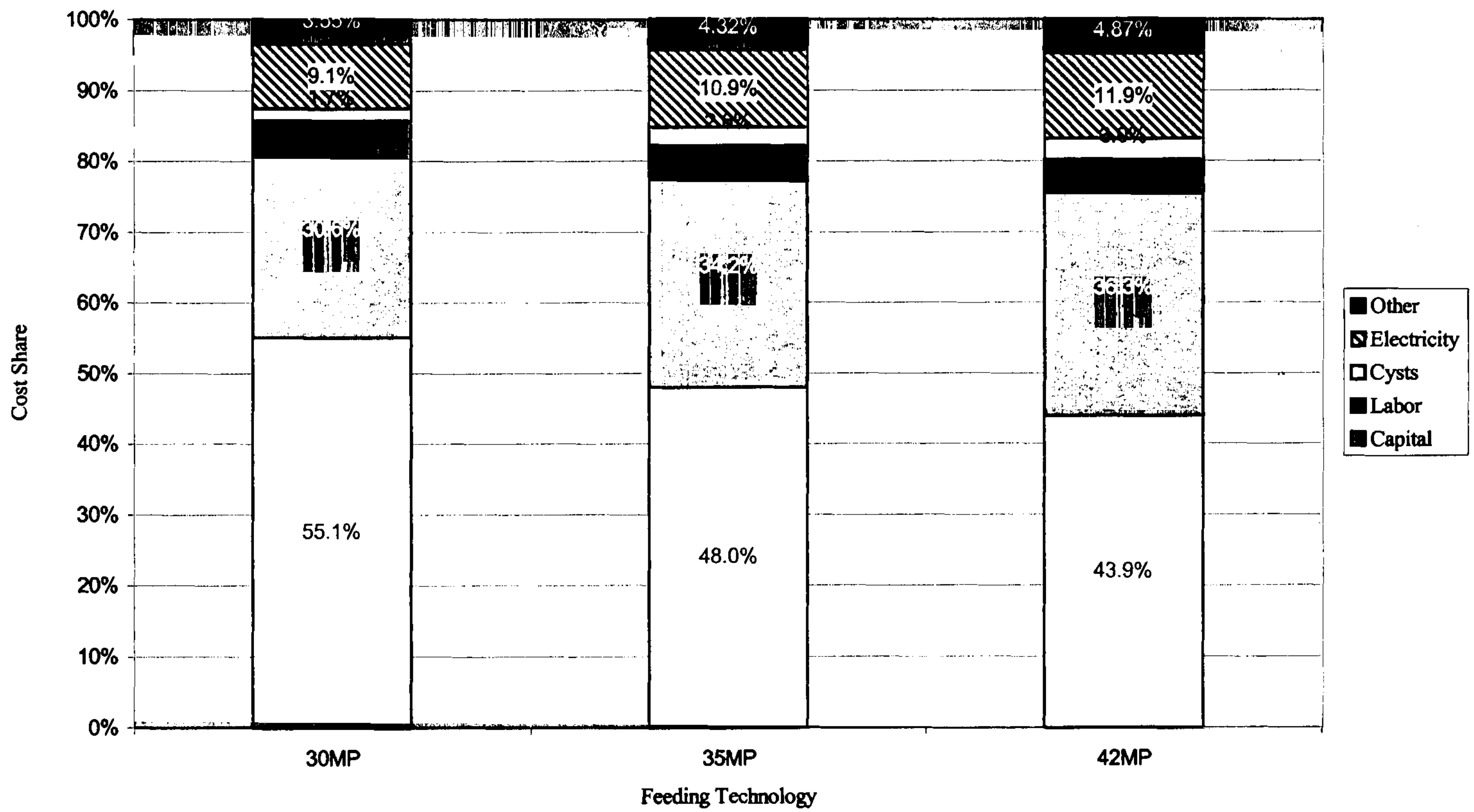


Figure 3.4: Cost Shares for the Live Feeds Component (% of total cost)



Sensitivity Analysis and Policy Implications

Sensitivity analysis is done to determine the effect of a price change on the total cost of production. This is especially useful for inputs whose prices are uncertain. In terms of sensitivity, the parameters that will be studied are Artemia cyst price, interest rate, and the effects of having two cycles per year instead of one. Artemia cyst price was chosen as one of the parameters to analyze, because there has been a great deal of concern over the rising prices. Since capital costs contribute a large cost share to the budget, interest rate and two production cycles per year were selected, because both alter the capital cost component.

Artemia cyst prices have been volatile over the past decade, and this trend is expected to continue in the future. In the past five years, cyst prices have more than doubled. In the model, a price of $40 per can was used. However, it is quite possible for this price to double or even quadruple. The cost share of the Artemia component of the total budget is only 1.7%, or $0.03 of the per-fish cost. The model was run again using higher cyst prices of $80 and $160 to determine the impact on the cost of production. Table 3.12 shows the comparison. A ten percent increase in the price of Artemia cysts would lead to a 1.5% increase in the per-fish cost, and it does not alter the dominance of one feeding technology or another. The Artemia cyst price is not as important as the biological literature suggests. The cost of producing juvenile haddock is much more sensitive to the cost of capital than to Artemia cyst prices.

Table3.10: Artemia Cyst Price Influence on Cost per -fish and Cost Share (Feeding Technology 4 (42MP) at High Production Level)

	Cost per-fish	Cost Share of cysts in live feeds budget	Cost Share of cysts in total budget	Cyst Cost/Fish
Artemia Cyst Price				
$40	$1.52	3.0%	1.7%	$0.03
$80	$1.54	5.8%	3.3%	$0.05
$160	$1.60	11%	6.2%	$0.10

In the base budget model, an interest rate of 8.0% was used. This rate is typical for an agricultural loan. However, because of the increased risk and uncertainty associated with aquaculture production, the interest rate may be higher. The model was run again, using a higher interest rate of 9.5% to see the impact of interest rates on the budget. The increased interest rate caused a per-fish cost increase of $0.09 (from $1.52 to $1.61). The capital cost share increased from 18.3% to 19.9%. A 10% increase in the interest rate would increase per-fish costs by approximately $0.05.

The third area where sensitivity analysis should be performed is the production of two cycles per year. Currently, haddock only spawn once per year. However, many marine finfish species have been able to be conditioned to spawn at different times during the year. It is thought that this conditioning process can also be done with haddock, allowing for two production cycles per year. Two cycles per year would double the output of the operation, and double the operating and maintenance costs of the base budget. However, there would be savings from having the capital costs spread over two cycles, rather than one. With the increase of production to two cycles per year, the per-fish costs (at the high production level) drop from $1.52 to $1.31, underscoring the importance of the large capital cost share.

Preliminary analysis indicates that juveniles need to be produced for $2.00 or less each. This $2.00 estimate comes from looking at price of Atlantic salmon smolts and from preliminary analysis of a complete haddock production cycle (egg to marketable fish). If cyst prices increase as dramatically as it is thought they might, or if interest rates are very high, there is the potential that the per-fish costs will be above $2.00. However, increasing the production level to two cycles per year results in a significant decline in per-fish costs, and this could potentially offset any increases in cyst price or interest rate. Therefore, it appears that the number one priority in research and policy is to find strategies to condition the broodstock to enable multiple cycles per year, since increasing to two cycles per year yields in the highest cost reduction.

Conclusions

This paper was designed to determine the economic feasibility of the production of juvenile haddock. This model accounts for the uncertainty and risks associated with production. With the current technologies and price levels, it appears that it viable to produce juvenile haddock in land-based facilities.

As suggested by the biological literature, the live feeds component contributes to a large part of the total operating budget, approximately 56-72%, depending on the feeding regime used. Prior research has attempted to determine the exact number of days the haddock should be fed the different types of diets (rotifers, Artemia, and MP). This fine-tuning of the days on each feed is not needed. Extremely early weaning, without the use of Artemia (feeding regime #1) is not feasible, due to very high mortality rates. Even with a quadrupling of Artemia cyst prices, the 28MP is still not the preferred feeding technology. The remaining four technologies are quite similar in price. Cost savings result from reducing the number of days on live feeds to a small extent. However, it is important to realize the tradeoff between reducing the days and the survival rates.

The three big issues that need to be addressed for future production are the uncertainty of Artemia cyst price, the interest rate on loans for aquaculture, and the technological advances of producing two cycles per year. If the interest rates increase to high levels, above 9.5%, or the Artemia cyst prices rise to levels above $300 per can it is likely that the cost of producing the juvenile haddock will be too high if the production levels remain the same. Therefore the top priority in future research would be to condition the broodstock to spawn more than once per year. Even with high interest rates and cyst prices, a doubling of production would offset them, making production economically feasible.

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Chapter 4
CONCLUSION

Commercial scale haddock production is still its research stages, both biologically and economically. Economic analysis helps to determine which areas need to be improved biologically to make the entire operation more cost effective. While haddock aquaculture is similar to the culture of other species, there are some significant differences. The two main differences occur during the juvenile production stage. One of these differences is the need for live feeds, and the other is the different culture techniques needed in the rearing from egg to juvenile.

Chapter 2 discusses the costs associated with the live feeds portion of the operation. The need for live feeds is specific to marine species. As more and more cold-water marine species are being studied for the possibility of culture, there are advances being made in live feeds production techniques. Chapter 2 studies these different techniques in terms of production, cost, and risk.

Chapter 3 analyzes the production of haddock from the egg to the juvenile stage. The early stages of production involve the use of live feeds and subsequent weaning onto a microparticulate diet. This weaning process is costly in terms of high mortality rates. Per-fish costs of production were determined using an economic engineering approach and incorporating uncertainty using Monte Carlo analysis. Haddock culture is currently only done in lab settings, so there is uncertainty about how the parameters will change as the production is scaled up to commercial size.

Initial economic analysis shows that juvenile haddock can be produced under $2.00 per-fish. These feasible costs only occur with high production levels. This research also showed that fine tuning the number of days on each type of feed is not necessary, as it had negligible effects on total cost. Areas that are of need of future biological research include conditioning broodstock so that there can be two production cycles per year as well as developing MP diets that are acceptable to larvae at first feeding. Eliminating live feeds entirely would decrease costs significantly by eliminating the capital and labor costs associated with live feeds production.

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Appendix A

CAPITAL COSTS FOR THE LIVE FEEDS

The tables in this appendix show the capital costs for the live feeds component. The percentage of the cost associated with the live feeds portion is noted. The useful life is 10 years for all equipment, except for the building and land. Land has an infinite useful life, and the building is estimated to have a useful life of 33 years.

Table A.1: Live Feeds Capital Costs (Low Production Level)

Item	Quantity	Total Purchase Price ($)	Depreciation and Interest ($)	Maintenance and Upkeep Charge ($)	Tax and Insurance Charge($)	Annual Ownership Cost($)	Percentage used for live feeds (%)	Total Annual Ownership Cost	
								Green Water ($)	Yeast ($)
Building/Land									
Land (acre)	2	70,000	3,220	0	490	3,710	10%	371	371
Building (sq.ft.)	5000	600,000	32,322	12,000	42,000	48,522	10%	4,852	4,852
Pumping/Filtering/Heating									
Intake pump	2	4,000	509	600	28	1,137	10%	113	113
Mechanical filter	1	600	76	90	4	171	10%	17	17
Ozone Generator	1	5,000	596	500	35	1,131	10%	113	113
Holding Tank	1	2,500	318	25	18	361	10%	36	36
Inline Heater	1	520	66	52	4	122	100%	122	122
Generator									
Generator	1	50,000	5,135	3,000	350	8,485	10%	849	849
Tanks									
Rotifer tanks & stands	3	987	125	10	7	142	100%	142	142
Initial Artemia decap	2	30	4	0	0	4	100%	4	4
Artemia decap	10	250	32	3	2	36	100%	36	36
Enrich vessel	3	660	84	7	5	100	100%	100	100
Plumbing/Miscellaneous									
Plumbing	1	20,000	2,546	400	140	3,086	10%	308	308
Algae production setup	1	2,500	318	25	18	361	100%	361	0
Misc. Live feeds	1	1,500	191	15	11	216	100%	216	216
Misc. Rotifer	1	500	64	5	4	72	100%	72	72
Misc. Artemia	1	500	64	5	4	72	100%	72	72
Totals		157,867	45,660	16,736	5,316	67,713		7,779	7,418

Table A.2: Live Feeds Capital Costs (Medium Production Level)

Item	Quantity	Total Purchase Price ($)	Depreciation and Interest ($)	Maintenance and Upkeep Charge ($)	Tax and Insurance Charge($)	Annual Ownership Cost($)	Percentage used for live feeds (%)	Total Annual: Green Water ($)	Total Annual: Yeast ($)
Building/Land									
Land (acre)	2	70,000	3,220	0	490	3,710	10%	371	371
Building (sq.ft.)	5550	660,000	35,891	13,200	4,620	53,711	10%	5,371	5,371
Pumping/Filtering/Heating									
Intake pump	2	4,000	509	600	28	1,137	10%	113	113
Mechanical filter	1	600	76	90	4	171	10%	17	17
Ozone Generator	1	5,000	596	500	35	1,131	10%	113	113
Holding Tank	1	2,500	318	25	18	361	10%	36	36
Inline Heater	1	520	66	52	4	122	100%	122	122
Generator									
Generator	1	50,000	5,135	3,000	350	8,485	10%	849	849
Tanks									
Rotifer tanks & stands	6	1,980	251	20	14	285	100%	285	285
Initial Artemia decap	2	30	4	0	0	4	100%	4	4
Artemia decap	5	125	16	2	1	18	100%	18	18
Enrich vessel	6	1,320	167	13	9	190	100%	198	198
Plumbing/Miscellaneous									
Plumbing	1	20,000	2,540	400	140	3,086	10%	308	308
Algae production setup	1	2,500	318	25	18	361	100%	361	0
Misc. Live feeds	1	1,500	191	15	11	216	100%	216	216
Misc. Rotifer	1	500	64	5	4	72	100%	72	72
Misc. Artemia	1	500	64	5	4	72	100%	72	72
Totals		171,395	49,423	17,952	5,747	73,123		8,517	8,157

Table A.3: Live Feeds Capital Costs (High Production Level)

Item	Quantity	Total Purchase Price ($)	Depreciation and Interest ($)	Maintenance and Upkeep Charge ($)	Tax and Insurance Charge($)	Annual Ownership Cost($)	used for live feeds (%)	Total Annual Green Water ($)	Total Annual Yeast ($)
Building/Land									
Land (acre)	2	70,000	3,220	0	490	3,710	10%	371	371
Building (sq.ft.)	6000	720,000	39,461	14,400	5,040	58,901	10%	5,890	5,890
Pumping/Filtering/Heating									
Intake pump	2	4,000	509	600	28	1,137	10%	113	113
Mechanical filter	1	600	76	90	4	171	10%	17	17
Ozone Generator	1	5,000	596	500	35	1,131	10%	113	113
Holding Tank	1	2,500	318	25	18	361	10%	36	36
Inline Heater	1	520	66	52	4	122	100%	122	122
Generator									
Generator	1	50,000	5,135	3,000	350	8,485	10%	849	849
Tanks									
Rotifer tanks & stands	10	3,290	417	33	23	474	100%	474	474
Initial Artemia decap	2	30	4	0	0	4	100%	4	4
Artemia decap	5	125	16	1	1	18	100%	18	18
Enrich vessel	10	2,200	280	22	15	317	100%	317	317
Plumbing/Miscellaneous									
Plumbing	1	20,000	2,546	400	140	3,086	10%	308	308
Algae production setup	1	2,500	318	25	18	361	100%	361	0
Misc. Live feeds	1	1,500	191	15	11	216	100%	216	216
Misc. Rotifer	1	500	64	5	4	72	100%	72	72
Misc. Artemia	1	500	64	5	4	72	100%	72	72
Totals		185,585	53,271	19,173	6,183	78,627		9,352	8,992

Appendix B

CAPITAL COSTS FOR JUVENILE PRODCUTION

The tables in this appendix show the capital costs for the juvenile component of production. The percentage of the cost associated with juvenile production is noted. The feed technology used, results in changes in the capital costs of the live feeds portion of the budget. The capital differences, building size and the number of rotifer tanks, can be seen in Table B.4.

Table B.1: Juvenile Capital Costs (Low Production Level)

Item	Quantity	Total Purchase Price ($)	Depreciation and Interest ($)	Maintenance and Upkeep Charge ($)	Tax and Insurance Charge($)	Percentage used for juvenile (%)	Total Annual Ownership Cost($)
Building/Land							
Land (acre)	1.6	56,000	2,387	0	392	100%	2,779
Building (sq. ft.)	4000	480,000	25,183	9,600	3,360	100%	38,144
Pumping/Filtering/Chilling							
Intake pump	2	4,000	504	600	28	80%	906
Mechanical filter	1	600	76	90	4	80%	136
Ozone Generator	1	5,000	590	500	35	80%	900
Holding Tank	1	2,500	315	25	18	80%	286
Chilling System	1	30,000	3,810	3,000	210	100%	7,020
Recirculating System	1	74,778	1,892	2,250	105	100%	21,237
Generator/Alarm System							
Generator	1	50,000	5,083	3,000	350	80%	6,746
Alarm System	1	15,000	1,892	300	105	100%	2,297
Tanks							
Incubators	12	2,520	320	50	17	100%	388
Larval Tanks	5	7,000	889	70	49	100%	1,008
Plumbing/Miscellaneous							
Plumbing	1	20,000	2,522	400	140	80%	2,450
Lighting	5	1,750	221	35	12	100%	268
Miscellaneous	1	2,000	252	20	14	100%	286
Broodstock							
Tanks	1	7,500	946	75	53	100%	1,073
Lighting	3	1,200	151	24	8	100%	184
Initial Broodstock Acquisition	60	6,000	757	0	42	100%	799
Totals		765,848	47,789	20,039	4,942		87,002

Table B.2: Juvenile Capital Costs (Medium Production Level)

Item	Quantity	Total Purchase Price ($)	Depreciation and Interest ($)	Maintenance and Upkeep Charge ($)	Tax and Insurance Charge($)	Percentage used for juvenile (%)	Total Annual Ownership Cost($)
Building/Land	1.6	56,000	2,387	0	390	100%	2,779
Land (acre)	5000	600,000	32,322	12,000	4,200	100%	48,522
Building (sq. ft.)							
Pumping/Filtering/Chilling							
Intake pump	2	4,000	504	600	28	80%	906
Mechanical filter	1	600	76	90	4	80%	136
Ozone Generator	1	5,000	590	500	35	80%	900
Holding Tank	1	2,500	315	25	18	80%	286
Chilling System	1	30,000	3,810	3,000	210	100%	7,020
Recirculating System	1	92,318	1,892	2,250	105	100%	26,437
Generator/Alarm System							
Generator	1	50,000	5,083	3,000	350	80%	6,746
Alarm System	1	15,000	1,892	300	105	100%	2,297
Tanks							
Incubators	12	2,520	320	50	17	100%	388
Larval Tanks	10	14,000	1,778	140	98	100%	2,016
Plumbing/Miscellaneous							
Plumbing	1	20,000	2,522	400	140	80%	2,450
Lighting	10	3,500	441	70	25	100%	536
Miscellaneous	1	2,000	252	20	14	100%	286
Broodstock							
Tanks	1	7,500	946	75	53	100%	1,073
Lighting	3	1,200	151	24	8	100%	184
Initial Broodstock Acquisition	60	6,000	757	0	42	100%	799
Totals		912,138	56,038	22,544	5,841		103,858

Table B.3: Juvenile Capital Costs (High Production Level)

Item	Quantity	Total Purchase Price ($)	Depreciation and Interest ($)	Maintenance and Upkeep Charge ($)	Tax and Insurance Charge($)	Percentage used for juvenile (%)	Total Annual Ownership Cost($)
Building/Land							
Land (acre)	1.6	56,000	2,387	0	392	100%	2,779
Building (sq. ft.)	5500	660,000	35,891	13,200	4,620	100%	53,711
Pumping/Filtering/Chilling							
Intake pump	2	4,000	504	600	28	80%	906
Mechanical filter	1	600	76	90	4	80%	136
Ozone Generator	1	5,000	590	500	35	80%	900
Holding Tank	1	2,500	315	25	18	80%	286
Chilling System	1	30,000	3,810	3,000	210	100%	7,020
Recirculating System	1	92,318	11,724	13,848	646	100%	26,218
Generator/Alarm System							
Generator	1	50,000	5,083	3,000	350	80%	6,746
Alarm System	1	15,000	1,892	300	105	100%	2,297
Tanks							
Incubators	12	2,520	320	50	17	100%	388
Larval Tanks	20	28,000	3,556	280	196	100%	4,032
Plumbing/Miscellaneous							
Plumbing	1	20,000	2,522	400	140	80%	2,450
Lighting	20	7,000	883	140	49	100%	1,072
Miscellaneous	1	2,000	252	20	14	100%	286
Broodstock							
Tanks	1	7,500	946	75	53	100%	1,073
Lighting	3	1,200	151	24	8	100%	184
Initial Broodstock Acquisitior	60	6,000	757	0	42	100%	799
Totals		983,638	71,659	35,552	6,927		111,384

Table B.4: Different Live Feed Capital Cost Components, Depending Upon Feed Technology (High Production Level)

	Early Weaning	30MP	35MP	45MP	Traditional
Building (sq. ft.)	23100	3600	2750	2250	2000
Rotifer Tanks	2196	173	120	94	83

BIOGRAPHY OF THE AUTHOR

Kate M. Waning was born in Lewiston, Maine on January 26, 1978. She was raised in Poland Spring, Maine and graduated from Edward Little High School in Auburn, Maine in 1996. She attended the University of Maine and received a Bachelor of Science degree in Aquaculture in 2000. She continued her studies at the University of Maine in Resource Economics and Policy.

After receiving her degree, she will begin her career at the University of Maine as an Instructor and Research Associate. Kate is a candidate for the Master of Science degree in Resource Economics and Policy from The University of Maine in December, 2002.