Capstone Advisory Committee Final Capstone Project Signature Form

Aquaculture in America: Economic Factors Driving Change

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MAS Marine Biodiversity and Conservation

Capstone Project

Capstone Advisory Committee

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Aquaculture In America

Economic Factors Driving Change

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http://underwater.com.au/image.php/id/97

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INTRODUCTION

This report analyzes the U.S. market with respect to finfish aquaculture. Factors affecting both the cost of production and U.S. consumer demand for aquaculture products were evaluated to find ways to lower costs and increase market demand for domestic finfish aquaculture products in the U.S. Issues important in directing public perception of aquaculture such as disease and genetic modification are examined to see how they shape demand. Both private and social costs are also evaluated to develop aquaculture's true cost. Finally a larval feed experiment was conducted to determine if growth could be altered through different feed densities and feeding schedules. Because feed derived from fish products can be the most costly aspect of aquaculture production to the producer and to society, studying ways to reduce the necessary fishmeal and fish oil inputs will reduce private costs and fishing pressure on wild stocks. Continuing research into larval fish growth and development is also highlighted to explain the path ahead to reduce both private and social costs, which may stimulate demand for finfish aquaculture in the U.S.

WHERE ARE WE NOW?

Aquaculture has been utilized by human civilization for thousands of years. Ancient Romans were known to raise fish and eels in ponds and tanks to allow for the consumption of fresh fish throughout the year (McCann, 1979). While modern day methods for raising captive fish began with simple operations, they have

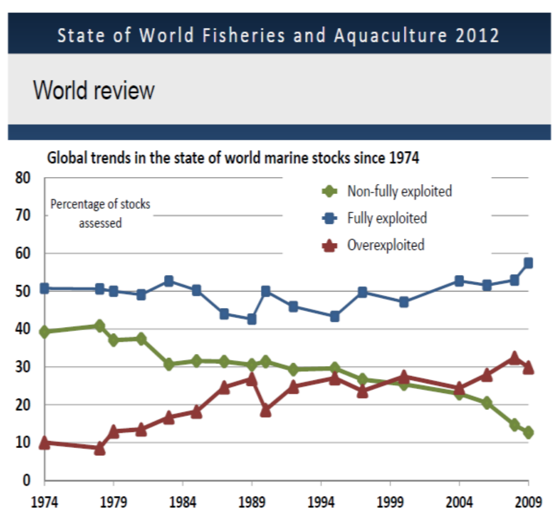

FIGURE 1: (F.A.O., 2012b)

expanded into industrial level operations, producing a global total of $119 billion dollars of fish annually. It is recognized as the fastest growing food industry worldwide at an annual growth rate of 8.8% (F.A.O., 2012a). As human populations continue to grow, a higher demand will be placed on the already fully exploited and over-exploited stocks of wild-caught fish. The Food and Agriculture Organization of the United Nations, shows that ninety percent of known fish stocks are either fully exploited or over exploited (Figure 1). Aquaculture around the world is steadily increasing in attempt to meet the greater demand.

Wild capture production around the world has virtually remained steady since the mid-1980s, while the production of aquaculture has risen almost 60 million tons in the same time (Figure 2). The United States is one of the few countries in the world whose aquaculture production rate has remained relatively unchanged within the last two decades (F.A.O., 2012a). Low aquaculture production along with increased regulations on wild fish harvests has decreased domestic seafood availability in the market. This has created a U.S. seafood deficit in which sixty percent of all seafood consumed in the U.S. is imported at a cost of $17.5 billion in 2010 (F.A.O., 2012a).

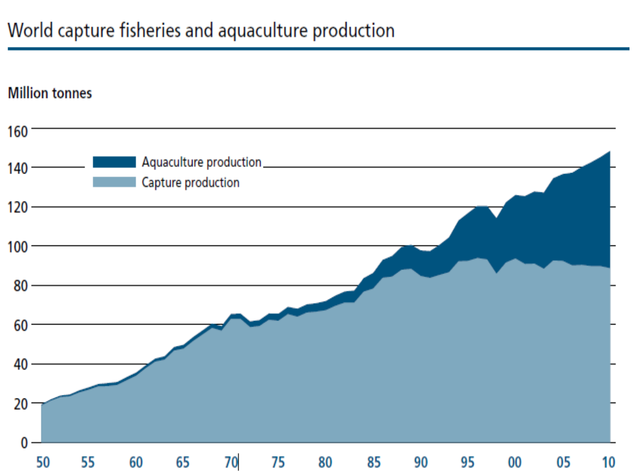

FIGURE 2: (F.A.O., 2012b)

In other countries around the world aquaculture is big business. Chile produced approximately 300,000 tons of salmon valued at $2.3 billion in 2011 (Global Aquaculture Alliance, 2012). In Norway, aquaculture production grew from 151,000 tons in 1990 to more than one million tons in 2010, thanks in large part to the farming of Atlantic salmon in marine cages (FAO, 2012a). Even after this growth, Norway was still only the world's seventh largest producer of aquaculture products in 2010 (FAO, 2012a). The F.A.O disclosed in its 2012 status of fisheries report that China produced a staggering 36.7 million tons of aquaculture products in 2010, accounting for more than sixty percent of the global production (not including aquatic plants and non-food products) (F.A.O., 2012a). The U.S. only managed to produce 495,499 tons or 0.83% of the global production in 2010 (F.A.O., 2012a). The U.S. has the largest Exclusive Economic Zone of any country, and has yet to fully utilize this water space for commercial production of aquaculture products. Domestic aquaculture has struggled to gain a foothold in the American markets. High startup costs, uncertainty, environmental factors, and a poor public perception have all kept investors and entrepreneurs away from aquaculture.

COST OF PRODUCTION

The cost to culture and raise marine finfish in captivity directly affects the bottom line of producers. This sets the price at which producers are willing to sell these products in the marketplace. Most of these factors fall under the category of private costs. Private costs are incurred solely by the producer, so a reduction in these costs will translate directly into savings for the producer. The other costs are social. Borne by society as a whole, these costs are usually environmental in nature, and generally are unaccounted for in the price of the fish. Many aspects of raising live fish can impact the cost of production, but a higher efficiency operation can achieve savings in private and social costs.

PRIVATE COSTS

Many different factors contribute to the cost of raising a fish from egg to adult. The feed can be the most costly input, accounting for 40-70% of the total budget (Fujiya, 1976). Total cost of feed may see an increase if finfish aquaculture continues to rely primarily on wild caught fish products. The current cost per unit of biomass of California yellowtail, for example, was found to be $1.92-$3.05 U.S. per kilogram of fish (Moran et al., 2009). With a fish that reaches an average of six kilograms before being harvested, growing 500,000 for market could cost $5.8 – $9.2 million.

Most species of cultured fish are in part chosen due to their robustness and ability to survive in stressful environments. Health concerns, including diseases and parasites, are always a threat to any aquaculture operation. Flatworms are the most common parasite infecting yellowtail aquaculture today (Kolkovski & Sakakura, 2004). These worms attach themselves to mucus membranes in the gills and mouth, and can be very harmful to stocks if left untreated. They cause reduced appetite, slow growth, or even death (Kolkovski & Sakakura, 2004). Viral disease is another serious threat to fish stocks, and due to the high density of fish in confined tanks and cages, infections can spread quickly. The infectious salmon anemia virus (ISAV) has been especially devastating to salmon populations all over the world. Chile's stocks experienced a near total collapse in 2007 when ISAV destroyed two thirds of their total harvest (Global Aquaculture Alliance, 2012). These illnesses not only cost the industry in terms of lost product, but in time and resources towards researching and administering drug treatments as well. In the United States, the Food and Drug Administration has published a list of approved drugs for use in aquaculture. This list outlines a small subset of drugs used in every aspect of the industry from removing bacteria and viruses from the water to vitamins fed to the fish to balance their diet. The FDA's list applies only to farms in the U.S., not to imported aquaculture products. This gives foreign farms a larger choice of drugs to choose from and a possible competitive advantage in domestic markets.

FIGURE 3: OCEAN FARM TECHNOLOGIES AQUAPOD™ NET PEN (OCEAN FARM TECHNOLOGIES, INC., 2012).

Culturing fish offshore presents entirely different challenges than raising animals on land. The cost of the pens can be millions of dollars to purchase, install and maintain. It is extremely costly to survey and maintain the fish on a daily basis. Large boats consuming diesel fuel are required to perform maintenance and harvest the fish, commercial divers are needed to clean and repair the cages, and environmental data must be monitored constantly. Figure 3 highlights the magnitude of some aquaculture cages, which can be more than 3500 cubic meters in volume (Ocean Farm Technologies, Inc., 2012).

Other costs incurred include the administrative costs required to keep and grow fish. Water filtration, oxygen, lighting, and lab equipment/supplies can all add up. Permits may also need to be applied for and purchased through the city, state, or federal government for water or land use. There are also inspections and certification processes that must be completed in addition to permitting costs. These can take months to years to complete and cost millions of dollars.

Social Costs

The social costs of aquaculture have been at the heart of aquaculture debate in the U.S., with feed being the primary concern. The most common aquaculture feed is made from fishmeal and other fish products. These feed products are derived from wild caught stocks in the form of whole fish or fish scraps from processing plants. Aquaculture's share of global fishmeal and fish oil consumption more than doubled over the past decade to 68% and 88%, respectively (Naylor *et al.,* 2009). While food technology has allowed for some substitution, aquaculture production has outpaced these developments, and requires more fish products than ever. Without proper substitutes, the aquaculture industry could push the costs of fish oil and fishmeal higher, reducing the aquaculture profit margin and encouraging illegal or environmentally damaging fishing practices to meet the demand. Also with the global nature of the feed industry, tracing the origin of feed products is difficult. This reduces the accountability by fishmeal and fish oil consumers to the environmental damage they do to local fisheries (Naylor *et al.,* 2009).

There is also an opportunity cost to the water or land used to raise marine fish. Marine aquaculture operations need to be located near the coast or in the waters off the coast, and when the land and water is purposed for aquaculture, they lose the ability to be used for hotels, campgrounds, or surf spots. Some attempts have been made to create free floating cages that would float in the open ocean, but they are not yet in full production (Handwerk, 2009). Coastal land and water around the U.S. is already used for huge industries including fishing, oil and gas extraction, and shipping. Carving out an area along the coast to start a new aquaculture production facility potentially limits the profits of some other industry. Another social cost is the carbon footprint of large scale fin fish production. Pumps and filters are required to run continuously on shore based farms, and boats burning fuel must tend cages offshore. Also, depending on the species cultured and the location of the facility, water may need to be heated or cooled to give the fish optimal growing conditions. All of these activities draw a large amount of power, and when powered by fossil fuels, create a substantial carbon output.

THE HARD SELL

Finfish aquaculture has had a poor public image in the U.S. due to uncertainty and misinformation. The market demand for aquaculture seafood will be important in the future shaping of the industry. Innovation is typically driven by necessity, and an increase in demand for cultured seafood would certainly push the industry to produce a higher quality product with fewer inputs that could be offered at a lower cost. Current perceptions are not very favorable with regards to cultured fish, especially salmon. Reports of high levels of toxic chemicals and disease among populations as well as the fear of genetically modified fish have made consumers weary of purchasing farmed over wild caught fish. Technology may provide a way to better inform customers of their choices and let them weigh the benefits and risks themselves.

OVERCOMING PERCEPTIONS

A study done by Amber and Hall (2008) looked at U.S. media coverage following the publication of two reports on chemical toxicity in farmed salmon. One report by the Environmental Working Group and another published in the journal *Science* in January 2004 (Hites *et al.*, 2004) both found higher levels of the toxins known as PCBs in farmed salmon than in wild salmon. Both reports claimed that these chemicals can lead to the development of cancer and cause birth defects. There was much debate in the scientific community about the validity of these results (Mozaffarian & Rimm, 2006; Tuomisto *et al.*, 2004; Senkowsky, 2004), but this media study found that the image the media portrayed was predominantly negative. They also found that there was sustained media attention to the severe and alarming health risks up to two years following the emergence of the Hites report, and very little mention of health benefits associated with seafood (Amber & Hall, 2008).

There is still a lingering doubt in consumers' minds about the safety of cultured salmon and other cultured species. Recent media has focused on the outbreaks of ISAV. This virus spreads quickly in dense populations and with no cure on the market, is fatal to infected fish. Although it causes a myriad of symptoms in fish, it was found harmless to humans by the Center for Food Security and Public Health at Iowa State University. In their study published in 2010, they found that it posed no risk to humans because the virus is inactivated by human body temperatures of 98.6°F - 104°F. An outbreak of ISAV in 2007 caused a near collapse of the Chilean salmon industry in which two thirds of their farmed stocks were lost to the disease (Global Aquaculture Alliance, 2012). Billions of dollars were lost in terms of lost product, jobs, and stock crash (Global Aquaculture Alliance, 2012). Compounding this disaster was the banning of Chilean salmon by many countries, including the U.S. The Alaska Commercial Fisheries News website named the event "Fish Farmageddon." The Chilean salmon farming industry is still trying to recover from this outbreak and to stop outbreaks in the future.

Canadian farms in Nova Scotia recently had an outbreak of ISAV, affecting 240,000 Atlantic salmon fish early this year. The Canadian Food Inspection Agency declared them fit for human consumption, and it asserts that the disease poses no risk to human health. This ruling is a first for the CFIA since it started regulating the fish farming industry in 2005 (Oved, 2013). However, because no countries will import the salmon, it will all end up in Canadian markets. It was unclear from the report if Canada would begin importing salmon with ISAV or would only begin selling domestic salmon with the disease. What the media reports do not include is that

240,000 fish weighs approximately 960 tons (Jensen *et al.,* 2012). In 2011 Nova Scotia produced 5,624 tons of farmed salmon and Canada as a whole produced 102,064 tons (Fisheries and Oceans Canada, 2013), making the diseased fish only about 0.94% of Canada's total output if production numbers remained constant in 2012 and 2013.

Genetically modified fish have also been at the center of controversy. Indirect genetic modification of food is common place in agriculture through hybridization especially corn and wheat in the U.S. However, the public is not as convinced it needs genetically modified seafood. Direct genetic manipulation where genes from one animal are spliced into another, in this case trout genes inserted into salmon, allows fish to grow larger and faster. Organizations such as Greenpeace and Friends of the Earth are leading the movement against genetically engineered (GE) fish products (Real, 2013). Most of the concerns center on the possibility of these GE fish escaping from their pens and breeding with wild populations. This would potentially create mutant offspring capable of out-competing their wild counterparts, and destroying wild populations in the process. This loss would affect commercial fishing interests and conservationists who value the health and existence of wild fish and ecosystems, but could increase revenue for private and sport fishermen looking to catch more fish or exotic fish species. The potential loss of wild stocks has been valued in a study done by Loomis in 1996. His survey found that residents of Washington State have shown that their willingness to pay (WTP) is $50–$70 per household for wild salmon conservation through habitat restoration efforts or dam removal. If wild populations were to go completely extinct, the cost to society as a whole could be infinite (Naylor, 2000).

Genetic modification of food is nothing new in America. Humans have been selectively breeding wheat, corn, and livestock for almost as long as we have been raising them (Uzogara, 2000). New techniques of genetic manipulation, in which specific genes are artificially inserted into food, have only been in use for the past few decades. One study has shown that Americans do support the idea of genetically modified food and crops (Gaskell *et at.,* 1999). Figure 4 depicts survey results from that study in which respondents were asked about their support for uses of biotechnology in five areas: genetic testing, GM medicines, GM crops, GM food, and xenotransplantation (GM animals for use in human transplantation). Americans showed a positive response to GM food. When U.S. respondents were asked, "If the USDA/FDA (separate questions) made a public statement about the safety of biotechnology, would you have a lot, some, or no trust in the statement about biotechnology?" Support for the USDA was at 90%, and support for the FDA was at 84% (Gaskell *et al.,* 1999). A follow up study with similar questions would help shed light on where American consumers support for GM food stands today.

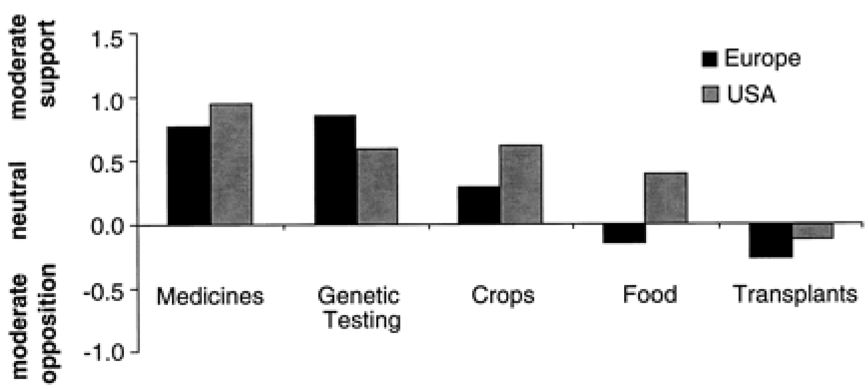

FIGURE 4: SURVEY RESPONSES FROM GASKELL ET AL, 1999 ON THE USE OF BIOTECHNOLOGY IN VARYING FIELDS OF SCIENCE.

TOOLS FOR THE CONSUMER

As technology grows, people are better connected with each other and have access to information previously unavailable to them. Greater information in the consumers' hand allows them to make more informed decisions and will help shape the demand generated for cultured fish. One industry that is growing to meet the demand for knowledge is the mobile application market.

The Seafood Watch program from the Monterey Bay Aquarium (backed by the Marine Stewardship Council) attempts to raise consumer awareness through its printed guides, website, and mobile apps. The program is aimed at consumers at all levels including restaurants, distributors and families to purchase their seafood from sustainable sources. The information provided by the Marine Stewardship Council's rigorous certification process ensures that seafood, whether farmed or wild, is produced sustainably. The easy to use ranking system within the app allows consumers to see what fish products are a best choice, good alternative, or bad choice. A similar application released by AppliFish, called iMarine, makes aquatic-related information available to anyone by providing basic information and maps on over 550 marine species, such as common names, sizes, and, distribution maps. These apps are a great start in informing consumers of the sustainability of their seafood, but better labeling may also play a factor. Eco-labels on seafood have been shown to sway consumer choice (Teisl *et al.*, 2002). With consumer confidence in the USDA and FDA high, eco-labels developed for aquaculture may also carry weight in the market. Labels that certify farmed fish as 'toxin free,' 'organic,' or 'sustainably grown' could have a major impact on the sale of farmed fish if developed and enforced by the FDA.

EXPERIMENTAL TRIALS

There have been a number of trials conducted at Hubbs-SeaWorld Research Institute that have attempted to find the most ideal conditions for raising healthy California yellowtail (*Seriola lalandi*) from egg to juvenile fish. These early stages in a fish's life cycle are critical as the larvae are the most fragile during this time. Many factors including temperature, light, water flow, turbidity, and others all contribute to the normal development of the larvae. Through the research HSWRI and others around the globe are doing, best practices can be put in place to reduce energy and costs while yielding a higher quality product in larger numbers. The study outlined below was focused on reducing the feed inputs to reduce cost for a producer. The small scale results here could translate into higher feed efficiency and reduce waste for much larger scale commercial productions that could save money and resources which could be reinvested to grow more fish.

This experiment was conducted to test the effect of different prey densities on the growth of *Seriola lalandi*. This experiment also tested what affect the timing of the food delivery would have. Feed schedules were broken up into a continuous feeding regime or fewer, larger batches of food administered periodically throughout the day.

Materials and Methods

Fifteen 300L experimental tanks were stocked with 15,000 eggs each. Once hatched, the larvae lived off of their attached yolk sacs for another two days. On day three, the larvae were offered a diet of live rotifers. Each tank was randomly assigned a prey density, and each received either five, ten or twenty rotifers per milliliter of water in the tank. Three tanks, one of each density, were fed continuously through the use of pumps and a supply of rotifers, while the others were fed their respective densities every three to four hours. Every other environmental factor including flow rate, light intensity, temperature and salinity was the same

FIGURE 5: ROTIFER

between treatments. Samples from the continuously fed tanks were taken seven times daily to ensure the correct density of prey items. Three 1mL samples were taken and rotifers per milliliter were counted under a compound microscope. The count was averaged over the three replicates to determine the rotifer per milliliter count in each tank. Samples of larvae from the continuously fed tanks were taken five times daily to check their gut content to see how many of the rotifers were being consumed.

At zero, four and seven days post hatch (DPH), samples of larvae were taken for photos and length measurement using an Evolution MP 5.0 camera mounted to a Leica MZ16 microscope at 75 x 1120 magnification. Lengths were measured using Image-Pro plus 5.1 software which allowed for accurate measures to be taken directly from the pictures taken. Dry and wet weight measurements were also taken at zero, four and seven DPH. Twenty individuals from each tank were collected and placed on filter paper over a beaker connected to a vacuum. Once the excess water was removed, the samples were weighed to obtain the wet weight. The samples were then placed into a Precision gravity convection oven to remove all of the water. After twenty four hours drying time, the samples were removed and weighed again to record their dry weight. On the seventh day post hatch, the experiment was ended and survivorship counts were taken. Final length, weight, and gut counts were also measured.

FIGURE 6: THE PICTURES ABOVE ARE OF TWENTY INDIVIDUALS FROM EACH EXPERIMENTAL TANK AT 75X1120 MAGNIFICATION. GROWTH STAGES SHOWN ARE AT: A) 0 DAYS POST HATCH, B) 4 DAYS POST HATCH, AND C) 7 DAYS POST HATCH. SCALE BARS SHOWN ARE 5MM LONG.

RESULTS

Statistical analyses were done on the data collected using analysis of variance (ANOVA) and Tukey's test to test for any significance between the treatments. Length grown, weight gained, numbers of prey items consumed, and survivorship were tested among the different treatments. Neither the density of prey nor the feed regimen had a significant effect on growth, nor was there any interaction between density of prey and feeding regimen.

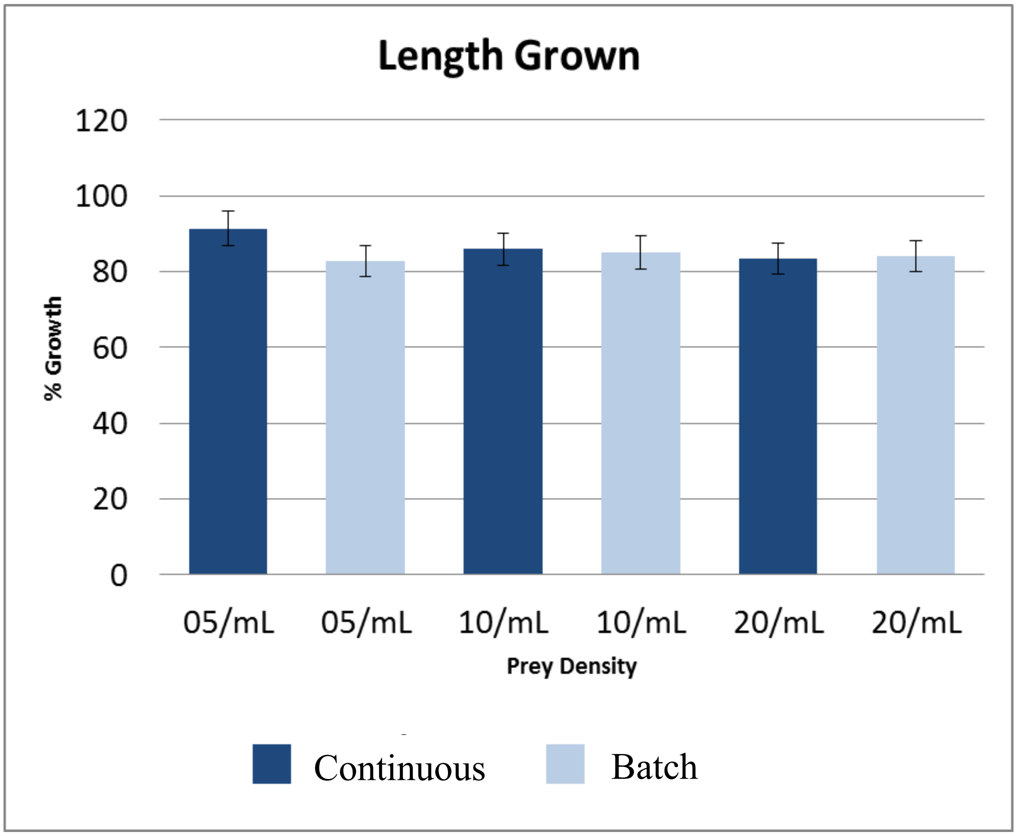

FIGURE 7: AVERAGE LENGTH GROWN OVER THE COURSE OF THE EXPERIMENT FOR EACH PREY DENSITY AS A PERCENTAGE OF 0 DPH LENGTH

Length was similar across all treatments and no significant difference was found (Figure 7). For the weight gained by each tank, the specific growth rate (SGR) was calculated using the formula:

$$\mu = (\ln W_t - \ln W_0)/t \tag{1}$$

where W_t is the final dry weight (grams), W_0, is the initial dry weight (grams), and t is the growth period (Fausch, 1984). The SGRs for the trial were also not significantly different across the prey densities or between the methods of feeding. The negative values are most likely not negative growth, but a combination of very low growth and sampling error. The fish productivity index (FPI) measures the total fish biomass produced during the trial for each tank. They were calculated using the formula:

$$FPI = [(W_f - W_i) \times \theta]/[F_\partial/(B_f - B_i) \times 10] \quad (2)$$

Where W_f is the final weight, W_i is the initial weight, θ is the percent survival, F_∂ is the food demanded, B_f is the final biomass, and B_i is the initial biomass (Kentouri et al., 1994).

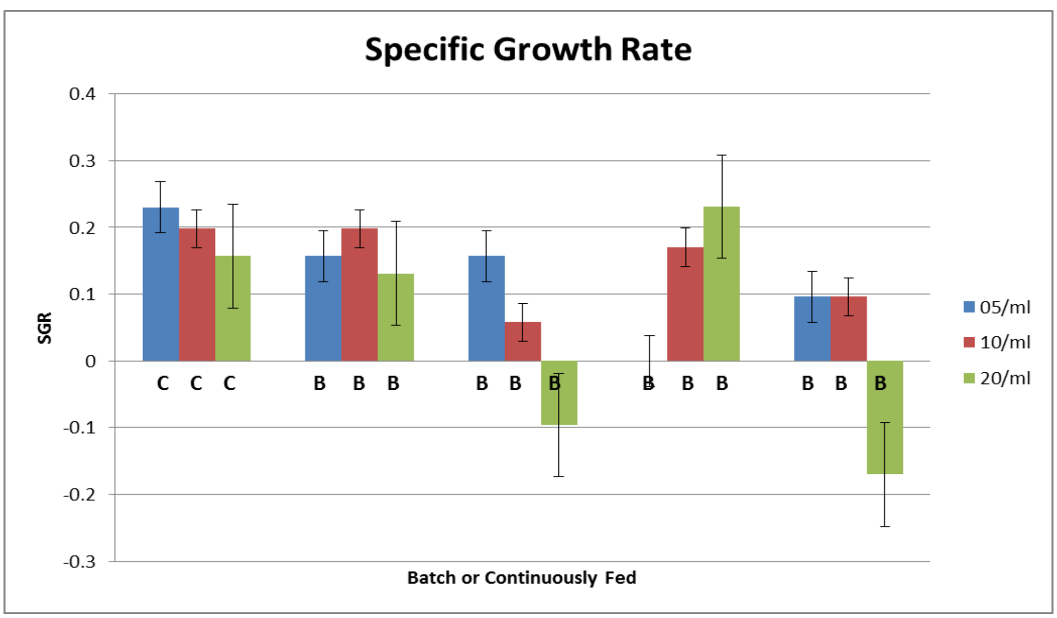

FIGURE 8: SPECIFIC GROWTH RATE FOR EACH EXPERIMENTAL TANK TAKEN AT 7DPH. DRY WEIGHT MEASUREMENTS ARE NORMALIZED WITH THE NATURAL LOG FUNCTION AND DIVIDED BY THE GROWTH PERIOD. 'B' REPRESENTS TANKS THAT WERE BATCH FED, AND 'C' REPRESENTS THE THREE TANKS THAT WERE CONTINUOUSLY FED AT DIFFERENT DENSITIES.

Parameter	Tank Feeding Regimen														
	5/mL Batch	20/mL Batch	10/mL Batch	5/mL Cont.	10/mL Cont.	20/mL Cont.	5/mL Batch	20/mL Batch*	5/mL Batch	10/mL Batch	20/mL Batch*	10/mL Batch*	20/mL Batch*	5/mL Batch*	10/mL Batch*
Initial Mean Weight (g)	0.001	0.002	0.001	0.001	0.001	0.002	0.002	0.004	0.003	0.002	0.002	0.003	0.005	0.003	0.003
Final Mean Weight (g)	0.003	0.005	0.004	0.005	0.004	0.006	0.006	0.003	0.003	0.003	0.004	0.005	0.003	0.004	0.004
Initial Biomass (g)	0.194	0.145	0.164	0.155	0.179	0.179	0.126	0.105	0.117	0.150	0.126	0.110	0.140	0.112	0.104
Final Biomass (g)	0.146	0.134	0.138	0.189	0.220	0.281	0.142	0.146	0.161	0.139	0.187	0.201	0.255	0.242	0.262
Biomass Gain (g)[a]	-0.048	-0.011	-0.026	0.034	0.041	0.102	0.016	0.041	0.044	-0.011	0.061	0.091	0.115	0.130	0.158
Food Demanded (mg)[b]				0.0113	0.0177	0.0188									
SGR (%/day)	0.157	0.131	0.198	0.230	0.198	0.157	0.157	-0.096	0.000	0.058	0.231	0.170	-0.170	0.096	0.096
FPI				0.025	0.057	0.085									
Mortality (%)				98.0	91.7	96.1									

TABLE 1: PERFORMANCE DATA ON EXPERIMENTAL TANKS

* Data not obtained on 0 DPH, data from 4 DPH used instead to calculate growth
a. Negative biomass numbers due to sampling error
b. Weight of rotifers calculated using average rotifer weights multiplied by average gut content
Blank cells indicate no data taken

The FPI for each continuously fed tank increases as feed density increases. This is due to the increasing biomass gain and food demanded numbers. Without replicate tanks on a continuous feed diet, it cannot be determined if these results are significant. Sampling error in the weight measurements could create a false reading.

Numbers of rotifers eaten each day were also collected for each of the continuously fed tanks. The percentage of larvae eating rotifers between the continuous tanks was significant (α=0.03). The 5/mL continuously fed tank (tank 5) had the lowest percentage of larvae eating at 35%, while 49% and 50.75% of the larvae were eating in the continuously fed tanks at 10/mL (tank 7) and 20/mL (tank 8) respectively. The average gut content between the tanks also showed a trend (α=0.06). Tank 5 had the lowest average prey item per fish at 1.83, tank 7 had 2.60, and tank 8 had the most at 2.99.

Time was a major contributing factor to both percentage of larvae eating prey, and average number of prey eaten ($\alpha < 0.01$). As the experiment progressed more larvae per sample had food in their gut, and the number of prey items consumed increased each day. In Figure 9, each day's average prey consumed per day is shown. For the first two days of feeding, the line is almost flat, showing not much difference between tanks. As the experiment progresses each day until the last, the average increases for each tank. On the last day, the experiment ended midday so a full day of data set was not obtained. Figure 10 is a similar graph that depicts the average prey consumption over the course of one day. As time progresses from morning to evening, the average prey items consumed increase in each tank.

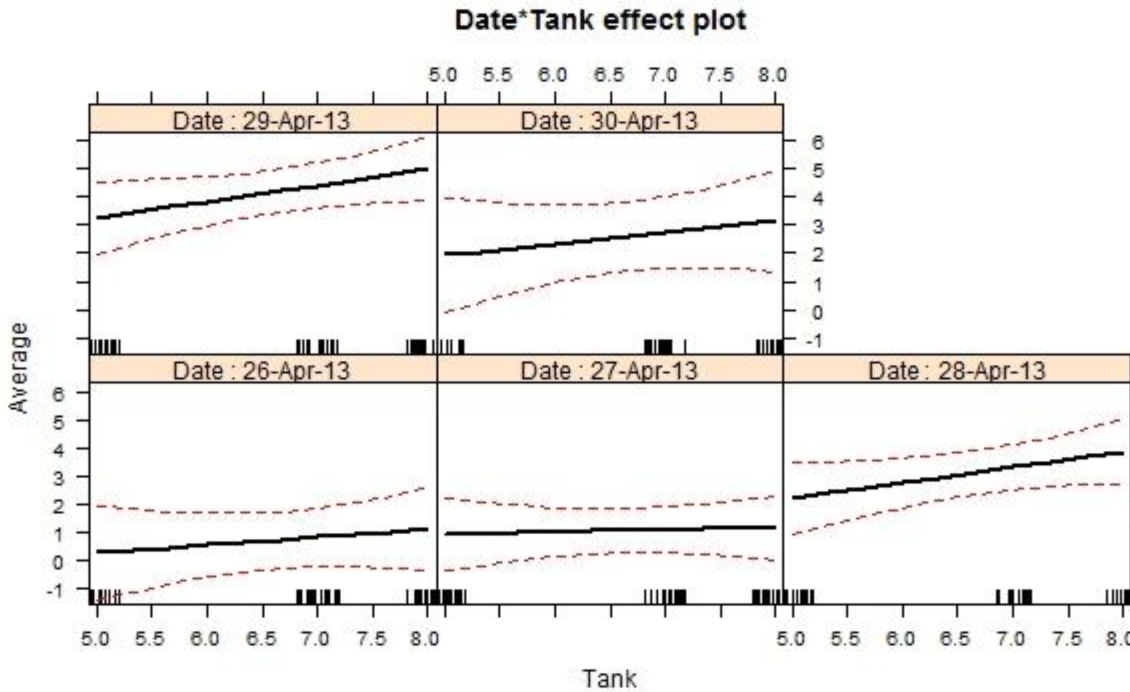

FIGURE 9: A GRAPHICAL REPRESENTATION OF AVERAGE PREY ITEM EATEN PER LARVAE IN TANKS 5, 7, AND 8. THE X AXIS REPRESENTS THE TANK NUMBER (5, 7, AND 8). THE Y AXIS REPRESENTS THE AVERAGE NUMBER OF PREY ITEMS CONSUMED. THE HASH MARKS ALONG THE X AXIS ARE SAMPLES FROM EACH TANK. THE SOLID BLACK LINE INDICATES THE AVERAGE PREY ITEM CONSUMED PER FISH, WHILE THE DASHED PURPLE LINES INDICATE THE ERROR. EACH BOX REPRESENTS ONE DAY OF FEEDING.

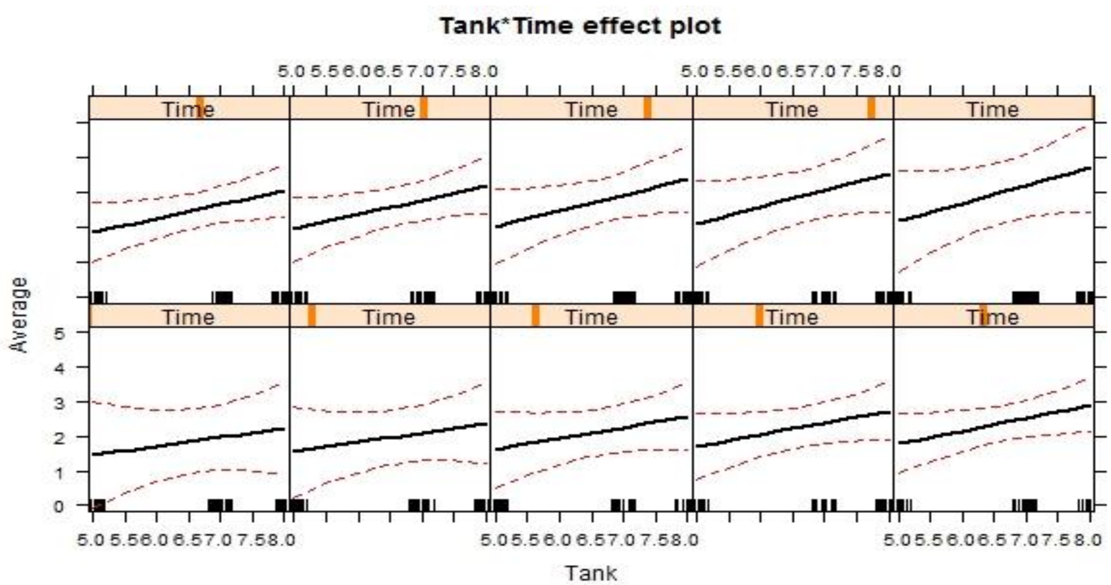

FIGURE 10: A GRAPHICAL REPRESENTATION OF AVERAGE PREY ITEM CONSUMED OVER THE COURSE OF ONE DAY. AXISES ARE THE SAME FROM FIGURE 8. EACH BOX NOW REPRESENTS A PERIOD OF TIME THROUGHOUT THE DAY. THE LOWER LEFT BOX REPRESENTS MIDNIGHT. THE BOXES MOVE FROM LEFT TO RIGHT, WITH THE ORANGE BAR INDICATING TIME OF DAY.

DISCUSSION

Although the larvae in the tank fed continuously at 20/mL had a higher percentage of fish eating and likely had a higher number of prey eaten per fish, growth remained the same. These results may be due sampling error or low sample size. It may also be due to the fish's physiology. At this stage of the life cycle, this species tends to follow a steady growth rate in length, following a generalized von Bertalanffy growth curve given by Ludwig von Bertalanffy (1938):

$$L(t) = L_\infty(1 - e^{-K(t-t_0)}) \tag{3}$$

where $L(t)$ is length at age t, L_∞ is asymptotic length, K is the von Bertalanffy growth constant (a measure of how rapidly the fish approaches its asymptotic length), t is age, and t_0 is the theoretical age at length zero (under the assumption that this growth curve applies to very young fish) (Taylor and Willis, 1998; Shiraishi et al., 2010).

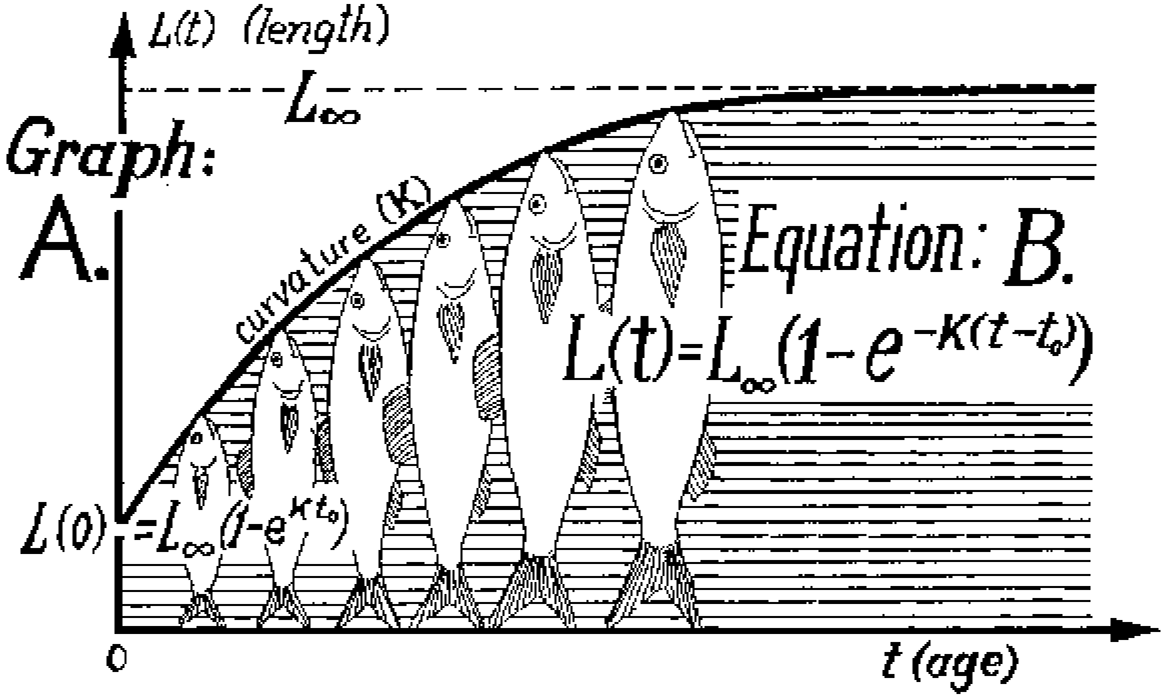

FIGURE 11: VON BERTALANFFY GROWTH CURVE FROM FAO.ORG

To maintain a constant density of twenty rotifers per milliliter for twenty four hours uses approximately 52.2 million rotifers each day. In contrast, maintaining a density of five rotifers per milliliter uses approximately 16.6 million rotifers each day, saving a little over 35 million rotifers per day. Batch feeding uses even fewer rotifers. Batch feeding at a density of five rotifers per milliliter five times a day will use approximately 7.5 million rotifers each day. These numbers are calculated for only one of the 300L experimental tanks. At around $0.25 to produce a million rotifers, a large production-sized facility would see significant savings. However, the feed is just one aspect where costs could be lowered, increasing the value of the fish grown.

The limiting factor in the reliable production of most marine fin fish species is mortality during the early larval stages when the fish are developing. Other factors, in addition to diet, contribute to healthy well developed larvae. Bacteria normally found in the environment can pose a huge risk to developing eggs and larvae. Most marine fish at this stage have an undeveloped immune system that puts them at a higher risk for infection than the larger, older fish of the same species (Olafsen, 2001). Disinfection of the eggs prevents transfer of bacteria and other pathogens from the broodstock population to the larvae, allowing the larvae to develop in a cleaner environment. A treatment of 100mg/L of formalin for 60min is the best option for disinfecting eggs of California yellowtail, and will remove many harmful pathogens from the surface of the eggs (Stuart et al., 2010). Bacteria are not all bad. Fish like other animals rely on a composition of microflora to aid in digestion and displace other more harmful bacteria. Studies into the use of probiotics during larval rearing have been conducted to test their effectiveness in managing the health of larvae, as they do in domesticated animals (Olafsen, 2001). Other environmental factors can be controlled for to allow the fish to grow as they would in the wild.

Light intensity and water turbidity have been known to have a significant effect on larval survival and development. Studies have been done to target the correct combination of both for larval *Seriola lalandi*. High light intensity (14,850 lx) with a green algae paste additive in the water allows the larvae to locate their prey more efficiently. This allows them to grow faster, have a higher survivability rate, and develop normally (Stuart & Drawbridge, 2011). All of these experiments individually are small pieces of the industry, but together they provide a solid baseline with which to produce the best quality product cheaply and reliably by reducing wasted effort and wasted resources. As research in larval growth continues, testing the effects of prey densities below 5/mL would be helpful to find the minimum amount of prey required to obtain a normal growth pattern. Also, from the data collected, it appears that feeding larvae at this stage will yield the same growth rates across the different prey densities and different methods of feeding. However, due to resource limitations, there were no replicate tanks that were fed continuously. Future experiments could include more continuously fed tanks to lessen the effect of sampling error.

CONCLUSION

It is no secret that wild populations of commercial fish are dwindling (Pauly and Palomares, 2005). Most wild catch fisheries in the United States are attempting to be sustainable and economically profitable at the same time, some with more success than others. The global seafood demand is growing at a rate faster than wild stocks can support. The tuna market report from the F.A.O. confirms that tuna catches in the Western Pacific and Atlantic Oceans are down and demand in the U.S. has increased by as much as 32% for frozen loins, driving prices up (Food and Agriculture Organization of the United Nations, 2013). As more effort is expended in catching wild stocks, and total benefits are decreasing, and costs for the consumers will rise to cover the gap.

Future aquaculture research will need to address consumer concerns with respect to consumption of resources and genetic variability. Focus on improving feed efficiencies and substituting away from fishmeal and fish oil will reduce the impact to wild stocks and allow aquaculture to expand in the U.S. to lower the seafood deficit. Costs can also be lowered and resources used more efficiently as the volume of production runs increases (Losordo and Westerman, 1994). Renewable energy sources such as wave, wind, and solar can also be implemented by farms alongside their production facilities to conserve resources and reduce the carbon footprint.

A transition away from net pens to solid construction pens is already being evaluated by many countries including Canada and Japan to reduce the loss of farmed fish to the environment

(AgriMarine, 2011). These pens would reduce loss through storm events and would provide a much more resilient structure for long term use. Solid wall pens boast a variety of benefits including separation of the farmed fish from the wild fish and surrounding environment, no solid waste pollution on the sea beds, no escapes, reduced disease transmission, and it creates a barrier to sea lice and plankton blooms (AgriMarine, 2011). Land facilities are another option and also ensure a very low probability of escape, but are more expensive to build and maintain.

Unfortunately, no aquaculture system is perfect, and environmental damage is still a concern for countries with large aquaculture industries. Many countries, including Norway, Canada, and England are proving technologies that the U.S. can easily adopt including acoustic, visual, and infrared feed sensors (Blyth *et al.*, 1993; Bjordal *et al.*, 1993; Foster *et al.*, 1995) and new pen construction materials (Chambers *et al.*, 2012). Advances in technology are always improving systems, and the U.S. could gain by using the equipment and methods from countries that have been making millions of dollars in profits from their aquaculture (Food and Agricultural Organization of the United Nations, 2012a).

America is in a unique position with respect to aquaculture. We have yet to build a significant national infrastructure for aquaculture that exists for livestock and agriculture farmers across the country. Through the implementation the latest technologies and lessons learned from other countries, the idea of building an industry around the idea of sustainability could be attained. The U.S. has the resources and the demand for domestic seafood, we just need the political and public will to develop this industry.

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