AN ECONOMIC ANALYSIS OF THE USE OF RECIRCULATING SYSTEMS IN THE PRODUCTION OF TILAPIA.

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An Economic Analysis of the use of Recirculating Aquaculture Systems in the Production of Tilapia

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DECLARATION

I hereby declare that this thesis is a bona fide record of research work done by me as a part of my master degree program from the Norwegian University of Life Sciences (UMB), Ås, Norway.

It has not previously formed the basis for the award of any degree, diploma, fellowship to me, or other similar title of any other university or society.

I hereby warrant that this thesis is based on work done by myself and where sources of information have been used, they have been acknowledged.

Ås, May 2012 F. Appiah-Kubi

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PREFACE

The submission of this master thesis marks the end of my MSc. Program in Aquaculture. The study was carried out at the Department of Animal and Aquacultural Studies of the Norwegian University of Life Sciences.

Economic analysis of Recirculating Aquaculture Systems (RAS) in the production of tilapia has been the focus of many researchers worldwide. A great deal of emphasis was placed on the biological and engineering aspects of the production in these past researches. Research works which incorporates the biological and engineering developments, together with the economics of RAS in tilapia production are scarce in Norway. Also, advances in commercialization of RAS technology in tilapia production in Norway is widely accepted to be in its infancy compared to other aquaculture production techniques. I believe this study incorporating the biological, engineering and economics associated with the production of tilapia on a commercial scale would provide useful data for making logical and applicable inferences, as well as, basis on which future researches into the economics of RAS could be hinged.

Differing from most of other studies on the economics of RAS in the production of tilapia, this analysis primarily focused on the operational (running) costs using data from both the prototype RAS production and commercial scale production. Another analysis which incorporated variables such as capital and infrastructure costs, depreciation rates and tax rates was developed, but unfortunately excluded from this final report because the plausibility of some data used could not be verified due to non availability of information. The financial feasibility of the various production scenarios is discussed together with the production variables found to have high impact on profitability.

F. Appiah-Kubi Ås, May 2012

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I would also like to thank Bjørn Reidear Hansen, who helped me in the data collection and for his moral support. Mr. Godwin Acquah Dwomoh and Isaac Kumah, your brotherly love and support cannot go unacknowledged. To all, who in diverse ways contributed directly and indirectly to the success of this thesis; I say, thank you and may the Almighty God bless you.

DEDICATION

This work is dedicated to my son Jerome Nyarko Appiah-Kubi, my lovely wife Gloria Appiah-Kubi, not forgetting my mum Madam Veronica Nyarko whose singular efforts saw to my rise on the education ladder. To God be all the glory, honour and praise for how far he has brought me.

ABSTRACT

An economic analysis of tilapia production was conducted using a recirculating aquaculture system facility, situated at the Norwegian University of Life Science (UMB). The goals were; (1) to evaluate and estimate the operational cost involved and from this, estimate the breakeven cost, (2) identify and describe the constraints unique to the RAS, (3) to perform financial feasibility of a (hypothetical) scale-up production, and (4) to conduct sensitivity analysis on some variables to highlight their effect on profitability. All assumptions made in this study, production scale and the economic analysis were based on the technology design, and production parameters existing at the UMB facility.

Tilapia (0.36g), were stocked in the tanks; temperature and water quality parameters were carefully managed until the fish reached the harvestable size (700g) after 140days. The survival rate and feed conversion ratio (FCR) were 91% and 0.8 respectively. Economic analyses was conducted on three different production scenarios, (1) 'actual' production carried out at the UMB facility, (2) analysis on the same scale of production, with the introduction of some correctional data from commercial productions, and (3) scale-up (hypothetical) production system based on the design criteria of the UMB facility.

The results showed that, the operational cost involving the UMB production was high and economically not viable. A price of NOK 73 is required to be able to breakeven relative to the prevailing market price of NOK 40. The production in this scenario needed to be increased by 54.8%, to be able to breakeven.

The introduction of cost data from commercial productions in the second analysis resulted in a drastic reduction in operational cost. Breakeven price and breakeven yield estimated were NOK 42.7 and 1163kg respectively. However, for the scale-up production, NOK 40.2 was the estimated cost to breakeven. The breakeven yield estimated for the scale-up production was 109663kg of tilapia. Indications thus, were that, prospects for economic success with RAS under Norwegian conditions can be improved by a large scale production. The sensitivity analysis revealed that, reductions in the cost of production variables such as labour, feed, and electricity, have marginal effects on profitability. Increases in sales price and production scale were found to have the highest impacts on profitability and improvements in these variables would yield maximum profit.

Key words: Scale-up, sensitivity analysis, breakeven yield, breakeven cost, economic analysis.

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ABBREVIATIONS

UMB: Norwegian University of Life Sciences

RAS: Recirculating Aquaculture Systems

FAO: Food and Agriculture Organization of the United Nations

EU: European Union

TAN: Total Ammonia Nitrogen

UAN: Unionized Ammonia Nitrogen

FCR: Feed conversion Ratio

CVP: Cost -Volume –Profit

Kg: kilogram

NOK: Norwegian Kroner

GIFT: Genetically Improved Farmed Tilapia

NCRAC: North Central Regional Aquaculture Center

1.0 Introduction

Aquaculture is one of the fastest growing sectors of food production in the world. Cultured species such as tilapia, catfish, salmon, trout, oysters and clams are high in demand and the profit level is very high. The boom in this industry can be attributed to the growing demand for a healthy, tasty and affordable food as well as the sharp decline in wild fish populations as a result of overharvest and water pollution (Helfrich & Libey, a). The rampant pollution of fresh water resources has also necessitated the need for the culturing of fish in waters free from contamination. Recirculating aquaculture system (RAS) technology has been found to provide a way in solving this problem. This is a technology designed for holding and growing a wide variety of aquatic species and defined as production units which recycle water by passing it through filters to remove metabolic and other waste products (Kazmierczak & Caffey, 1995). The systems can be designed to cater for different capacities and efficiencies. In comparison to the traditional aquaculture practices, RAS offers more independence from the external environment (i.e. increased levels of control) which provides a basis for improved risk management (Rawlinson, 2002). Majority of the worlds tilapia productions are done using the pond systems, however, in the temperate regions, RAS is employed in the production due to the cold climatic conditions. This makes the production cost higher since huge capital is expended on the RAS construction and the running of other production mechanisms such as heating, pumping and filtering of the water (Alceste & Jory, 2002). A lot of European countries are now using RAS in fish production; however, production level is very low compared to other forms of fish culture (Martins *et al.*, 2010). The construction and operation of these facilities require high capital injection and this sometimes serves as disincentive to prospective investors (Schneider et al., 2006). To make up for this, high stocking densities are required in the productions to be able to cover the investment costs and generate profit. However, the need for high stocking densities also comes with some welfare challenges (Martins *et al.*, 2005). Aquaculture production using RAS has been the focus of research and developmental efforts of many groups for decades. Most of the research has been going on outside Norway; whereas here, it has almost exclusively been aimed at cold water species and there is consequently no data on the economic performance of a commercial scale recirculating production systems for tilapia in Norway.

The purpose of this thesis project was to conduct an economic analysis on the production of tilapia using recirculating systems and from this deduce the following:

- The operational cost involved in a closed recirculation systems in a temperate region.
- Identify and describe the constraints unique to the closed system culture.
- Conduct sensitivity analysis to highlight the variables that affects profitability
- To perform an economic analysis (financial feasibility) of the systems in a bigger set up.
- Suggest key areas where more attention should be focused in future researches.

1.1 Species and Production Parameters

Tilapia, commonly, refers to a group cichlids consisting of three economically important genera. These are taxonomically distinguished from each other according to their reproductive behaviours: *Tilapia, Oreochromis* and *Sarotherodon,* all commonly known as "tilapia" (Mjoun & Rosentrater, 2010). The Nile tilapia (*Oreochromis niloticus*) and various hybrids are the most commonly produced tilapia species (Green, 2006). Other less commonly cultured species include Blue tilapia (O. aureus), Mozambique tilapia (*O. mossambicus*), Zanzibar tilapia (*O. urolepis hornorum*) and red tilapia (*T. rendalli and T. zilli*). *O. niloticus* represents about 75% of the world production (FAO, 2009a). Tilapia culture can be in either fresh or salt water, in tropical and subtropical climates, but the culture can be constrained in temperate climates where production must be carried out in indoor tanks (Lim & Webster, 2006 *in* Mjoun & Rosentrater, 2010). Optimal growing temperatures are typically between 22°C- 29°C and spawning normally occurs at temperatures greater than 22°C (Mjoun & Rosentrater, 2010a). Most tilapia species are unable to survive at temperatures below 10°C, and growth is poor below 20°C (Mjoun and Rosentrater, 2010b). They can tolerate a pH range of 3.7-11 but optimal growth rates are achieved between the pH of 7-9 (Ross, 2000).

1.2 Culture Attributes of Tilapia

The tilapias are second to carps in terms of production as farmed table fish and they exhibit some unique characteristics that serve as a drive for its continual growth and may soon surpass carp production. The global demand for their products is high, can be cultured in a variety of production systems and in different geographic regions to contribute to the high world production. They have been identified as a prime species for use in recirculating systems because of their tolerance to crowding and low water quality (Drennen & Malone 1990). They are known to have good-tasting, mild flavour flesh and widely accepted as food fish, used in many cuisines. A range of variant coloration offers consumers different choices. Reproduction wise, they can breed in captivity without hormonal induction of spawning. They produce large eggs, culminating in the production of large fry (at hatching) that are hardy and omnivorous at first feeding. Sexual maturity is reached in less than 6 months, making them good candidates for selective breeding. They are tolerant of a wide range of environmental conditions (Chervinski, 1982), including low dissolved oxygen levels (1 ppm); high ammonia levels (2.4 to 3.4 mg/L unionized), and will grow in water ranging from acidic (pH 4) to alkaline-pH 11 (El-Sayed, 2006). Tilapia can tolerate CO_2 up till 20mg/l and high H_2S levels (Halver & Hardy, 2003) and various strains can be grown in water varying in salinity from fresh water to full strength seawater (Watanabe et al., 1997).

They feed on a low trophic level with the constituents of the genus *Oreochromis* being omnivores, feeding on algae, aquatic plants, small invertebrates, detritus and in addition, a variety of feeds of animal origin (Watanabe, 2002). The tilapias are able to grow rapidly on lower protein levels and tolerate higher carbohydrate than many carnivorous species cultured. They can be fed with prepared feed that includes a high percentage of plant proteins which are comparatively less expensive than feed containing a high percentage of fish meal and other animal protein sources.

1.3 World Production and Trade

In 2008, commercial aquaculture production was about 2.8 million tonnes with a corresponding estimated value of $3.7 billion. The production was forecasted to reach 3.7 million tonnes by the end of 2010 (FAO, 2009; FAO GLOBEFISH, 2011a). By 2015, world production is expected to reach between 4.6 million tonnes and 5 million tonnes (FAO, 2010).

China is largest consumer and producer (produces about 50% of global production) of tilapia, with a production estimated at 1.15 million tonnes in 2009, from 1.13 million tonnes recorded in 2007, from (FAO GLOBEFISH, 2010 and 2011b). In 2011, China’s production was expected to reach 1.18 million tonnes by the end of the year (FAO, 2012).

According to the third quarter markets report for the year 2011, the EU markets imported about 15832 tonnes of tilapia and the figure shows a marginal increase of 4% compared to the importations for the same period in 2010 (FAO GLOBEFISH, 2012b). The EU markets are largely supplied by China, Indonesia, and Brazil. Spain has the highest imports of tilapia (3522 tonnes), followed by Poland (2267 tonnes). The report further asserts that, demand for the product is increasing and this has necessitated the initiation of some innovative projects in other parts of the world, including in Africa to cater for the shortfalls. However, China's contribution to production levels would still rank the highest and it is expected that, prices for the commodity would stabilize as the consumption grows. But as it stands now, any reduction in production levels and exports from China would likely have an impact on the market price indices (FAO GLOBEFISH, 2012c).

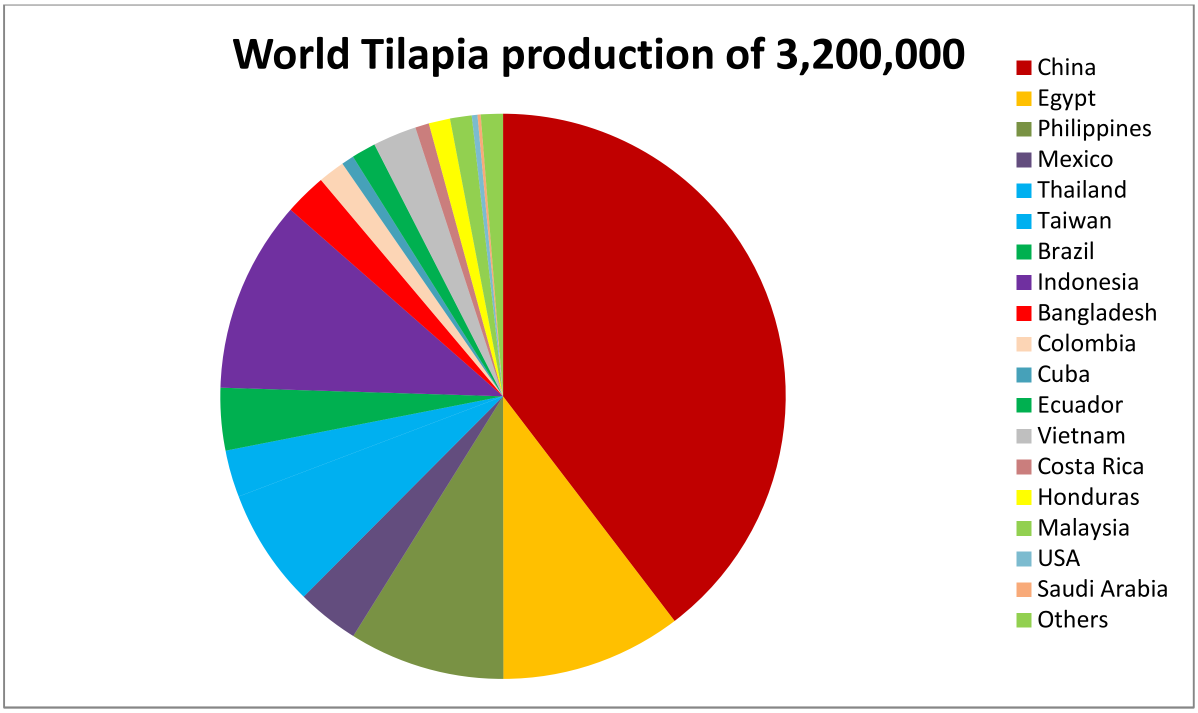

Figure 1: Major Tilapia producing countries in the world

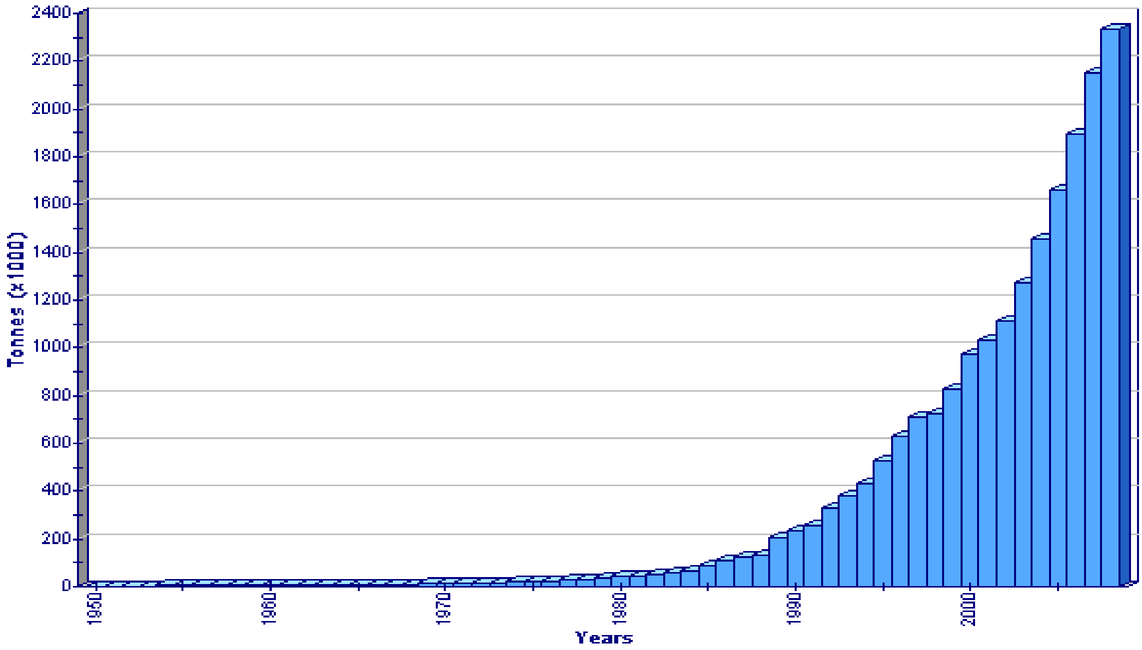

Figure 2: Global Aquaculture production of Nile Tilapia.FAO Fishery Statistic, 2011.

1.4 Recirculatory Aquaculture Systems

Recirculation aquaculture systems (RAS) are new and a unique way to culture fish. In place of the old conventional methods of growing fish, RAS offers a means to rear fish in indoor tanks where the environment can be controlled. The system filters and cleans the water for recycling back through fish culture tanks (Helfrich & Libey, b). In RAS, more than 90% of the water is recirculated through a series of biological and mechanical filtration systems so that only a fraction of the water is consumed (Rawlinson & Foster, 2000). “New” water is added to the tanks only to make up for losses through splash outs; evaporation and for those that is used to flush out waste materials. Fish cultured using this technology must be provided with a congenial environment and conditions suitable for growth and to remain healthy. Clean water, dissolved oxygen, and optimal temperatures are required to ensure better growth. These are achieved by the filtration system, aerators and heaters incorporated in the technology design. The filtration system purifies the water and removes or detoxifies products harmful to the culturing media and species. Organic particles from faeces and uneaten feed are removed by the mechanical particle filters, whereas the poisonous metabolic waste products TAN and NO2 (total ammonium nitrogen and nitrite) are oxidized to less toxic compounds (NO3) in nitrification filters. These filters are sometimes referred to as aerobic biofilters or nitrification filters. In the construction of the RAS facility, proper sizing of all system components is very important. When the RAS plant is oversized for its application, the system would function but the cost of running the facility would be high. Undersized RAS, on the other hand, would not be able to maintain proper environment to sustain fish production.

1.4.1 Advantages of RAS

RAS offer various advantages ranging from reduction water consumption (Verdegem et al., 2006 *in* Martins et al., 2010), to the provision of improved opportunities for waste management and nutrient recycling (Piedrahita, 2003 *in* Martins et al., 2010). The systems environment can be controlled to achieve better hygiene and disease management (e.g. Summerfelt et al., 2009; Tal et al., 2009 *in* Martins et al., 2010). It offers a near complete environmental control to maximize fish growth year-round, and the flexibility to locate production facilities near large markets (Masser et al., 1999; Schneider et al., 2010) to deliver a fresher, safer product and lower transport cost (Timmons et al., 2001). In terms of product security RAS offers a high degree of product traceability (Smith, 1996; Jahncke & Schwarz, 2000) and biological pollution control (no escapees, Zohar et al., 2005 *in* Martins, et al., 2010). They may be used as grow-out systems to produce food fish or as hatcheries to produce eggs and fingerling, for stocking and ornamental fish for home aquariums (Helfrich & Libey, c)

1.4.2 Risk Management and General Production techniques

The systems are complex and require personnel with the required expertise to successfully manage. Regular monitoring and management are required to maintain the complex system which involves heating, aeration, circulation and biofilter systems. Any electrical or mechanical breakdown may result in huge mortalities and this is a major concern when culturing fish using this system. To operate the system at maximum or near maximum carrying capacity, contingency measures in the form of emergency alarms and backup power and pump systems needs to be installed. Biological risk factors are very high in the use of this technology and constant attention is required to swiftly deal with any anomaly which may occur in order to prevent huge losses.

A recirculation system grows two organisms; fish and a culture of bacterial resident in the biofilter. This requires constant monitoring of the biofilters to ensure optimum fish growth since the efficiency of the biofilters is very critical to the success of the production (Kazmierczak &

Cafey, 1995b). However, these biofilters have their limitations and management of other parts of the system may not compensate for the risks posed and the system may fail. Thus, technical competence is required to perform various tasks such as planning, implementation and measurement of the performance of processes involved in the running of the setup and to compare it to standards practices. Although production is the main priority, insight about marketing trends are very important in order to maximize profit. Data collection by the manager would provide a basis for comparison of the actual outcome of the production process with the average performance data (Huirne et al., 1992). A successful combination of the different areas of management would ensure maximum outcome.

1.4.3 Recirculation Systems in Norwegian Aquaculture industry

The production of freshwater fish for consumption is very limited in Norway. Eikebrokk & Ulgenes, (1997) identified strict environmental regulations introduced to minimize the risk of eutrophication of fresh water resources, disease transfer to wild fish stocks, and escapees making a possible genetic impact on wild fish stock, as the reasons for the limited culture of freshwater species. Recirculation which offers an alternative means is somehow considered uneconomical due to the availability of good quality fresh and saline water in Norway. However, the trend is changing and many farmers are now employing the recirculation technology. They further stated that, the change in trend may be attributed to the demand for reduced water consumption rates, the increase in biomass production per unit volume of water, and the need for more economically viable effluent treatment solutions that would tackle the environmental issues related to particle separation and disinfection requirements.

Almost all the commercial scale recirculating systems are for salmon farming and none is known to produce tilapia on a commercial scale. About 85 million smolts are produced using RAS in Norway (Del Campo et al., 2010) and these smolts are very high in quality; with high rate of survival and growth after sea transfer (Terjesen et al., 2008). The culture of tilapia using RAS in Norway is expected to receive much attention in the near future due to the growing world population, high demand for the commodity, pollution of fresh water resources and climatic changes.

2.0 Materials and Methods

2.1 Description of the UMB tilapia laboratory

The tilapia laboratory at the Norwegian University of Life Sciences (UMB) was established in 2006 and the first tilapia cultured (*Oreochromis niloticus*, Nile tilapia), came from a Genomar hatchery in Singapore as a yolk sac fry. This population has been reproduced at the laboratory ever since.

The Tilapia laboratory consists of 3 separate rooms; feeding section, reproduction room and water treatment section. The feeding room has 10 big tanks each 250L and 10 small tanks each with a capacity of 100L.In addition 5 bigger tanks of capacity 400L is also incorporated in the system. All the tanks are connected to the re-use system with automatic feeders installed on each tank. Feeding and light regimes can be easily adjusted using the automatic feeders and the lightening system. The total water volume of the system is 7000L and more than 99% of the water is re-used in normal operations, allowing for addition of only 2L freshwater per minute (Hansen, pers.com). The flow rate is averagely 150L/min and a water temperature of 26°C is maintained throughout the system.

The volume of media in the biofilter is 1.1m^3 and a 1kg feed input would produce 0.04kg TAN in the system, with a TAN removal rate of 25deg. The filter media used is 1.2kg/m^3 per day in normal operations. A level sensor in the biofilter tank is also connected to the fish lab alarm system. Each fish tank has an individual aeration to keep oxygen at an acceptable level for some hours in case the circulation pump or the central airblower fails.

The facility was constructed by the University for research purposes and various research works involving growth studies, nutrition and production are conducted here. The facility is manned by qualified technicians who manage the day to day running and also act as resource persons to students when the need arises. Actual data on the RAS at this facility and some other data on commercial scale tilapia productions for this thesis work were collated under the guidance of Bjorn Reidear, Hansen (a technician at the laboratory).

Figure 3 below, shows the technology design and the main components of the system. The water is aerated in the biofilter with the use of air blowers.

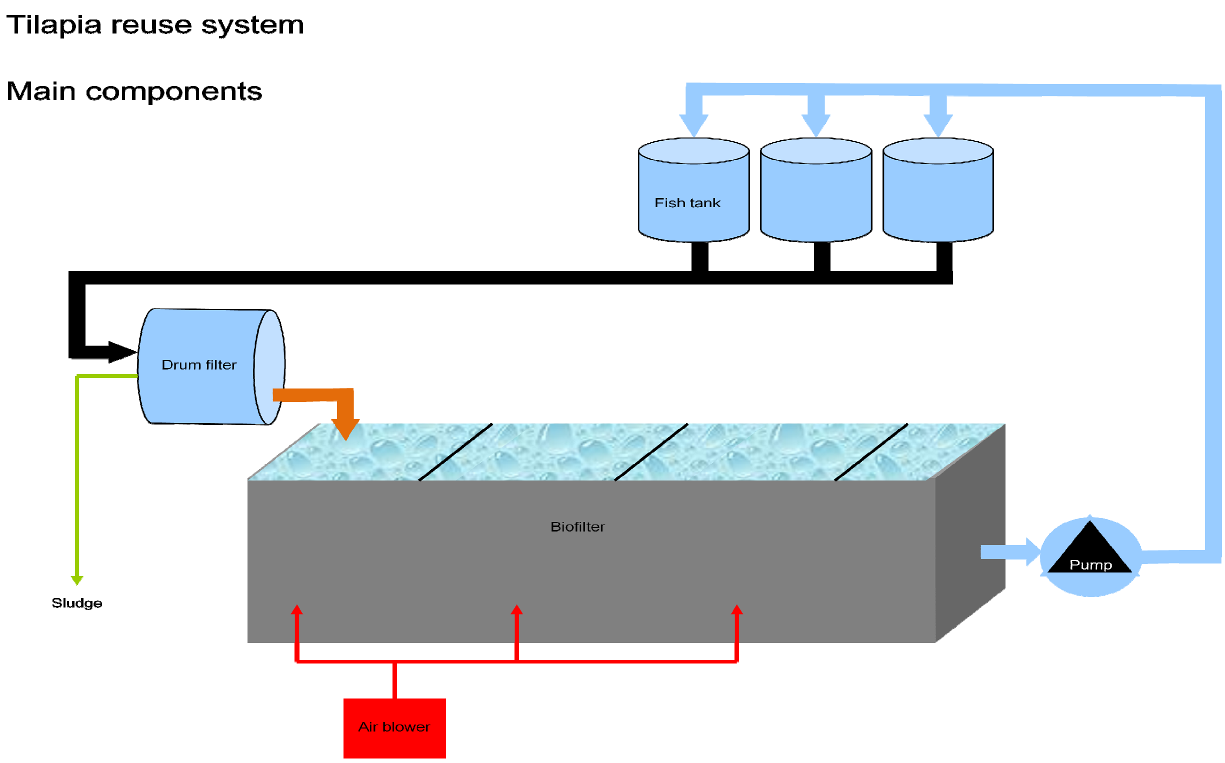

Figure 3: A schematic design of the basic components of the facility.

2.2 Production Setup

The study was carried out for a 20 week period; from November 2010-March 2011 (winter period in Norway). About 1500 fingerlings of 0.36g size (1-1.5cm length) were produced using the hatchery setup at the facility and stocked in the tanks. The various production parameters (such as feeding, heating, and chemical analysis) were managed daily till they were ready for harvesting. A total of 1364 market size (average weight of 0.7kg) tilapia and weighing 1091.2kg were harvested at the end of production for the market. Data on the biological parameters (feed, survival rate, temperature and pH), engineering parameters and economical parameters (cost of feed, electricity cost, Labour, market price) were recorded, and are summarized in Table 3. The data obtained were analysed and used in the economic model (budget) estimations for the production.

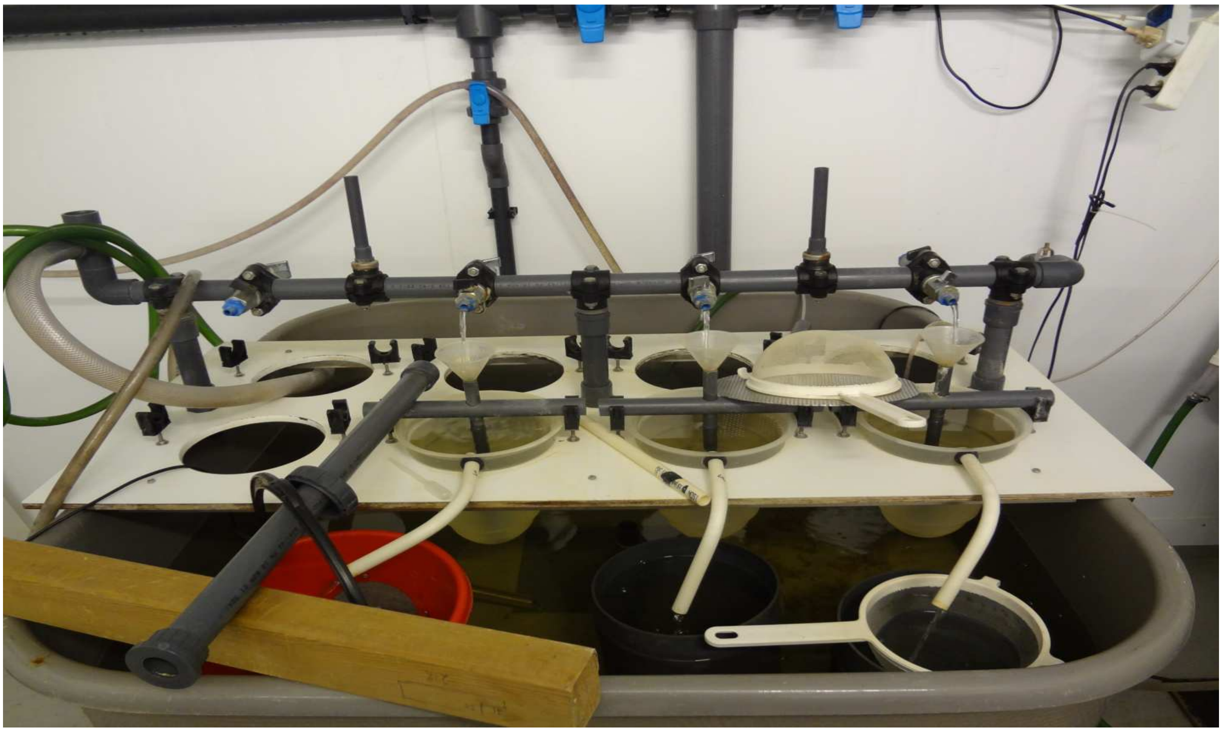

Figure 4: The hatchery (part) used in the production of fingerlings.

Figure 5: The weaning tanks used in the production.

2.3 Production scenarios and models for estimations

Three scenarios of production were developed and presented in this project. The first scenario deals with the actual production carried out at the prototype (UMB laboratory) facility. A second scenario) budget was prepared for the same level of production. Some correctional factors (cost from commercial level production) were introduced in this budget since the running of the facility and other auxiliary activities carried out are geared towards research goals and may be unrealistic in normal operations of a commercial RAS facility. In the third scenario, production was scaled-up by the ratio 1/100. The models for estimations were applied to all three scenarios of production and the various estimations, made for each scenario are presented in the results chapter.

The models for estimations are the calculatory models based on which the various estimations were made. Some of these tools would be described in detail under the various sub-headings.

2.3.1 Biological Model

These tool were used to estimate incomes and production; growth and mortality. The simplest tool to use is the formulas for biomass, *B (t)*, and biomass value, *V (t):*

$$B(t) = N(t)w(t) \qquad (1)$$

Where *N* is the number of fish at time *t*, and *w* is the weight of the fish at time *t*. The sales output (value of the fish) from the production is calculated by multiplying price with quantity:

$$V(t) = p(w)B(t) \qquad (2)$$

Where *V(t)* is the biomass value and p(w) is the price pr. kg fish. The kg price is assumed to increase as the weight of the fish increases *(p' (w) > 0)*. This formula does not take into consideration the effect of seasonal variations on the price of fish (Bjørndal 1987).

Feed Conversion Ratio (FCR):

This is another important biological production parameter to consider.

$$FCR = \frac{FB}{BM_2 - BM_1 - FT} \qquad (3)$$

Where FCR is kg consumed feed per kg growth, *FB* consumed feed in kg, BM_2 is biomass at harvest, BM_1 is start biomass, or biomass at stocking, and FT is fish lost to mortality (Einen & Roem, 1997).

2.3.2 Economic (model) Analysis techniques

These are the theoretical concept that represents the economic processes underlying the set of production variables and shows quantitatively, the relationship between these variables. The economic analysis methods employed in this thesis project are:

i. Cost-volume-profit analysis (breakeven analysis and profitability analysis)
ii. Sensitivity analysis

2.3.2.1 Cost-volume-profit (CVP) analysis

The volume of fish sales relative to its expenses has an important influence on financial feasibility. Understanding the relationship between the volume of production and expenses involved in the production plays a key role in achieving profitability objectives (O'Rourke, 1996). When sales volume is less than anticipated, expenses as a percent of sales must be much higher than anticipated. In order to be more profitable, there must be an increase in production/sales or decrease expenses or both. The relationship between sales and expenses as well as the nature of the expenses is very important in determining profitability of the venture. This technique is used to examine changes in profits in response to changes in sales volumes, costs, and prices. CVP analysis is done to plan future levels of operating activity and provide information about the products of services to emphasize; volume of sales needed to breakeven and achieve a targeted level of profit; the amount of revenue required to avoid losses; know whether to increase fixed costs; determine how much to budget for discretionary expenditures and to know whether fixed costs expose the organization to an unacceptable level of risk. Breakeven analysis forms an integral part of this form of analysis.

The net income of the production can be estimated using the following formula:

$$Net\ income = Total\ revenue - Total\ production\ cost \quad (4)$$

Variable unit cost:

According to Hoff, (1998), Variable unit costs represent the cost involved to produce a kg of the produce and it's given by the formula:

$$variable\ unit\ (kg) cost\ = \frac{variable\ costs}{Harvested\ Biomass} \tag{5}$$

Marginal Contribution:

The marginal contribution is the amount of money needed to cover the fixed costs and an eventual profit.

$$Marginal\ Contribution = Operational\ income - Variable\ costs \tag{6}$$

The *marginal contribution per unit* represents the profit per unit sale. It is a useful quantity in carrying out various calculations, and can be used as a measure of production leverage.

The marginal contribution per unit *(C)* in kg is given by Unit Revenue *(Price, P)* minus Unit Variable Cost *(V):*

$$C=P-V \tag{7}$$

The *Contribution Margin Ratio* is the percentage of Contribution over Total Revenue, which can be calculated from the unit contribution over unit price or total contribution over Total Revenue:

$$\frac{C}{P} = \frac{P-V}{P} \times 100 = \quad = \frac{Total\ marginal\ contribution}{Total\ Revenue} \times 100\% \tag{8}$$

Marginal contribution in kg

This gives the kg required to cover the operational costs and profit equals zero.

$$marginal\ contribution\ in\ kg = \frac{Marginal\ contribution\ (NOK)}{Cost\ of\ prod.per\ kg \quad (NOK)} \tag{9}$$

Breakeven analysis

Breakeven analysis informs producers about the price they need to receive for their product in order to cover all costs of production. It also indicate to the producer, the kilogram of fish, and price for the fish needed to cover the variable, fixed, and total costs of production.

Breakeven price and breakeven yield/produce

The breakeven cost/price is the price at which the product must be sold in order for profit to be zero. It is also the sales level at which the accruing revenue is exactly equal to the cost of making the output.

$$Breakeven\ point = \frac{total\ cost\ of\ production}{quantity(kg)produced} \qquad (10)$$

. The *breakeven per unit yield* represents the number of units, or kilograms needed to be sold in order to break even.

$$Breakeven/\ unit\ kg = \frac{total\ cost\ of\ production}{Unit\ price\ per\ kg} \qquad (11)$$

It should be noted that CVP is a short run, and marginal analysis which assumes that, unit variable costs and revenues are constant. It also assumes that, fixed cost and variable costs are separate and different.

2.4 Sensitivity Analysis of identified variables that may affect Profitability

Sensitivity analysis was conducted to compare the effect of some variables on the profitability of the productions and to know the areas where an improvement in performance may have a positive impact on the economic performance of the RAS (Losordo & Westerman, 1994). The simplest form of sensitivity analysis (one-way sensitivity analysis) was employed. This was done by varying one variable by a (+/-) percentage and the impact on the financial performance of the production were examined. The analysis was then repeated for the other variables identified in the operational costs. Table 1, shows the important variables that were included in the analyses based on the results obtained from the UMB laboratory and the scaled-up (hypothetical) production. Feed, labour, and electricity cost were the main costs involved in the operation of the prototype (UMB) facility and were used in the sensitivity analysis. Market/sale price was included in the analysis to cater for the ever-changing pricing level. The identified cost variables were varied by +/- 20% since such variations usually occur in commercial productions (De Ionno et al., 2006). The price instability on the market was catered for by comparing the performance at prices NOK32 and NOK48.

Table 1: Summary of variables used in sensitivity analyses and the corresponding variations applied to assess the potential impacts on the financial performance of the UMB facility and the scaled-up production.

Variable	Degree of variation
Operational costs	
Feed	+/-20%
Electricity	+/-20%
Labour	+-20%
Production	+/-20%
Revenue	
Sales price	NOK32 vs. NOK 48

2.5 Alternative budget and Economies of scale (scaled-up production).

In order to assess and compare the dynamics and effects of the production parameters on the profitability, an alternative budget for the same level of production at the UMB facility was developed using data on some operational costs from commercial scale production. Another economic model (budget) was developed for a scale-up production (hypothetical) based on the UMB facility design criteria, with a scale-up ratio of 1/100.

Table 2: Basic costs and units of economic, engineering and biological parameters monitored at the UMB facility.

Economic parameters	Unit	Unit price
Market Price/kg	NOK	40NOK
Fingerling cost/g	NOK/fing.	0.25NOK
Initial no. of fingerlings	#	1500
No. Harvested	#	1364
Feed cost	NOK/kg	9NOK
Amount of feed used	kg	1705kg
Electricity cost	NOK/kW/Hr	1NOK
Labour	NOK/hr	200NOK
Engineering cost		
Production Cycle-days	#	140
Production cycle weeks	#	20
Number of tanks	#	15
System volume	liters	7000l
Cost of Water use	NOK/1000liters	30NOK/m^3
Flow rate	l/min	150l/min
Electricity used	kW/hr	8.6kW
Biological Parameters		
Initial Biomass	kg	0.36kg
Final biomass	kg	1091.2kg
Survival rate	%	90.9%
Feed conversion ratio	#	0.8
Harvestable weight	kg	0.7kg
Slaughtering cost	NOK	3NOK/fish
Water Analysis	NOK	10NOK each

Price of 1kW/Hr from Statistics Norway (2011). The price per kg of tilapia was arrived at after a market survey conduct in Oslo.

2.6 Cost estimations of the main operational areas in the production setup

The various costs involved in the operation of the recirculating system for the UMB and scale-up productions; the amount of feed required in producing a kilogram of tilapia, electricity, labour and maintenance were estimated individual as shown below:

2.6.1 Fingerlings

The fingerlings used in the production were produced at the laboratory using the hatchery setup. The eggs were manually striped, fertilized from the broodstock and under careful temperature regime manipulations, the fingerlings were produced to feed the weaning tanks. A total of 1500 fingerlings, averagely 2.5cm in length and weighing 0.36g were produced for the study. It must be noted that, the cost of the fingerlings produced was estimated and used in the budget estimations. The cost of one (1-1.5 inches) fingerling (0.36g) on the market is approximately 0.25NOK depending on the volume being purchased (Hansen, pers. Com, November 4, 2010). The total cost of the fingerlings was estimated to be NOK 375.

2.6.2 Feed and feeding

A feed containing all the essential minerals and vitamins for a higher growth performance was used in the production, with an estimated FCR of 0.8. Strict adherence was given to the regular feeding schedules. Automatic feeders were used to ensure frequent feeding intervals per day to ensure high conversion rate and feed was evenly distributed on the feeders to ensure even growth and prevent stunting. Total amount of feed used was estimated to be 1705kg. The price of a kg of the feed was pegged at NOK9 (Hansen, pers, com, November 4, 2010). Generally, feed constitutes the highest variable cost in every production and it is expected to vary with an increase in production level. In the commercial level (scaled up-1/100) production, the quantity and cost of feed is expected to vary commensurately with scale of production.

2.7.3 Labour Costs

RAS systems are highly sensitive to changes in the normal operations. Changes in flow rate, accumulation of waste particles and feed may cause high mortalities and poor product quality. Due to its sensitivity to changes, well trained personnel are required to manage the abnormalities which may occur daily. The labour cost for the UMB laboratory production was estimated from one hour per day's work, with an hour's wage pegged at 200NOK (Hansen, pers, com, November 4, 2010). Assuming a greater level of automation and economies of scale, an estimated labour cost of NOK1.5 (Hansen, pers.com, November 5, 2010) was assumed per a kilo of tilapia produced for both the alternative and hypothetical commercial scale production budgets. This figure was arrived at after considering the labour cost in producing a kilo of Atlantic salmon. According to Statistics Norway (2011), the estimated labour cost for producing a kilo of Atlantic salmon is NOK1.5. Due to the unavailability of data on labour cost on tilapia production, the labour cost for Atlantic salmon was assumed for the estimation purposes though it is a known fact that the modes of culturing are different (salmon production is in net pens whereas the tilapia was in tanks). Since this thesis project is for educational purposes only, the adopted figure for labour in these budgets was assumed to be within range.

2.6.4 Electricity

The main components of the system that consumes a considerable amount of power are the heaters, pumps, and the feeders**.** The system has 2 heaters with 3kW capacity each. Three pumps were identified namely, pump for drum filter, and pump for circulation and the airblower for cleaning the drum filter.

Table 3: Shows the various components where electricity usage occurs and the amount consumed.

Component	Number	kW consumed	Total (kW)
Heater	2	3Kw/each	**6**
Pumps			
Drum filter	1	0.75	
Circulation	1	0.75	2.1
Airblower	1	0.6	
Hatchery/Feeders		0.5	0.5
TOTAL			8.6

Price of 1kW/Hr of electricity is approximately 1kr. (Statistics Norway, 2011).

The heaters are thermostat regulated and are switched on/off after use. The filters, pumps and airblower are situated in a different room some few meters away from the tanks room. Energy loss occur in the form of heat through the transfer process, building due to inadequate insulation system, evaporation from the water surface, waste accumulation and splash out from the tanks. Notwithstanding, about 75% of the heat generated are recycled (Hansen, pers.com, November 4, 2010). About 80% of total electricity produced is used in the running of the UMB facility (Hansen, pers. Com, November 4, 2010).The price of 1Kw/Hr of electricity is approximately NOK1 (Statistics Norway, 2011). The same percentage was used in the electricity estimations for the alternative budget and the scale-up production budget.

2.6.5 Water analysis

Feeding and subsequent growth leads to the generation of waste products which reduces the oxygen level in the system. These waste products need to be removed because of their potential negative impact on fish growth, and mortality. Metabolic waste products take two forms in most recirculating systems; solids and total ammonia nitrogen (TAN). The toxic portion of TAN, NH_3-unionized ammonia nitrogen (UAN), is a component of the feedback mechanism that can inhibit fish growth through loss of appetite and in high levels, may cause fish mortality.

The biofilters control the buildup of UAN in the recirculating system whereas suspended solids are removed from the system by the mechanical filters. This makes the efficient operations of the biological and mechanical filters very critical to the growth of the fish and the stability of the recirculating system. An efficient operation of both filters leads to the absence of growth reduction or mortality feedbacks (Kazmierczak & Cafey, 1995c).

Three different analyses were conduction during the 'actual' production; TAN, NO_2 and NO_3 analysis. A total of 150 analysis each were conducted during the production at an estimated unit cost of NOK10 (Hansen, pers.com). Cheaper methods were employed in carrying out these tests during the production. According to Hansen, (pers.com, March 30, 2011), the 'normal' number of chemical analyses conducted at the laboratory was high and thus a reduction in number (60analysis) was recommended for the alternative budget and the scale-up production.

2.6.6 Chemicals (Bicarbonate/Lime)-pH control:

In the RAS technology, the biofilters are incorporated to oxidise the ammonia generated. The process proceeds in two stages; Nitrosomas bacteria oxidize ammonia to nitrite and the Nitrobacter bacteria oxidize nitrite to nitrate. For each gram of ammonia nitrogen oxidised, 4.57g of oxygen and 7.14mg of alkalinity as CaCO3 are required and if the alkalinity is not replaced, the pH of the water would drop (Hutchison et al., 2004). A way of replacing the alkalinity consumed is to add sodium bicarbonate to the system at rates up to 250g for every 1kg of food introduced into the RAS (Wheaton et al. 2002). The estimated cost of lime used at the laboratory facility was 5000NOK (Hansen, pers.com, March 30, 2011). For the alternative budget, efficiency of more than 95% was assumed and thus a drastic reduction is expected in the cost of bicarbonate used. The cost of bicarbonates used for the estimations involving the alternative budget and the commercial level budget was pegged at NOK1, 000 and NOK10, 000 respectively. The cost of bicarbonates is expected to go up with an increase in scale of production since the amount of feed usage would increase with an increase in production.

2.6.7 Slaughtering

Tilapia is processed by filleting, gutting or decapitation of the head. The cost of preparing each tilapia for the market was pegged at approximately 3NOK (Hansen, pers.com, March 30, 2011). This figure was arrived at relative to the cost of slaughtering a kg salmon in Norway. According to statistics Norway (2011), the slaughter cost for a kilogram of salmon is NOK3. Comparatively, the fillet yield from a kg salmon is higher than tilapia. This clearly indicates that a considerable effort is required in slaughtering tilapia compared to salmon. This figure was used in all the budget estimations for every kilo of tilapia slaughtered.

2.7 Operational cost Analysis –UMB RAS facility

The units cost of the Economic, Biological and Engineering parameters are shown in Table 1. The economic aspect deals with the unit cost of fingerlings, market price of a kg of tilapia, cost of a kg of feed and the amount of feed used during the entire production. It also takes into consideration the amount and cost of the electricity used and labour cost relative to hours of work per day. The engineering parameters include the system volume, unit cost of water, the flow rate, as well as the production cycle. Water analysis, FCR, initial biomass, final biomass, survival rate and slaughtering costs constitute the biological parameters.

2.8 Alternative budget

As indicated earlier, a careful assessment of the high costs involved in the operations of the UMB laboratory production, necessitated the development of an alternative budget for the same level of production with the introduction of some correctional factors. This was done by the introduction of some data (costs) obtained from commercial scale production. Table 6 and 7, summarizes the various cost estimates involved in the production and the economic model estimates respectively.

2.9 Scale-up

For the purpose of this thesis projects, the physical model for scaling was employed and some assumptions were made to support the model. It was assumed that, geometric, dynamic, kinematic, thermal and biological similarities exist between the prototype (UMB facility) and the commercial scale (hypothetical) recirculating system. Although some of these assumptions (dynamic, kinematic and biological) are difficult to fulfill in practical sense, they were assumed to be achievable in this project.

The production level at the prototype setup was scaled up by the ratio 1/100, with an assumed survival rate of 91%. The amount of power consumed was assumed to be 80% of the total energy produced as in the earlier estimations (Hansen, pers.com, November 4, 2010). Cost estimates were developed using data from industry suppliers, statistics Norway and discussions with the facility attendant at the UMB laboratory. A budget was prepared for this scale of production and the various economic analyses were developed.

3.0 Results

The operating costs for the various scenarios were developed for comparison purposes between the different production scales and the results are presented individually below.

Table 4: Summarizes the fixed and variable costs, cost of prod. Kg of tilapia and the % of parameters to total production cost (UMB laboratory).

Parameters/category	Total cost	Cost/ kg prod/NOK	**%** of total cost
Fixed cost			
Electricity	23116.8	21.2	29.0
Fingerlings	375	-	0.5
Labour	28000	25.7	35.2
Water Analysis	4500	4.1	5.7
Bicarbonates	5000	4.6	6.3
Total fixed cost	**60991.8**		
%of fixed cost to prod. cost			**76.6**
Variable costs			
Feed	15345	14.1	19.3
Slaughtering	3273.6	3.0	4.0
Total variable cost	**18618.6**		
%of variable cost to prod. cost			**23.4**
Total prod. cost	**79610.4**		
Cost of prod. kg tilapia	**73.0**		

Labour recorded the highest percentage cost involved in the production carried out at the UMB facility, followed by electricity and feed in that order. In this production, labour was treated as a fixed cost since the hours of work and cost of work per hour by the facility attendant was fixed and not subject to any increment regardless of the level of production. Although costs of fingerlings are sometimes treated as a variable cost, it was not done so in this case. In this scenario, the level of production was up to the carrying capacity of the facility and there was no room for an increase in production level.

Table 5: Summarizes the estimations from the economic models for the UMB facility.

Economic model		Formula No.	Amount
Sales/income		2	43648
Net Operating income/PL		4	-359662
Variable unit (kg) cost	NOK	5	17.1
Marginal contribution	NOK	6	25029.4
Marginal contribution	kg	9	343
Marginal contribution pr unit(kg)	NOK	7	22.9
Gross margin ratio		8	57
Break even cost/price	NOK	10	73.0
Break even yield/produce	kg	11	1990.26

The net operating income shown from the table indicates a loss relative to the production cost. This is due to the high level of fixed costs involved in this production. More was contributed to overcoming the fixed cost than to profit.

Table 6: Summarizes the operational costs, cost of producing a kg of tilapia and the % impact of each parameter to total production cost for the alternative budget.

Parameters/category	Total cost	Cost/ kg prod/NOK	% of total cost
Fixed cost			
Electricity	23116.8	21.2	49.7
Fingerlings	375	-	0.8
Water Analysis	1800	1.7	3.9
Bicarbonates	1000	0.9	2.1
Total fixed cost	**26291.8**		
%of fixed cost to prod. Cost			**56.5**
Variable costs			
Feed	15345	14.1	33.0
Labour	1636	1.5	3.5
Slaughtering	3273.6	3.0	7.0

Total variable cost	**20254.6**	
% of variable cost to prod. cost		**43.5**
Total prod. cost	**46546.4**	
Cost of prod. kg tilapia	**42.7**	

Electricity recorded the highest percentage cost followed by feed. Labour is the least costs in the variables and this is due to the assumed unit cost relative to the level of production. As mentioned earlier, labour shows economies of scale when the scale of production is high and therefore exhibited this tendency in the scale-up production. Therefore, the labour cost is expected to increase with any increase in production. Table 7, shown below indicates the various economic model estimations.

Table 7: Summarizes the results of the economic model estimations for the alternative budget.

Economic model		**Formula No.**	**Amount**
Sales/Income		2	43648
Net Operating income/PL		4	-2898.4
Variable unit (kg) cost	NOK	5	18.6
Marginal contribution	NOK	6	23393.4
Marginal contribution	kg	9	657.3
Marginal contribution pr unit (kg)	NOK	7	21.4
Gross margin ratio		8	53.5
Break even cost	NOK	10	42.7
Breakeven yield/produce	kg	11	1163

The net operating income estimated indicates a marginal loss. However, the potential to breakeven with an increase production is high.

The production would be able to break even, when the kilogram produced from the setup equals the breakeven yield. Any additional kilogram of fish produced after the breakeven yield would result in profit.

Table 8: *Summarizes the fixed and variable costs, total operation costs, cost of producing a kg of tilapia and the % impact of each parameter on the total production cost for the scaled-up production.*

Parameters/category	Total cost	Cost/ kg prod/NOK	% of total cost
Fixed cost			
Electricity	2311680	21.2	52.7
Water Analysis	1800	0.02	0.04
Bicarbonates	10000	0.10	0.23
Total fixed cost	**2323480**		
%of fixed cost to prod. Cost			**53.0**
Variable costs			
Fingerlings	37500	0.34	0.86
Feed	1534500	14.1	35.0
Labour	163680	1.50	3.70
Slaughtering	327360	3.0	7.50
Total variable cost	**2063040**		
% of variable cost to prod. cost			**47.0**
Total prod. cost	**4386520**		
Cost of prod. Kg tilapia	**40.2**		

Electricity constitutes the highest cost in the production, with cost of fingerlings being the least among the main variables that affect profitability. Costs of fingerlings, feed, and labour were treated as variable cost in this scenario, since they are expected to vary with an increase in production. Total fixed cost in this production setup, was reduced drastically and the potential for further reduction is high. This can be achieved by the introduction of energy efficient equipment which would reduce the power consumption level of the system.

Table 9: Summarizes the results of economic model estimations for the scaled-up (hypothetical) production.

Economic model		Formula No.	Amount
Sales/Income		2	4364800
Net Operating income/PL		4	-21720
Variable unit (kg) cost	NOK	5	18.9
Marginal contribution	NOK	6	2301760
Marginal contribution	kg	9	57544
Marginal contribution pr unit (kg)	NOK	7	21.1
Gross margin ratio		8	52.7
Break even cost	NOK	10	40.2
Breakeven yield/produce	kg	11	109663

The PL estimated in this scenario indicates a marginal loss in revenue (negative). However, there is the possibility of making profit with a further increase in production since the loss recorded is very marginal and increase in sales would offset the loss incurred.

Table 10: Summarizes the results of the sensitivity analysis performed for the identified variables.

	Production cost	
Variable	**UMB**	**Scaled-up prod.**
Electricity costs		
+20%	-40585.8	-484056
-20%	-31339.0	440616
Feed costs		
+20%	-39031.4	-328620
-20%	-32893.4	285180
Labour costs		
+20%	-41562.4	-54456

-20%	-30362.4	11016
Production output		
+20%	-8729.6	-872960
-20%	8729.6	872960
Sales price		
NOK48	-8729.6	-872960
NOK32	8729.6	872960

The results from the production output and sales price sensitivity analysis produced identical results for both scenarios analysed.

4.0 Discussion

The operating costs were estimated for the various scenarios and compared. The facility sizes and the scale of production, labour, electricity, feed and FCR, were found to be the principal areas that have significant impact on the operations of RAS. These together with the limitations of the study are discussed individually below.

4.1 Cost of Labour

According to Samples & Leung, (1986), in practical studies, labour expenses are generally considered as fixed cost since they do not vary in response to an increase in production scale. Labour (35.2%) in the UMB production estimations, was treated as fixed costs since the cost would remain the same regardless of an increase in production scale. However, in the alternative and scaled up production estimates, labour and fingerlings were considered as variables costs. This is because the assumed cost of labour per kg of tilapia produced is expected to increase with an increase in production. In the alternative budget, labour formed 3.5% and 3.7% in the scale-up budget. In commercial scale production, additional labour may be required in areas of marketing, management and general production. The amount of labour utilized on farms varies widely, but, with increasing scale of production, specialization of tasks by individuals and the introduction of labour saving devices (automation of some production components), it is expected that the unit cost of labour per kg of tilapia produced will decrease.

4.2 Electricity

Electricity constituted 29.0% of the total production costs in the UMB budget. The percentage increase highlighted in the alternative and scaled-up budget estimations (49.7% and 52.7% respectively) is attributable to the influence of labour cost reduction in these budgets. A reduction in energy use is possible by improving the system design and management of airlifts and biofilters (Roque d’Orbcastel et al., 2009) and the incorporation of denitrification in the recycling loop (Eding et al., 2009). Decreasing head losses associated with moving water through the larger pipes, and an increase in pump efficiencies at higher flow rates in the scale-up productions would further reduce energy cost.

4.3 Cost of feed

Feed formed 19.3% in the UMB facility productions. In the alternative and scale-up budgets, 33% and 35% were for electricity estimated respectively. These results highlight that, feed constitute the highest variable cost and varies with scale of production as shown in the scale-up budget. An improvement in feed quality is expected to reduce the amount required and impact positively on the production cost. Poor quality feed usage would add on to the running cost since more feed would be required to achieve the same weight gain. The feed used for this project was of high quality (FCR 0.80).

4.4 Fingerlings

The GIFT strains used in the production are genetically superior compared to other strains like the red tilapia in terms of survival, feed consumption and conversion rate. They are more efficient in conversion of ingested feed into body mass. According to a study conducted by Wing-Keong et al (2008), the GIFT tilapia showed up to 33% better feed conversion rate, and greater potential for growth with a high dietary protein levels and greater feed intake depending on diet, than that observed in the red tilapia. This makes them good candidates for commercial scale production using RAS. The costs of fingerlings estimated for the UMB and scale-up productions, were seen to be low and meet the FAO criteria for buying fingerlings. According to FAO, (2003), the unit cost must be low to make the on-rearing economically viable, and still allow a reasonable profit by the producer (FAO, 2003). However, internal production of fingerlings is widely seen to be the best option for commercial scale productions.

4.5 Economies of Scale

The financial estimations showed that the UMB facility standard and capacity constitute a risk factor in terms of profit maximization. The budget estimations from the UMB facility production showed a large loss (NOK-359662) relative to the production cost. This is attributable to the high fixed cost involved in the operations and the limited carrying capacity of the facility. Labour and electricity costs were found to be high for such a scale of production. The result from the estimations is an indication that, the facility is incapable of becoming profitable regardless of any realistic variations in the identified operational variables which are known to impact on profitability. This confirms the generally known assertion that, small RAS are more expensive to operate per unit of biomass held than larger units. However, since the facility is for only research purposes, operations and costs involved are quite unique to the facility.

The alternative budget estimations highlighted how some of the production variables that affect profitability, behave with an increase in production scale. Electricity, Labour and feed were found to be the principal parameters that affect profit margins. In small production levels, these parameters are seen to impact negatively on profit margin but shows varying degree of economies of scale with an increase in production level. In that budget, labour showed the highest potential for economies of scale within the variable costs. This was confirmed in the budget for the scale-up production. Although, this budget estimation also recorded a loss, it showed that with realistic reductions in labour and feed costs, an increase in production has a strong potential of breaking-even.

The scale-up budget estimations also recorded a loss. However, this loss was marginal compared to that obtained for the UMB facility production. The possibility of breaking even and eventually profit through an increase in production was very high for this production scenario. The breakeven price estimation in this production was NOK 40.2. This means, a loss of NOK-0.2 is made on each kg sale. It is therefore projected that, a further 600kg increase in production would be enough to post some profit. The drastic reduction in production cost shown in the scale-up production compared to the UMB production, was due to the increase in sales volume from the scale-up production. The contribution from each sale towards fixed cost coverage became less relative to the contribution to profit. As a result, more was contributed to profitability in the scale-up production, than to the coverage of fixed cost since production cost per unit kg decreased with the increase in production. The Scale-up production therefore showed economies of scale and the potential to breakeven and eventually make profit was high for this scenario.

According to a NCRAC tilapia report (2002), on a study of the economic analysis of RAS for the production of tilapia on commercial scale (1814.369 tonnes), the breakeven cost per kg of tilapia was estimated to be USD2.46 (equivalent to NOK13.78), with a production cost of USD 4,461,921 (equivalent to NOK24986757.6). The estimations were based only on the fixed and variable costs excluding capital costs. These results are in sharp contrast to the results obtained from the scale-up production of this study, which had a breakeven price of NOK 40.2 compared to NOK 13.78 obtained for the NCRAC study. These observable contradictions can be attributed to the wide difference in scale of production (109120kg for this study compared to 1814369kg for the study conducted in the USA at Grayson Hills Farms in Harrisburg, Illinois). The economic conditions of the country where the study was conducted also influences the production cost. This is because, costs of electricity, labour, feed etc differ from country to country. Another difference observed was the inclusion of the costs of oxygen, maintenance and interest rates in the estimations. These variables were not factored into the estimations involving this study. The NCRAC study is believed to have benefited from economies of scale due to the high level of production involved.

4.6 Sensitivity Analysis

From the sensitivity analysis conducted, a decrease in the cost of production variables such as labour, feed, and electricity, produced marginal effects on profitability. Increase in sales price and production were found to have the highest impacts on profitability. These findings support the earlier findings highlighted in Losordo (1991) and Losordo & Westerman (1991). It must be pointed out that, the findings herein referred to, included gains realized from an increase in FCR and reduction in overall system cost. A variation of +/-10% was used to analyse the input variables. However, these two variables (FCR and capital cost) were not factored into the sensitivity analysis in this study. This due to the high quality feed used for the study (FCR 0.8) and the uncertainties associated with the cost of the system used for the study. Nonetheless, these findings show the areas where further improvements may have huge impacts on the profitability of commercial scale production using RAS.

5.0 Conclusion

The results from the thesis project have shown the effect, scale of productions have on per unit cost of production. Thus, the scale-up facility benefited from economies of scale compared to the UMB production. It has also shown that, variables such as increases in production, and sales price, reduction in labour, feed and electricity costs influences profitability. It was gleaned from the results that, small scale productions are not economically viable compared to large scale productions.

The study did not firmly establish profitability due to its focus, and the exclusion of capital cost and interest rates. However, it did show that, potential for economic success with the scale-up production was high. Thus, amortization of injected capital in the construction of RAS facility could be achieved within a short period by increasing production. It is important to note that, the financial estimations in this study reflect only the production conditions in Norway. Therefore, the potential for profitability in other countries may differ due to differences in environmental conditions (the need for heating etc), technology design, labour, feed and energy costs.

An in-depth study, should be conducted in future, with a facility that meet the standard for commercial production in order to obtain credible data that will form the basis for all assumptions and further research in the production of tilapia using RAS in Norway.

5.1 Limitations of the study

The economic models and some of the cost figures used in the analysis were based on certain assumptions. While some of these assumptions are educated guesses, others are closer to reality and thus, may impact on the validity of the costs estimations and economic analyses (Calberg, 2007). Notwithstanding, the potential accuracy of the assumptions can be improved by adopting conservative approaches to the use of these assumptions. In practice, the scale-up facility may not provide all the engineering assumptions made and would impact negatively on the production. However, this can be addressed by selecting and adapting the technology to fit the scale of production and environmental requirements of the area where the facility is to be sited (Summerfelt et al., 2001).

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Appendix

Conversion Rates from DNB, Norway.
Accessed on: https://www.dnb.no/en/fx-rates
1 USD ≡ NOK 5.6

Definitions

Economies of scale refer to the potential reduction in per unit production costs resulting from increased scale of production, realized through operational efficiencies.

Amortization refers to the act of spreading payments of capital expenses over a period of time (Investopia, 2012).