Master‘s thesis

Organic Accumulation under Salmon Aquaculture Cages in Fossfjördur, Iceland

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Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

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Student‘s name

Abstract

Marine based salmon aquaculture inputs large amount of organic material into the surrounding environment. This organic material is mainly composed of uneaten salmon feed and faeces. This material often accumulates in the environment under the cages. In Iceland there is no data on organic output coming from aquaculture nets and sparse data on the impacts of accumulation of this organic material. This study will be the first in Iceland to look at the amount of organic material that accumulates under salmon cages and areas of greatest accumulation. Six sediment traps were used to sample sediment underneath two salmon cages in Fossfjördur Iceland Three were placed 20 m from the cages and three were placed 0 m from the cages. The trap contents were then dried, weighed, and placed into a sodium hypochlorite solution in order to dissolve organic material. After organic material was dissolved samples were dried and weighed to determine how much of the original dry weight was organic. Traps that were closest to the nets (0 m) had greater organic content when compared to traps that were father from nets (20 m). Traps that were down current also collected greater amounts of organic material when compared to traps up stream. This spatial trend was linked to deposition rates of feed pellets settling in a closer proximity to cages whereas faeces dispersed farther. Throughout the study period the overall trap organic material increased. This temporal trend was linked to the increase use of feed pellets as the fish grew throughout study. This study was the first study of its kind in Iceland and aims to provide baseline data into organic output and accumulation occurring underneath salmon cages. The methods used in the study can also be utilized as a tool for management and the development of a monitoring program. This data shows that there is an opportunity for further research into mitigation and management of this issue in order to try and reduce the impact of organic accumulation.

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$g/m^2/day$ ………………………………………………………………………………………………....grams per meter^2 per day

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1. Introduction

1.1 Context

1.1.1 Aquaculture

Aquaculture, is a term used to describe the rearing of any aquatic organisms in both coastal and inland areas. The stock can be owned both individually or corporately and involves the manipulation of one or more stages of the organism's life cycle in order to enhance production (FAO, 2003). Salmon aquaculture is a production process where young salmon smolts are raised to adults so they can be harvested and sold on the market. The smolts often come from freshwater hatcheries where raised until they are ready to be moved to the marine cages or pens. The farmed salmon are raised in cages or pens which can range from small to large depending on the operation. The cages or pens float in sheltered coastal areas where they are protected from harsh coastal environmental conditions. The cages are intended to hold the salmon in captivity with the use of nets, while at the same time, remain open to the underwater environment creating an open system (Mikkelsen, 2006). Using the marine environment for salmon aquaculture eliminates two processes that are required in closed land based or freshwater aquaculture: the need to filter cage water is absent due to the natural flushing of the ocean and the requirement of facilities to keep the water chemistry such as temperature and saline levels constant (Lui and Sumaila, 2010).

The production of salmon is one of the most successfully raised aquaculture species and is responsible for providing 60% of the salmon consumed worldwide (FAO, 2008). Although aquaculture technology has been used since the 1970's there have been recent innovations that have allowed a substantial increase in the scale and intensity of production. Salmon aquaculture in the 1980's produced a few thousand tonnes which increased to 1.3 million tonnes in 1999 and then to 2.8 million tonnes in 2008 (FAO, 2008). During the past few decades the production of farmed salmon increased substantially while production costs have substantial decreased. Recently, the cost of salmon production was about a quarter of the cost in the 1980's (Asche et al, 2009).

1.1.2 Aquaculture in Iceland

Aquaculture is relatively new in Iceland (Paisley et al, 2010). The early stages of aquaculture involved hatching salmonids in captivity and then releasing them into rivers (Paisley et al, 2010; Kristinsson, 1992; IAA, 2009). This practice is known as stocking or stock enhancement which began in the late 1800's and still continues today (Kristinsson, 1992; IAA, 2009). The first instance of a species being reared for commercial consumption in a farmed setting did not occur until 1951 (Kristinsson, 1992).

Ocean ranching is a rearing method that only involves Atlantic salmon in Iceland. One of the benefits of this industry is the clean freshwater as well as productive ocean environments (Arnason, R, 2001). Salmon fishing at sea has also been illegal since 1932 (Ísaksson et al, 1997). True ocean ranching involves releasing young reared smolts into small rivers and streams. The young smolts use the coastal environment to mature for around a year before returning at which point they are harvested (Arnason, R, 2001). This process of rearing and releasing for harvesting and slaughtering took hold in 1961 when the Icelandic government developed an experimental State Salmon Rearing station. During the 1980's a number of large privately owned facilities were established. In the early 1990's the salmon rearing industry peaked with six large facilities in operation (Arnason, R, 2001; Ísaksson et al, 1997). These facilities released around 6 million salmon smolts and had an annual return of around 500 metric tonnes. By the mid 1990's, however, returns and economic profits were low due to the price of salmon dropping internationally. This made the industry no longer economically viable causing it to decrease considerably (Arnason, R, 2001; Ísaksson et al, 1997) and eventually close in 1996 (Directorate of Fisheries, 2011). Today smolts are only released in rivers and streams for the purpose of sport fishery stock enhancement (Directorate of Fisheries, 2011).

The first case of a species being reared for commercial consumption in a farmed setting occurred in 1951; rainbow trout were imported from Denmark and grown until they reached a marketable size (Kristinsson, 1992). The first known attempt to raise salmon in marine based cages was in 1972. Then in 1978, the first land based farm was developed (Kristinsson, 1992; IAA, 2009). During the 1980s, there was a vast expansion in aquaculture development, research, and education (Paisley et al, 2010). One of the major contributors in aquaculture development is the environmental conditions of Icelandic inland and coastal waters (Kristinsson, 1992). There are disease free environments as well as continuous supply of freshwater and geothermal water for heating (Kristinsson, 1992; IAA, 2009).

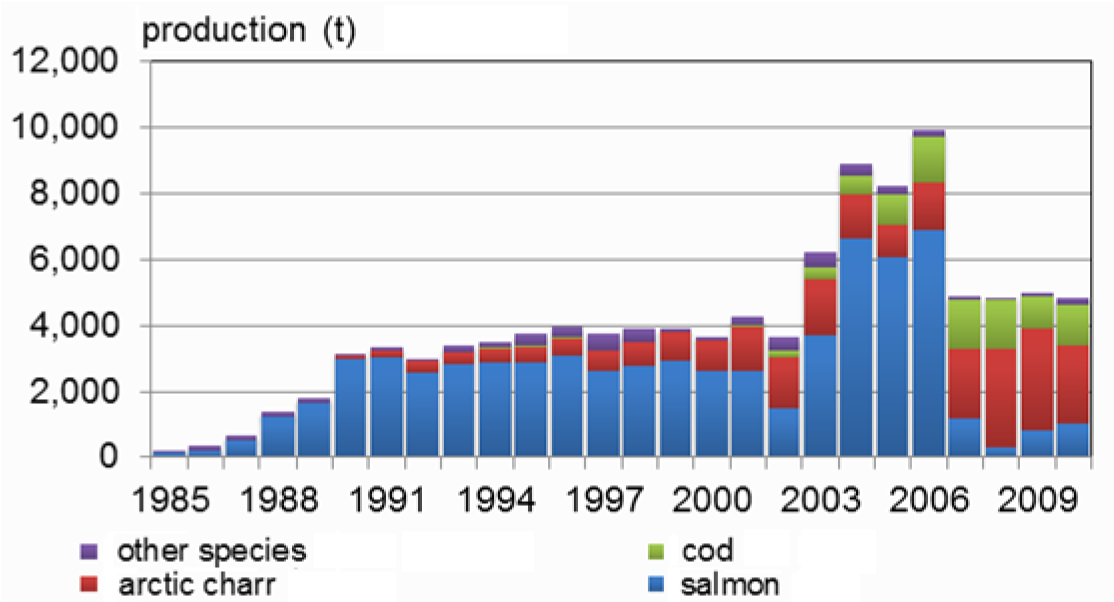

Figure 1: Aquaculture production totals in tons for different species in Iceland. The rise and fall of salmon aquaculture can be seen in blue. (Directorate of Fisheries, 2011).

Salmon aquaculture peaked in 2006 at around 10000 and dropped the following year due to low export values forcing two of Iceland's large companies to close (figure 1) (Paisley et al, 2010). The main species raised on land based farms in Iceland is now Arctic char. This species is followed by cod and salmon which are both raised in marine cages (Paisley et al, 2010). As of 2009, there were approximately 45 fish farms registered in Iceland (IAA, 2009). Out of the 45 farms, 11 are marine cages, 10 for farming cod, 1 for farming salmon, 30 are raising juvenile salmon and four producing juvenile marine species (IAA, 2009). There are also 30 additional land based farms that are mainly raising Arctic charr and about ten experimental developments looking into mussel farms (IAA, 2009).

The farm that was used for this study is operated by Fjardalax, a company that is based out of Tálknafjördur. Fjardalax's salmon reared at this site will be sold to Whole Foods Market Inc. Whole Foods Market Inc. a worldwide retailer of natural and organic foods. By selling only organic and natural foods it has standards which restrict the use of numerous chemicals. As a result, Fjardalax is required to sign a compliance statement and use feed that contains only fish meal, fish oil, whole wheat, vegetable meals, non-synthetic colorants and premixed vitamin mixture. All fishmeal and fishmeal sources are attained from sustainable sources and are harvested domestically in Iceland. All vegetable sources for feed are also genetically modified organism free (Laxa Feedmill ltd in Appendix 4). Fjardalax is also restricted from using antibiotics, pesticides, and antifouling substances on their equipment. By following these guidelines they are able to certify the salmon produced here as a natural product and will get around 900 ISK/kg.

1.1.3 The Management and Control of Aquaculture in Iceland

In order to control the production, development, and environmental concerns of aquaculture, licenses are required (Ísaksson, 2001). The purpose of the licenses is to create restrictions on the location, the species, and the amount of fish being farmed (Directorate of Fisheries, 2011). There are two different licenses required in order to proceed with production, an environmental and an operating license (Directorate of Fisheries, 2011). Figure 2 shows the process of attaining licenses as well as the governing Agencies responsible and their responsibilities.

The environmental license must be attained before the operating license is granted. It addresses concerns about pollution, harmful chemicals, distribution of suspended solids and other localized environmental concerns (Ísaksson, 2001). The environmental licence is granted by two different governing bodies depending on the size of the operation (Directorate of Fisheries, 2011; Jonsson, 2000). Marine fish farms that have a production that is less than 200 tonnes per year or freshwater farms that have less than 20 tonnes per year acquire licences through the Local Heath Inspections Authority under the Ministry of Environment (Directorate of Fisheries, 2011; Ísaksson, 2001; Jonsson, 2000). For marine fish farms that produce more than 200 tonnes and freshwater farms that produce more than 20 tonnes per year licensing is granted by the Icelandic Environmental and Food Agency under the Ministry for the Environment (Directorate of Fisheries, 2011; Ísaksson, 2001; Jonsson, 2000). If marine fish farms exceed 200 tonnes per year or if freshwater fish farm exceeding 20 tonnes per year with effluent released into freshwater they are both required to report to the Icelandic Planning Agency (Ísaksson, 2001). The Planning Agency will often collaborate with other agencies to decide if an environmental impact assessment/statement (EIA/EIS) is required (Ísaksson, 2001). These EIA/EIS's must be attained if they are required before continuing with the Environmental license process (Directorate of Fisheries, 2011; Ísaksson, 2001; Jonsson, 2000).

Once the environmental licence is acquired an application for an operating license is retrieved from the Directorate of Fisheries (Directorate of Fisheries, 2011).Operating licences deal with ecological concerns such as parasites, disease and genetic issues. The farm applying for a license is responsible for indicating all possible ecological impacts as well as threats to wild salmon. Failing to do so can result in the farm paying for further research into unknown threats dealing with the specifications of an operating license. A license is granted after the Fish Disease Committee, the Fish Disease Veterinarian, the Freshwater Fisheries Committee as well as the Institute of Freshwater Fisheries have cleared the farm for issues regarding ecological and genetic concerns (Jonsson, 2000). These agencies report to the Directorate of Fisheries who issues a non-transferable license for a 5 year operation period. The operation license will state restrictions pertaining to the type of species and maximum tonnage of species that can be produced (Ísaksson, 2001). It will also have specifications for protective measures for escaping fish as well as the recovery of those fish. Once a licence has been granted the farm is still responsible for reporting any escapees as well as recovery (Naylor et al, 2005, Ísaksson, 2001; Jonsson, 2000).

The specific agencies that grant these licences are responsible for the environmental monitoring and operational inspections and monitoring of the farms. Marine based farms are required to have at least two inspections a year and land based farms have one. Aquaculture farms are accountable for keeping track of the health of the fish, record the feeding as well as fish transfers. They are also required to present a report to the Directorate of Fisheries with total production, food use, where the stock was attained and annual sales (Ísaksson, 2001, Jonsson).

The farm used for this study was larger than 200 tons requiring Fjardalax to have an Environmental Impact Assessment (EIA) completed before licences were granted. This required the company to take sediment samples at the site before the fish were present. It also entails that analysis of benthic sediment occur after harvest the salmon. This will require Fjardalax to take benthic samples 6-9 months after the last harvest in order to determine what will occur next with the site. If there is little impact when comparing the new samples pre-production samples the cages will begin being restocked. If the cages are not able to be restocked due to a major impact the frames will be moved to a new location and stocked with the new generation.

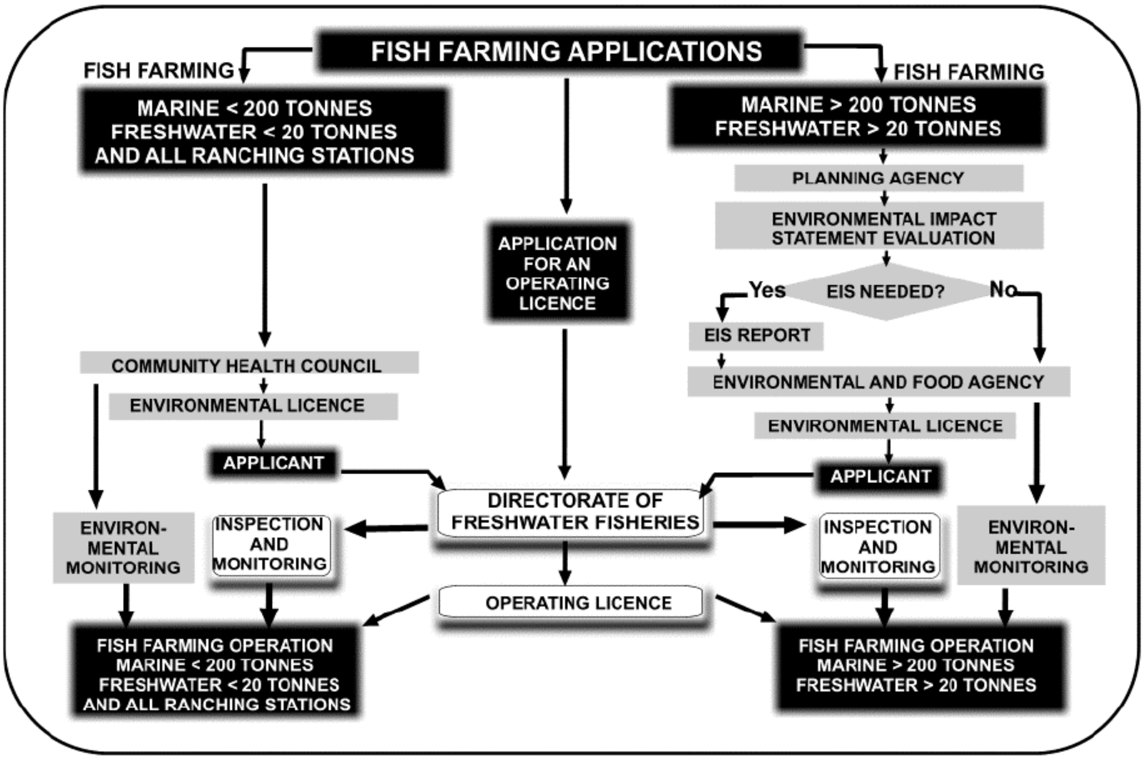

Figure 2: *Flow chart of the application process and agencies involved for attaining an operational and environmental license (Ísaksson, 2001).*

A species specific way Iceland protects wild salmon from the negative impacts of salmon farms is regulatory measure no 226/2001. This prohibits their development in sensitive areas (Figure 3). This includes omitting any fjords or bays that are in close proximity to major salmon rivers. This reduces the impact of parasites and genetic interactions but mostly ecological impacts with wild fish (Ísaksson, 2001). Ecological interactions include competition for resources, habitat as well as destruction of spawning beds. Farmed salmon often breed later and will destroy native salmon spawning beds that already exist (Fleming et al, 2000).

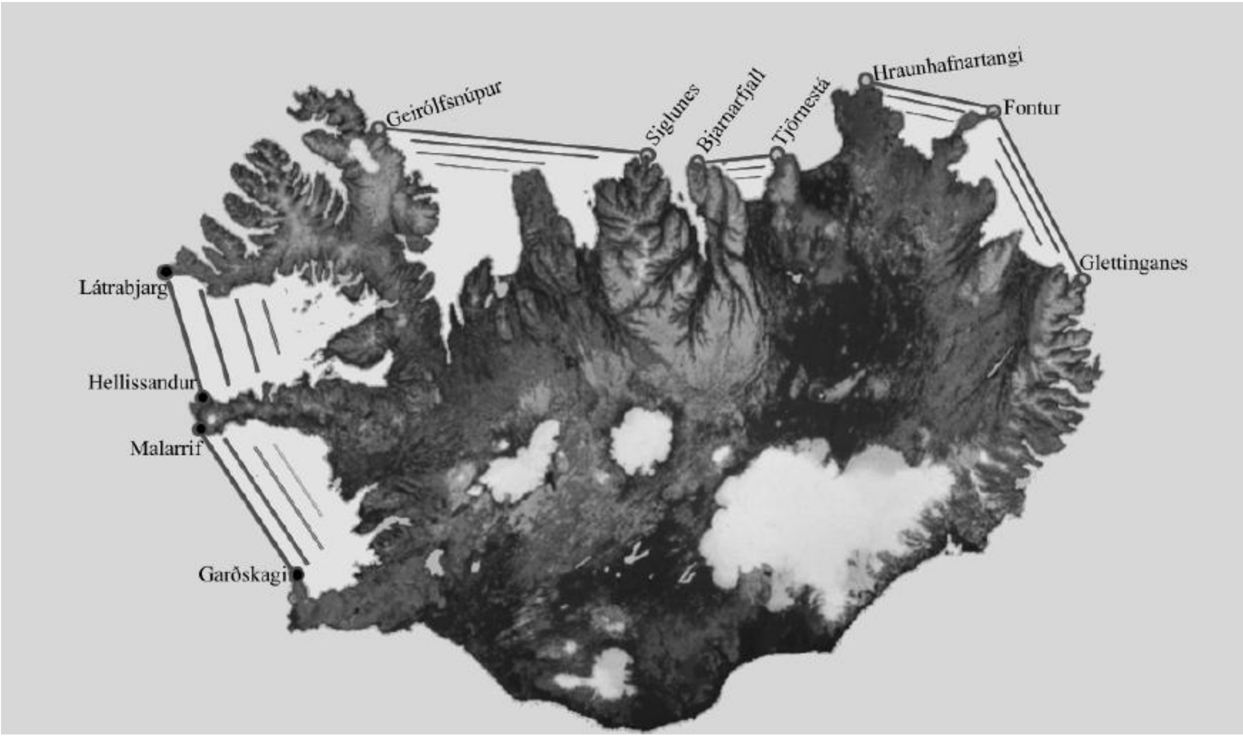

Figure 3: Areas in Iceland where the rearing of fertile salmon is prohibited (Ísaksson, 2001)

1.2 Literature Review

1.2.1 Introduction

This literature review will provide information about the various aspects of Atlantic salmon (*Salmo salar*) aquaculture as they relate to organic outputs and accumulation. This sediment trap study is among the first of its kind to be done in Iceland and it is important to understand all the different inputs and variables that can impact accumulation and output. The purpose of this study is to determine the organic output from marine based salmon aquaculture. It will focus on organic output and accumulation from salmon aquaculture cages In order to have perspective it is important to understand what salmon aquaculture is and the main components of production.

Feed is one of the key components of marine aquaculture. This results in feed accounting for one of the various outputs from the cages and one of the inputs into the sediment traps. Section 1.2.2 will discuss the various components of feed as well as the controversy surrounding this discussion. Section 1.2.3 describes the various organic outputs from the cages. It also describes the general impact that occurs as a result of this output and accumulation. Section 1.2.4 of this literature review describes various methods of mitigation.

1.2.2 Salmon Fish Meal

Waste feed is the major component of organic outputs from salmon aquaculture (Holmer et al, 2003). Salmons are a carnivorous finfish species which means their feed must contain fish meal and fish oil (Deutsch et al, 2007). Salmon aquaculture uses a variety of feed, each having different quantities of fish meal ranging from 20-50% and fish oil ranging from 9-35% (Tacon and Metian, 2008; Brooks and Mahnkin, 2003). Captured pelagic fish, leftover fish trimmings and rejects are the raw components used to produce fish meal and fish oil. It roughly takes 3 kilograms of feed to produce one kilogram of farmed salmon (Naylor et al. 1998). In 2004, 33 million tonnes of feed was used in salmon aquaculture with 27.4 million tonnes coming from whole fish caught by dedicated fishing fleets and 5.6 million tonnes of trimmings and rejects from commercial fish (FIN, 2004). As a result salmon aquaculture is directly dependent on and requires input from other fisheries. The required 3 kg of captured fish to produce 1 kg of farmed salmon brings into question whether the business is economical viable, especially when the 3 kg of captured fish can negatively impact the fisheries of a different region (Naylor et al. 1998). It is important to understand that because salmon feed is a major production cost as well as a major component to organic output that should be minimized. There are various feeding regimes that try to maximize feeding and minimize wastage (Menicou and Vassiliou, 2010).These regimes include using cameras to monitor feeding, using lights to increase daytime feeding hours as well as feeding only during specific times (Menicou and Vassiliou, 2010). Fjardarlax`s feeding regime will be discussed later in the method section.

1.2.3 Organic Output and Accumulation

The focus of this study is to determine the potential organic output for salmon aquaculture. The most significant detrimental impact of aquaculture is the degradation of the benthic zone around or near aquaculture sites. Organic output is the major contributor to this negative environmental impact (Kalantzi and Karakassis, 2006). Organic output from aquaculture consists mainly of uneaten feed and faeces (Carroll et al, 2003; Brooks and Mahnkin, 2003; Holmer et al, 2003). Approximately 12.5% of the ingested feed will be excreted in feces. This is because in modern day feed there are indigestible products such as calcium and inorganic phosphate ash (Brooks and Mahnkin, 2003).

How organic output spreads depends on numerous factors; current speed, depth of the area surrounding the cages, and operational characteristics all can affect the distance the organic output will dilute, settle and accumulate (Hargrave, 1997; Kalantzi and Karakassis, 2006, Carrol et al, 2003). If there are strong currents the organic material will become diluted and spread and deposit farther from the source (Cole et al, 2009; Kalantzi and Karakassis, 2006). Likewise, if the current is weak, the organic material will deposit to a greater extent closer to the farm (Cole et al, 2009; Kalantzi and Karakassis, 2006; Rapp et al, 2006). It should also be noted that fish feces has a much slower settling rate in the water column compared to uneaten feed. This means that depending on the current, feces will likely spread over a greater area (Rapp et al, 2006; Giménez et al, 2011). The spatial dispersion of aquaculture particulates (D in m) is directly equal to current velocity (V in ms^{-1}) multiplied by the depth of the area (d* in m) divided by the sinking rate of the particulate (S in ms^{-1}) (Shakouri, 2003).

$$D=V\times (d^*/S)$$

The actual accumulation of organic output on the ocean floor also depends on numerous factors. Topography of the ocean floor such as slope, dips, gullies, and rocks can influence sedimentation accumulation rates (Shakouri, 2003). A study done by Stucchi et al, 2005 looked at sedimentation rates around salmon cages. The sampling was done at depths of around 40 m. They found that traps at 5, 30, and 331 m from the cage were collecting 3.8, 1.7, and 1.0 g/m^2/day of organic material. A study done by Morrisey et al. 2000 used sediment traps at depths of around 25 m to determine sedimentation rates of New Zealand salmon aquaculture. They found that rates ranged from 8.84 g and 18.5 g of total volatile (organic) solids (TVS) /m^2/day with reference sites ranging from 0.89 to 1.01 g TVS/m^2/day.

When organic matter begins to accumulate on the ocean floor it can impact both the ocean floor sediment biogeochemistry as well as benthic organisms (Holmer et al, 2003). At first, when organic output begins to accumulate under farms, organism diversity may actually increase as a result of the extra food available. A variety of organisms will move in and begin to break down the excess material and prey on decomposer organisms (Tet, 2008). When organic deposition begins to accumulate at a rate beyond the capacity for this decomposition, oxygen levels will diminish. If the deposition is very high, plant and animal life will not survive in the anoxic environment. Over time, and as organic waste continues to collect, the ecosystem will change from a diverse one to a system dominated by low or lack of oxygen tolerant species (Burridge et al, 2010). However, bacteria will continue to colonize, continue the decomposition activity and use up the remaining oxygen. These anoxic conditions occur because there are types of bacteria are unaffected by the low or lack of oxygen and are able to survive and reproduce. As the bacteria continue to colonize they consume the remaining oxygen and thus create anoxic conditions (Tet, 2008; Mazzola et al, 2000). When this occurs, CO_2 levels increase, reducing redox values. The bacteria present in the ecosystem will change from bacteria that utilize oxygen to ones that utilize sulphur and nitrate. Nitrate reducing and sulphate bacteria will continue to degrade organic matter increasing levels of ammonia and sulphide (Brooks and Mahnkin, 2003 Burridge et al, 2010). A typical type of sulphide (H_2S) oxidizing bacteria that is found at aquaculture sites and areas with high organic deposition is *Beggiatoa sp.* (Brooks and Mahnken, 2003). Sites with *Beggiatoa sp.* will often have thin white colored blankets of excreted bacterial mucus covering the patches of surface sediments (Wilding and Hughes 2010; Brooks and Mahnken, 2003). *Desulfovibrio* and *Desulfotomaculum* are two other types of sulfate reducing bacteria that convert sulfate to hydrogen sulphide (Brooks and Mahnken, 2003). These bacteria are found within the anaerobic sediments layers in the benthic zone (Brooks and Mahnken, 2003).

Salmon farms are also responsible for the input of large quantities of nitrogen and phosphorus. These are water soluble and can drastically alter water column quality. If levels of nitrogen and phosphorus get too high they will cause algae blooms which can lead to a change in species composition as a consequence of anoxia (Whitmarsh et al, 2005). On average, during its production life time, a 200,000 fish salmon farm will typically release nitrogen equal to 20,000 humans, phosphorus equal to 25,000 humans and fecal matter roughly equivalent to a city of 65,000 people (Hardy, 2000).

1.2.4 Mitigation

Understanding the various outputs and accumulation from salmon aquaculture will not only give us an idea of the potential environmental impacts but also the opportunities for mitigation. There is literature on numerous forms of mitigation for large scale aquaculture which include the use of multi-trophic systems and cage fallowing.

1.2.4.1 Multi-trophic Systems

A multi-trophic system is best described as incorporating numerous trophic levels simultaneously in order to minimize wastage of inputs. This system uses a variety of organisms that can be classified into two groups: fed and extractive species. The species being farmed is the fed species and extractive species are those that use organic output from the farm as a nutrient source. These organisms include macro algae such as seaweed and filter feeders such as mussels (Neori et al, 2004). Some of benefits from a multi-trophic system are not only is waste feed utilized by other organisms but organic output is utilized and decreased (Buschmann et al, 2009). By incorporating numerous economically viable trophic levels this method can be both environmentally and economically beneficial (Buschmann et al, 2009; Whitmarsh et al, 2006). It is crucial that when developing such as system only species that are native to the ecosystem be used (Neori et al, 2004). There have been numerous studies that look at both trophic types and how they develop in proximity to salmon aquaculture. These studies have been done in both lab and field settings (Reid et al, 2010; MacDonald et al., 2011; Meir et al, 2009; and Buschmann et al 2001). When looking at filter feeders an acceptable species that could be cultivated are blue mussels (*Mytilus edulis)* because they are native to Icelandic waters (Sigvaldadóttir et al, 2000).

A study by Reid et al, 2010 and MacDonald et al., 2011 found that blue mussels were able to capture and use solid organic wastes from salmon aquaculture in lab studies. Reid et al also found that in a field setting the same results were attained. A study by Meir et al, 2009, however, found that mussels grown at different proximities to a salmon farm had no difference in growth. When developing a multi-trophic system placement of mussels is important in order to ensure a constant stream of organic matter. If mussels are placed at the wrong proximity to the cages they may not receive organic matter and the mitigation of output is not reduced (Reid et al, 2010) I

The use of macro algae, has been found to have much more success in removing excess nutrients such as carbon, nitrogen, and phosphorus from farm sites (Neori et al, 2004). A study done by Buschmann et al 2001 found that by cultivating 50-60 hectares of economically viable red algae *Gracilaria chilensis* and brown algae *Macrocystis pyrifera* could reduce the nitrogen produced by 1500 tonnes of salmon by 80% yearly. However, like mussels, the placement of sea weeds and how effective they are at removing nutrients from the waste is highly dependent on placement and hydrodynamic factors (Neori et al, 2004).

Further research is required into the cost/benefit of multi-trophic aquaculture. The lack of data and studies in Iceland means this potential mitigation option has yet to be determined as a reliable option.

1.2.4.2 Fallowing

As was mentioned earlier, the organic matter that leaves marine aquaculture sites often settles in the immediate area if the environmental conditions do not favour wide spread dilution. A method of mitigation to reduce the long term negative impacts of this output and accumulation is fallowing (Macleod et al, 2004a). Fallowing is a process where aquaculture production is terminated for a set period of time in order to allow the benthic community underneath farms to recover (Pereira et al, 2003). Fallow times can range from weeks to months depending on the environmental conditions of the site (Macleod et al, 2004a). There are also a number of ways in which recovery can be determined. Assessments both of the chemical characteristics as benthic infaunal community of the site can be compared to reference sites (Macleod et al, 2004a; Pereira et al, 2003). If aquaculture sites have no reference indicators or sites to compare to AZTI's Marine Biotic Index (AMBI) can be used. (AMBI) was designed to compare environmental degradation of benthic ecosystems in European Waters (Borja et al., 2000). Today AMBI is commonly used under the European Water Framework Directive to evaluate environmental degradation of coastal marine ecosystems (Warwick et al, 2009).

There have been numerous studies done on the recovery of cage sites during fallowing periods. Macleod et al 2004b looked at the recovery of two farm sites during a 3 month fallowing period. Although the benthic community did not recover at both sites to the same level of reference sites, there was recovery. Ecological functions also recovered at one site but not the other. It was thought that environmental conditions could explain this. At site one, conditions favoured deposition so the ecosystem was accustomed to high amounts of organic matter. However, at site two, conditions were different; the ecosystem had very little background organic matter deposition and the organic matter had a much larger impact on the system. This study shows that fallowing is a suitable option for allowing systems to recover. It also indicates that environmental conditions play a major role in the recovery rate and success of fallowing. McGhie et al, 2000 looked at cage fallowing at two different salmon aquaculture sites. They used a 12 month fallowing period to determine how much organic matter would break down during this period. They found that after 12 months, although oxygen levels under the cages had increased from anoxic, there was still presence of organic matter. Another study by Macleod et al 2004a also found similar results, that chemical characteristics recovered much quicker to reference sites than did benthic infaunal. Even after 36 months, benthic infaunal had not returned to reference levels. Many of these studies show there can be some level of recovery depending on environmental conditions. However, these studies were done on sites with relatively shallow depths of around 20 m. There needs to be further research done in

Iceland to determine if fallowing is a beneficial mitigation method in promoting the recovery of farm sites from organic output.

1.2.5 Summary

This review has discussed the various aspects of literature that pertain to particular applications of this project. The various negative impacts of salmon aquaculture such as the fish meal controversy, organic output and cage site accumulation. Organic accumulation is the focus of this project and suitable mitigation options that are viable for this particular site in Iceland have also been mentioned such as cage site fallowing and multi-trophic systems

1.3 The Study

1.3.1 Purpose

Organic output from marine salmon cages accumulates in the surrounding environment at different sedimentation rates. These rates can be affected by numerous factors from the source of organic material to ocean currents (Hargrave, 1997; Kalantzi and Karakassis, 2006, Carrol et al, 2003). The purpose of this study is to study the organic output directly related to the salmon cages in Fossfjördur and to determine if an accumulation rate can be calculated. In Iceland, there have been no studies completed on the discharge of organic output from salmon farms. This project is the first study to research this and could prove to be beneficial management tool for monitoring accumulation and aiding in management decisions.

1.3.2 Goal and Objectives

Using sediment traps, determine if organic output can be directly related to salmon farms and if so at what accumulation rate.

- Place sediment traps perpendicular to the current to determine if there is organic output
    - Determine organic accumulation rates (g/m²/day)
- Determine spatial and temporal patterns of organic output using feed data, feed characteristics and distribution patterns.
    - Using settling rates, currents and depth, create a dispersion model to support spatial patterns
- Compare findings to other research and determine the potential impacts of organic accumulation.
- Determine if methodology can adequately be used as a tool for monitoring accumulation and organic output

1.3.3 Project limitations

There are limitations for this project. Currently in Iceland there are no other results to compare findings. In order to compare my findings to other research I had to use other studies from different regions that had similar environmental conditions. Time as well as limited resources were the biggest limitations for this project. With only 4-5 months of research time and results were constrained by this time period. As well, due to resource limitations, only a specific number of traps were available for use.

1.3.4 Organization of Paper

The following project is broken into five sections. Section 2 provides information about the study site as well as Fjardalax's cage specifications, cage schedule, and feed regime as well as a detailed account of the methods used during my research. In section 3 results are provided through a number of tables, graphs, and descriptions. In section 4 my results are analyzed and interpreted. In section 5 my conclusions are stated with management, recommendations, for further research, and potential mitigation.

2. Method

2.1 Study Site

The study site is located in Fossfjördur in the Westfjords, Iceland. Fossfjördur is a glacial fjord that is part of Sudurfirdir which opens up into Arnarfjörður. Bíldudalur is the nearest town and is about 10 kilometers north. Fossfjördur is a steep and deep sloped fjord with depth reaching up to 80 m. The farm is located in an area with a depth of around 50-60 m which is about 500 m east of the shoreline. The current at the study site was measured with an ADCP current meter from December, 14th 2010 to January, 31st 2011. The meter was located 275 m northwest of the cage site. There was a very strong bottom current (3.5cm/s) and a medium strong surface current (4.2cm/s) (table 1).

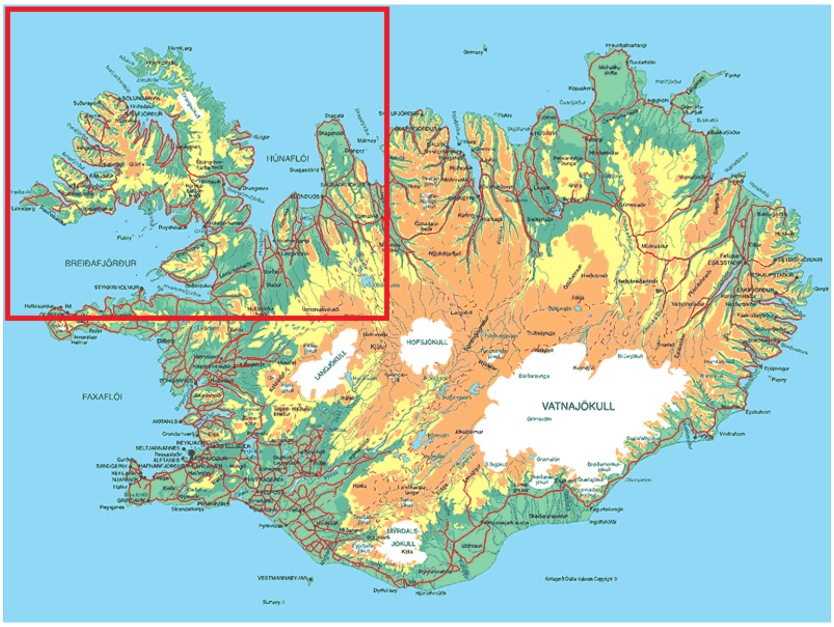

Figure 4: Map of Iceland with the Westfjords isolated in the red box. (http://www.husavikcottages.com/iceland.gif accessed 2011).

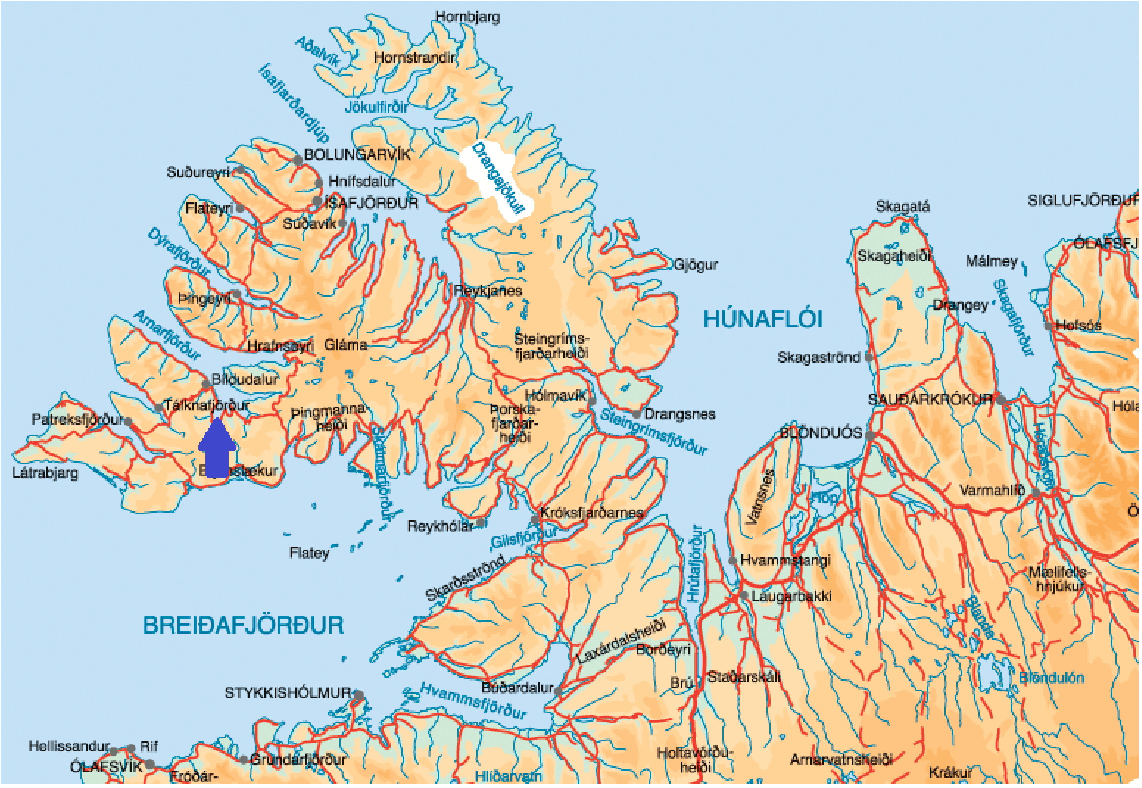

Figure 5: The Blue arrow indicated the location of the study in Fossfjördur which is in Westfjords of Iceland (http://en.gisting.is/, accessed, 2011).

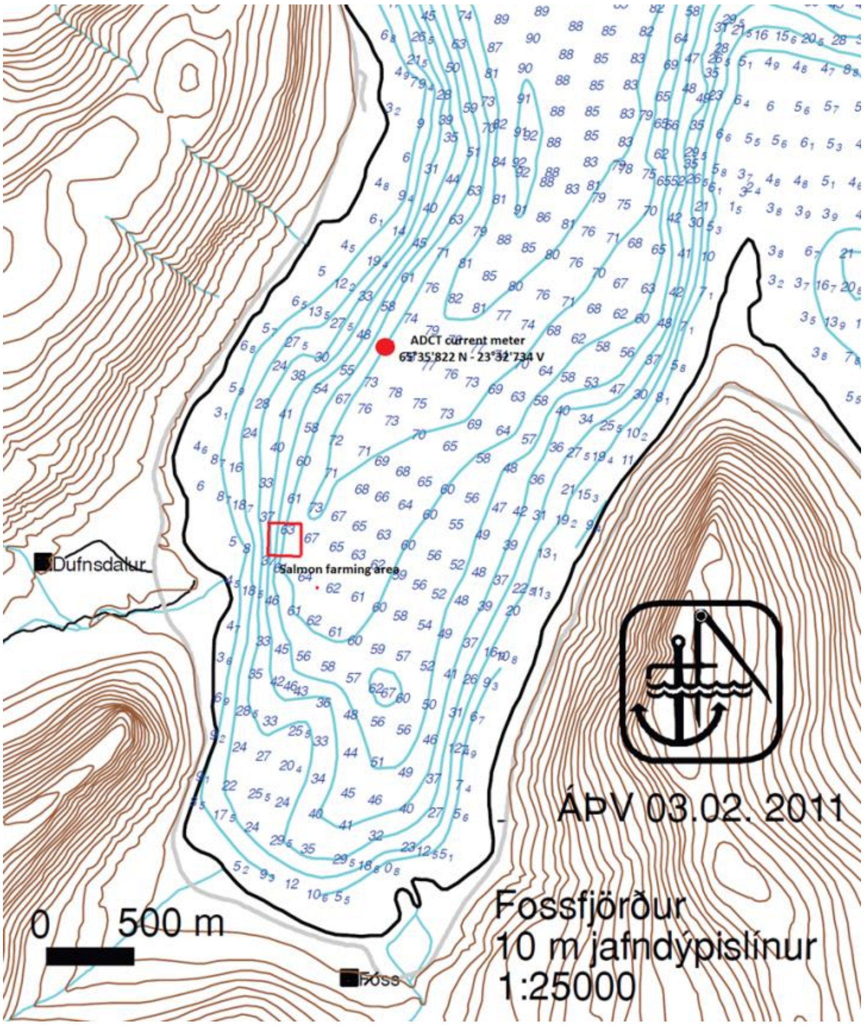

Figure 6: Fossfjördur bathymetry indicated by the blue values as well as the site placement (red box) and the current placement (red point) (Figure from Project Proposal, Georg Haney, 2010).

Table 1: The average current speed; maximum speed; and direction; for surface mid-range and bottom currents in Fossfjördur measured between December 14th, 2010 and January 31st, 2011.

Depth	Average Speed	Maximum Speed	Direction
15 m	4.2 cm/s	21.5 cm/s	184°
34 m	3.8 cm/s	14.7 cm/s	198°
58 m	3.5 cm/s	15.5 cm/s	201°

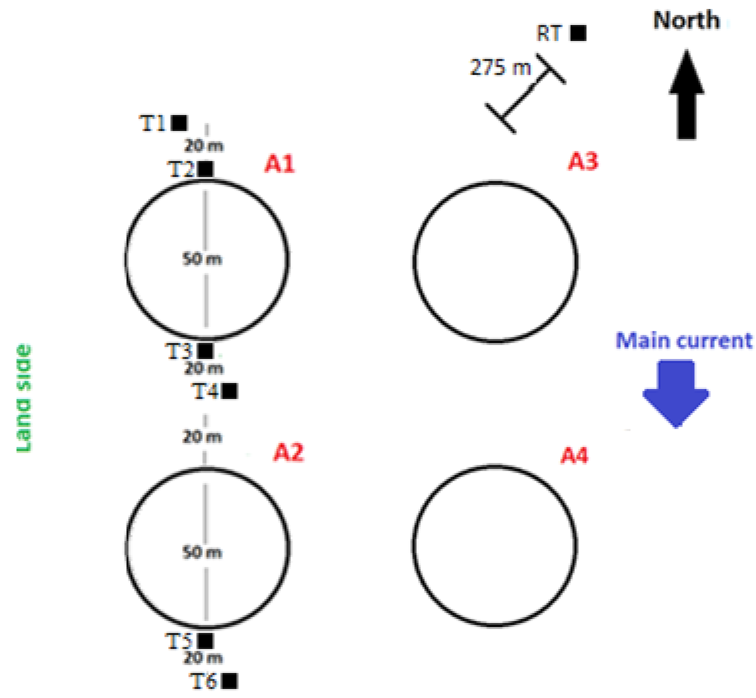

Figure 7: Cage parameters as well as cage orientation. Labels A1, A2, A3, and A4 represent the four cages that make up the farm. The blue arrow indicates the current direction; the black arrow indicates north and land side labels where the shore is. The locations of sediment traps are also illustrated. T1 to T6 indicate the individual sediment trap placements and RT along with the 275m indicate the reference trap location. RT is located 275m North East of the cages (Diagram from project outline submitted for sedimentation project, Georg Haney, 2011).

2.2 Cage Specifics and Schedule

The cages that this study focused on were cages A1and A2 (figure 7). Both cages are 50 m in diameter, have a net depth of 20 m and were stocked with Atlantic salmon on June 12, 2011. Cage A1 was stocked with 98000 smolts with an average weight of 200g each. Cage A2 was stocked with 74000 smolts with and average weight of 280g each. The planned harvest time for Cage A1 is August 2012 with the salmon averaging 5.5kg each to give a total of 500 tons. The planned harvest for Cage A2 is November 2012 with salmon averaging 6 kg each to give a total of 400 tons. Cages A3 and A4 were stocked on August 12, 2011 and will be harvested in the summer of 2013. The total tonnage for cage A3 and A4 will be 600 and 700 tons respectively. After the fish are harvested, the cage sites will remain empty until benthic sediment analysis is done.

2.3 Feeding Regime

Fjardalax uses a feeding system called Orbit GMT which consists of various stages and equipment. On shore there are large tanks containing the specific food required for each cage. Depending on the size of the fish in each cage determines the size of food they will receive. Cages A1 and A2will receive feed the same way. Food is sent to the cages with air pressure where it is distributed by a floating centrifugal spreader located in the center of each cage. The feeder spins and distributes feed around the surface of each cage. Underwater cameras are used for monitoring the salmon, when the fish stops eating the system is turned off. In each cage there is a large 800 watt light 5 m below the surface. This light is used from the beginning of September until May in order to increase salmon feed consumption during periods of low light. This is very important during the winter months as there will be little day light.

2.4 Sediment Trap Setup

There were seven sediment traps used for this study. Six were used to acquire sediment samples from the cages and one reference trap for background fjord accumulation. Each trap had two clear polyvinyl chloride (PVC) clear cylinders with an opening of 7.0 cm. Each cylinder had a lead weight on the bottom and was attached to a swivel arm with a bolt. This allowed the two cylinders to move and remain vertical at all times. The rest of the trap was comprised of a stainless steel plate and a counter weight on the opposite side as well as swivel loops for attachments on the top and bottom. The weights and plate ensure the traps stay perpendicular to the current. Each trap bottom was attached to a 15 kg anchor by 1.6 m of rope allowing each trap to remain 1.6m off the ocean floor at all times. There was 8-10 m of rope attached to the top of the traps; this rope was attached to floats, to ensure the trap was vertical. This anchor, trap, and float system was then attached to a float on the ocean surface and to the ropes on the cage. There was enough slack on the line that the traps remain on the bottom regardless of storms or tides. After the second month of sampling the anchor weights on each trap were exchanged for a lighter weight of around 3 kg. The lighter anchors made sample collection easier while at the same time keeping the trap on the ocean floor and perpendicular to the current. The 15 kg anchor remained on the reference trap because the floats on the surface were not attached to anything permanent.

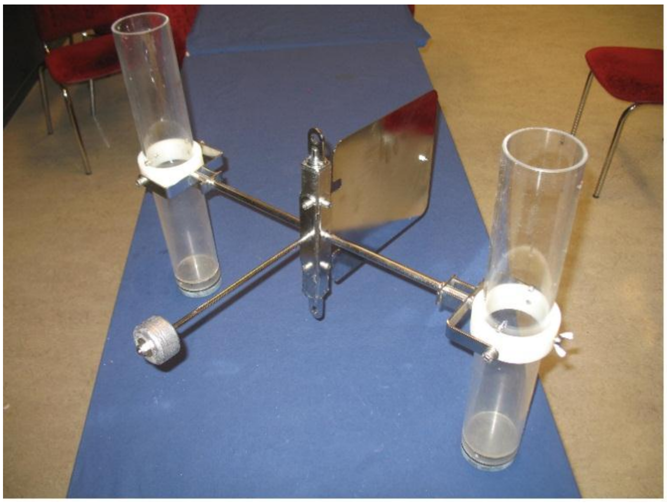

Figure 8: Sediment traps used for this study (Photo credit Georg Haney, 2011).

2.5 Sediment Trap Placement and Collection

The current moved through the cages in a north to south direction this was based on measurements taken by the current meter. Trap placements were set up to try and create a transect that followed the current direction (figure 7). Trap 1 through 6 were placed along an imagined transect line. In order to see if there was any output that moved slightly up current trap 1 (T1) was placed approximately 20 m up current from the cage. The reference trap was placed 275 m up-current and to the northeast and far away from any output that would come from the farm. Placing a reference trap here allows us to gather data on background organic accumulation in the fjord. The traps were first placed in the water on June 8, 2011 and left there for a test period of 2 weeks to make sure that they would gather samples. From this point samples were collected monthly.

After each sample period (one month) the traps were removed one at a time from the water. Both trap cylinders were decanted to remove extra water in the sediment tube without losing any sediment. The remaining sediment and water was then emptied and rinsed into labeled one liter buckets. Each cylinder was then rinsed into the bucket, reattached to the trap and lowered back into the water. This sampling process was used for each trap during each sampling period. The samples were then frozen until sample analysis. During sample collection general characteristics of the samples were also recorded. These characteristics included; smell, color, presence of mucus and presence of food pellets. Trap sample characteristics were recorded as absent or present for rotten egg smell, white mucus (*Beggiatoa sp*) and the presence of food. If the traps had feed pellets the number of whole feed pellets in the trap was also recorded. The color of the sediment in each trap was also recorded.

2.6 Sample Analysis

All of the samples collected were separated into 1 of 4 sample sets according to the collection date. Sample analysis began by taking out a set of samples and allowing them to thaw. Sample set 1 was only decanted once before proceeding with next steps. However, for sample sets 2, 3 and 4, samples were decanted and then replaced with fresh water. This replacement diluted the sea water to a level that left minimal salt when samples were dried. A final decanting was then done on the samples using a syringe in order to remove as much liquid as possible without removing sediment. During this time a salt control sample was taken with 15.00g of the remaining water in and was placed into a pre-weighed petri dish. The remaining sediments in each sample were then rinsed into a pre-weighed labeled glass petri dish. The samples and the salt control were then placed in an oven. The samples were dried for approximately 20 hours at 70 degrees Celsius. The samples were removed and weighed on a 10mg tolerance scale (Ohaus Explorer). The results were recorded and dish weight was subtracted to give dry weight.

The dry samples were scraped into plastic 250 ml containers with labels for their respective sample set and trap number. Each container received approximately 50 ml of Sodium Hypochlorite (bleach) 15.0%. The samples were left in a fume hood. When the samples had stopped bubbling, another 50 ml of bleach was added. If the sample did not bubble any further then it was assumed that the bleach had dissolved all of the organic matter. If bubbles still appeared oxidation was still occurring and they were placed back into the fume hood until bubbles stopped appearing. At this point, more bleach was added. This process was repeated until the sample stopped bubbling.

The samples in bleach were filtered with an Aero Press coffee filter (~15 microns). If there was sediment present in the liquid that had passed through the filter the whole sample was filtered again. The filter and the sediment were then rinsed with water into a separate container. The sediment and water were filtered again with an Aero Press coffee filter. The bleached sample was filtered once and then filtered with water a second time to remove any bleach that would remain as a salt after drying. The filter with the sediment was placed into a pre-weighed labeled petri dish. If there was sediment in the liquid after it was filtered this liquid was filtered again. A new filter was used if a sample required more filtering. This filter was then added to the first filter in the petri dish. This process was done until the liquid was sediment free. Some samples required 4-5 filters in order to accomplish this. A control filter was also used for each full set of samples. The filter was put through the same steps as the sample and then placed into a pre weighed petri dish. A control sample of 10.00g of liquid (water and bleach) was also placed in a pre-weighed petri dish. Each of the controls was then used to calculate the max and min values for each sample. The samples and controls were placed in an oven and dried using the same procedure as before. Once they were removed they were weighed and the loss of weight between the two dry weights is organic weight. This method with the exception of sample set 1 (which was not diluted) was used for remaining three sample sets.

2.7 Concerns with Sampling

There were a few sampling concerns that should be noted and may affect the results with some uncertainty. The location of the traps was either directly next to the cages or 20 m away. However it should be noted that this was a surface measurement. The depth of the study site prevented us from placing the traps at this measurement directly on the ocean floor. Secondly assumptions were made for current speeds may impact the dispersion model created from the results. Current readings for sample collection periods were unavailable. Current readings directly at the site were also not available. Current meter readings were taken during the winter and at the location of the reference site (figure 6 and 7). Current speeds were assumed to be the same at the site as they were at the reference site during the winter months of December and January. The lack of knowledge for background accumulation rates in Icelandic Fjords meant that the data collected from the cages would only be compared to one trap worth of background data. Only having one background trap reduces the likelihood of attaining the actual background accumulation rate. It also increases the chance of background error because if there is a problem with the trap we lose an entire sample set worth of data. Cages A3 and A4 were not included in this study because they were not stocked until the end of August. Their distance to the trap locations, location of the cages and the current direction was thought be enough to exclude their data from this study. This being said they may still have an unknown impact on this study.

2.8 Data Analysis

Organic weight was calculated by subtracting the weight of the sample after bleaching from the original dry weight. This was the most relevant weight for this study because it allows us to attain an organic output level for each trap. Organic weight was then divided by dry weight and multiplied by 100 in order to show organic accumulation as a percentage. This was important to calculate because if there was a large portion of inorganic material it would result in a low percentage regardless of the organic content. Organic weight was also calculated into an accumulation rate (grams/ meter^2 /day). This was done by first calculating how much open surface area each cylinder had at the mouth opening which was 0.003846m^2. This surface cover area was then adjusted to 1 m^2. The number of cylinders surface area (0.003846m^2) that is required to completely cover 1m^2 is 259.977. This means that in order to calculate an accumulation rate (g/m^2/day), organic weight for each cylinder must be multiplied by 259.977 and then divided by the number of days each trap was in the water to give the total amount of accumulation per day. Accumulation per day is also crucial to this study because it standardizes all of the organic output into a daily rate for each trap. Once all these calculations were completed for each of the traps two samples an average was taken for each trap. Each sample set has an original data table with both trap samples in appendix 1and a table with averages for each trap in the upcoming result section.

Using the four sample sets two graphs were generated: organic %, and g/m^2/day. All of the data collected on the control samples in the lab was then used to create maximum and minimum values. These max and min values in each figure show the amount of possible variation calculated from the control samples. Salt control weights were used for minimum values and filter and bleach control weights for maximum values. This is a result of sea water salts and bleach salts remaining after the sample was dried making it weigh more.

2.9 Feed Analysis

The amounts and types of feed were recorded daily by a computer onto excel tables for each cage. This data was acquired and analyzed to be used towards discussion points. General feed parameters were also collected for both 3mm and 4mm pellets. Two different tests were done; a settling rate was calculated as well as the organic content that bleach is able to dissolve. A pellet was dropped into a 40cm tube filled with freshwater. The time it took for each pellet to sink from the surface was recorded. This was done 20 times for both sizes of pellets. The same process was then repeated with salt water to see if there was a difference of speed as density increased. The times were recorded in seconds and then multiplied by 2.5 to determine settling rates per 100cm. Settling rates along with the average current and depth was then entered into the dispersion equation by Shakouri, 2003 to determine spatial dispersion. These rates were then converted to meters per second. Bleach analysis on feed was done the same way as the sediment samples. Feed was dried, bleached until bubbles stopped being produced, then filtered, dried and weighed.

3. Results

3.1 Trap Sample Results

Sample sets 1 and 2 do not have trap averages for trap 3 due to misplacement and trap sample loss. Each trap number is followed by the approximate distance the trap was from the net. It should be noted that trap 1 is 20 m up current from cage A1 (see trap placement in method figure 7 page 22).

3.1.1 Sample Set 1

Sample set 1 was collected on 23/06/11 and was in the water for the shortest amount of time. Traps were left in for 15 days in order to make sure traps were working correctly. The minimum values for figures 9 and 10 are very low. This is because this sample set was not diluted with fresh water before determining the dry weight. This resulted in a high amount of salt precipitate. This sample set overlooked when being compared to the over study trends as a result of the high maximum values and different methods used. Although the reference trap has a similar amount of organic weight and accumulation rates it has a very low percentage when compared to the other samples. This is because of a large amount of inorganic sediment collected during the sample period.

Table 2: Trap averages for sample set 1 (15 days of deployment, 08/06/11 - 23/06/11).

Trap Number	Dry Weight (g)	Organic Weight (g)	Organic %	$g/m^2/day$
RT	5.86	0.94	15.16	16.29
T1 (20)	1.26	1.07	83.67	18.46
T2 (0)	0.95	0.59	62.89	10.23
T3 (0)	n/a	n/a	n/a	n/a
T4 (20)	0.93	0.55	59.12	9.53
T5 (0)	1.03	0.62	60.05	10.75
T6 (20)	1.50	1.07	71.92	18.46

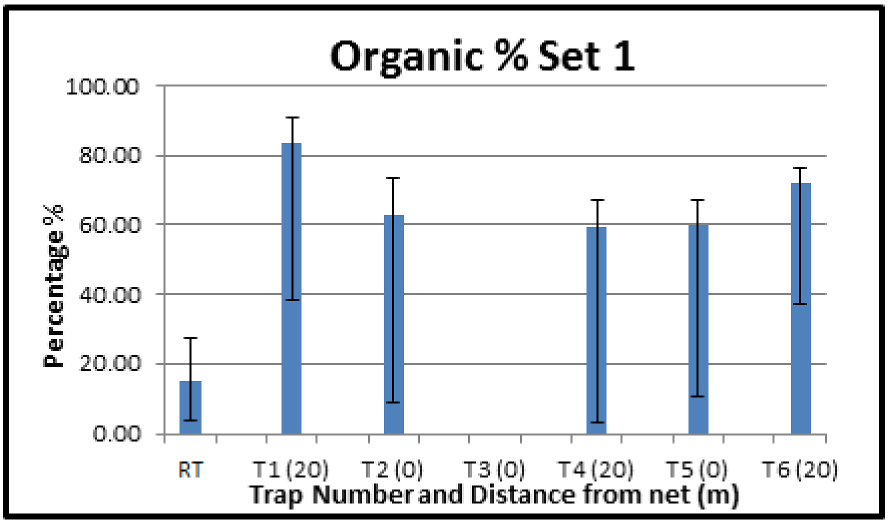

Figure 9: Percentage of organic material found in each trap for sample set 1 (08/06/11 - 23/06/11). T1, T2, T3 and T4 are traps located around cage A1 (see figure 7). T1(20m) and T2(0m) are up current from cage A1 and T3(0m) and T4(20m) are down current. T5(0m) and T6(20m) are located around cage A2 and are both down current. RT is located 275m north east of the farm.

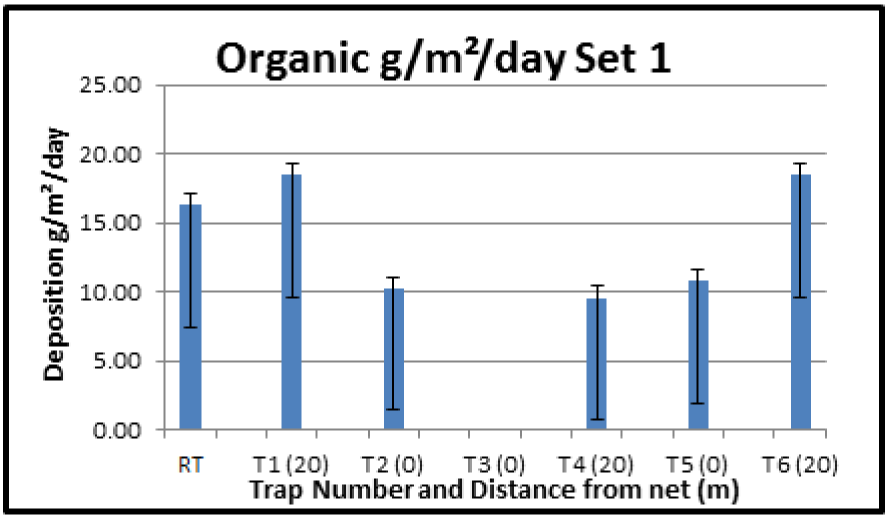

Figure 10: Average daily organic accumulation *per m² during sample set 1 (08/06/11 - 23/06/11). T1, T2, T3 and T4 are traps located around cage A1 (see figure 7). T1(20m) and T2(0m) are up current from cage A1 and T3(0m) and T4(20m) are down current. T5(0m) and T6(20m) are located around cage A2 and are both down current. RT is located 275m north east of the farm.*

3.1.2 Sample Set 2

Sample set 2 was collected on 28/07/11and was in the water for the longest amount of time. Traps were in for 35 days due to logistical issues with sampling. Traps that were closest to the cages (0m) had the highest organic percentage and highest accumulation rates (table 3; figure 11 and 12). Traps T4 and T6 also had similar organic percentages to trap at 0m however when comparing percentage to accumulation rates they are much lower than traps at 0m. Organic percentage was also very high for T1 however due to the very small amounts of overall weight it has a very high minimum value. When looking at T1 in accumulation it is again low when compared to traps at 0m. Although the reference trap has a one of the highest organic weights and accumulation rate it has a very low percentage when compared to the other samples. This is because of a large amount of inorganic sediment collected during the sample period (figure 11 and 12).

Table 3: Trap averages for sample set 2 (35 days of deployment, 23/06/11 - 28/07/11).

Trap Number	Dry Weight (g)	Organic Weight (g)	Organic %	$g/m^2/day$
RT	18.89	1.04	5.55	7.69
T1 (20)	0.44	0.26	59.81	1.97
T2 (0)	1.77	1.11*	62.40	8.21
T3 (0)	n/a	n/a	n/a	n/a
T4 (20)	1.56	0.45	28.35	3.34
T5 (0)	3.02	1.26*	41.72	9.36
T6 (20)	1.88	0.47	25.25	3.53

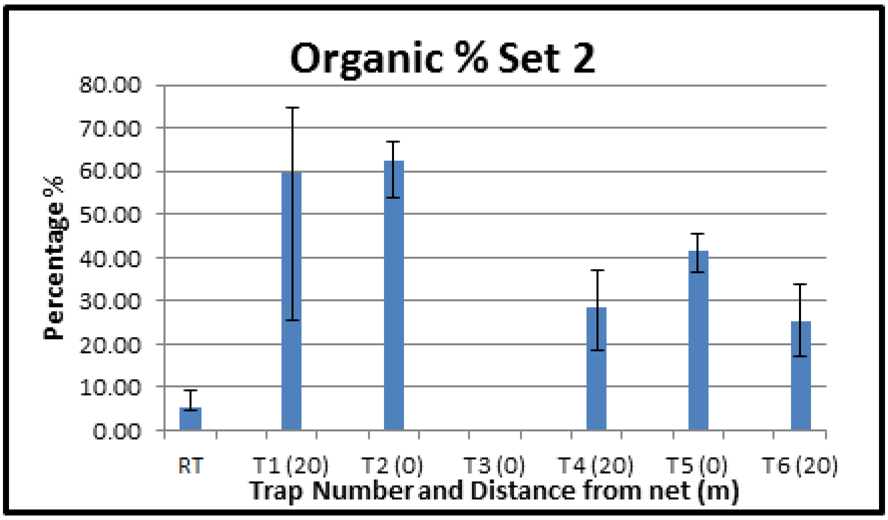

Figure 11: Percentage of organic material found in each trap for sample set 2 (23/06/11 - 28/07/11). T1, T2, T3 and T4 are traps located around cage A1 (see figure 7). T1(20m) and T2(0m) are up current from cage A1 and T3(0m) and T4(20m) are down current. T5(0m) and T6(20m) are located around cage A2 and are both down current. RT is located 275m north east of the farm.

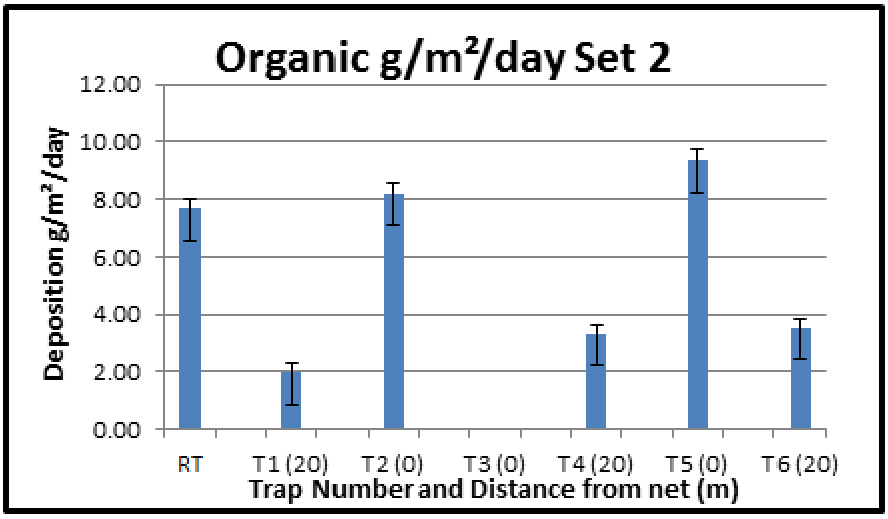

Figure 12: Average daily organic accumulation *per m² during sample set 2 (23/06/11 - 28/07/11). T1, T2, T3 and T4 are traps located around cage A1 (see figure 7). T1(20m) and T2(0m) are up current from cage A1 and T3(0m) and T4(20m) are down current. T5(0m) and T6(20m) are located around cage A2 and are both down current. RT is located 275m north east of the farm.*

3.1.3 Sample Set 3

Sample set 3 had more of a distinctive pattern for organic percentage and accumulation compared to sample set 1 and 2. Both organic percentage and accumulation traps at 0m acquired the most organic material (table 4; figure 13 and 14). The highest organic percentage was found in trap T2 however the highest accumulation rate was found in trap T5. Both of these traps were at 0m form the cage but T2 was up current from cage A1 and T5 was down current from cage A2. Although the reference trap has a similar amount of organic weight and accumulation rates it has a very low percentage when compared to the other samples. This is because of a large amount of inorganic sediment collected during the sample period

Table 4: Trap averages for sample set 3 (28 days of deployment, 28/07/11 – 25/08/11).

Trap Number	Dry Weight (g)	Organic Weight (g)	Organic %	g/m²/day
RT	16.99	1.03	6.06	9.56
T1 (20)	1.94	0.53	27.45	4.97
T2 (0)	2.43	1.24	50.34	11.51
T3 (0)	3.16	1.09	34.48	10.07
T4 (20)	3.45	0.68	19.57	6.31
T5 (0)	5.30	1.65	31.11	15.32
T6 (20)	4.29	0.82	19.26	7.66

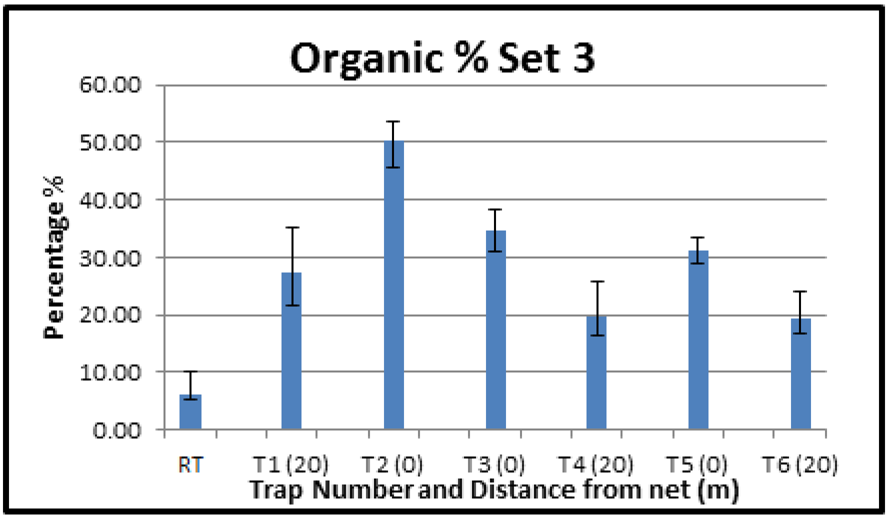

Figure 13: Percentage of organic material found in each trap for sample set 3 (28/07/11 – 25/08/11). T1, T2, T3 and T4 are traps located around cage A1 (see figure 7). T1(20m) and T2(0m) are up current from cage A1 and T3(0m) and T4(20m) are down current. T5(0m) and T6(20m) are located around cage A2 and are both down current. RT is located 275m north east of the farm.

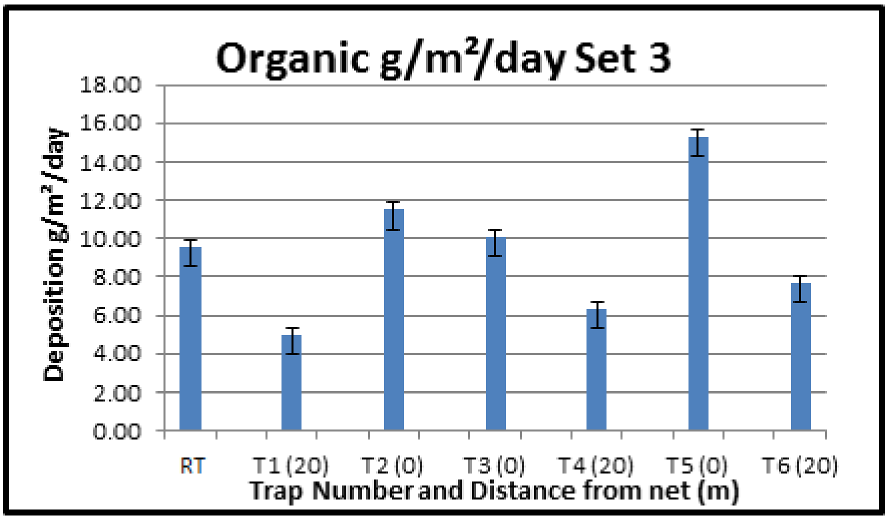

Figure 14: Average daily organic accumulation per m² during sample set 3 (28/07/11 – 25/08/11). T1, T2, T3 and T4 are traps located around cage A1 (see figure 7). T1(20m) and T2(0m) are up current from cage A1 and T3(0m) and T4(20m) are down current. T5(0m) and T6(20m) are located around cage A2 and are both down current. RT is located 275m north east of the farm.

3.1.4 Sample Set 4

Sample set 4 traps had a more evenly distributed accumulation and organic percentage than previous sample sets. The highest accumulation rate and organic percentage was found was at T3 (0m) (table 5; figures 15 and 16). However with the exception of T3 and T1 the other cage traps accumulation rate was found to be around

10.00 g/m²/day. Trap T1 was 20m up current from cage A1 had had the lowest accumulation rate of 4.74g/m²/day. Organic percentage was still similar to sample sets 2 and 3 with the highest amount found in traps at 0m from cage. Although the reference trap has one of the higher amounts of organic weight and accumulation rate it has a very low percentage when compared to the other samples. This is because of a large amount of inorganic sediment collected during the sample period

Table 5: Trap averages for sample set 4 (28 days of deployment, 25/08/11 – 22/09/11).

Trap Number	Dry Weight (g)	Organic Weight (g)	Organic %	g/m²/day
RT	46.07	1.42	3.06	13.14
T1 (20)	3.16	0.51*	16.36	4.74
T2 (0)	4.71	0.98	20.82	9.10
T3 (0)	5.76	2.19*	37.93	20.29
T4 (20)	5.38	0.88	16.45	8.22
T5 (0)	4.74	1.17*	24.72	10.86
T6 (20)	5.65	1.02	17.97	9.42

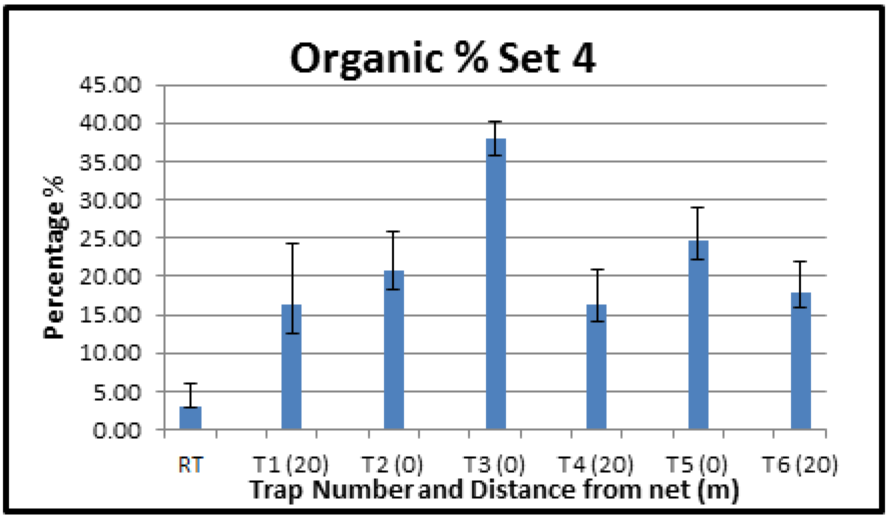

Figure 15: Percentage of organic material found in each trap for sample set 4(25/08/11 – 22/09/11). T1, T2, T3 and T4 are traps located around cage A1 (see figure 7). T1(20m) and T2(0m) are up current from cage A1 and T3(0m) and T4(20m) are down current. T5(0m) and T6(20m) are located around cage A2 and are both down current. RT is located 275m north east of the farm.

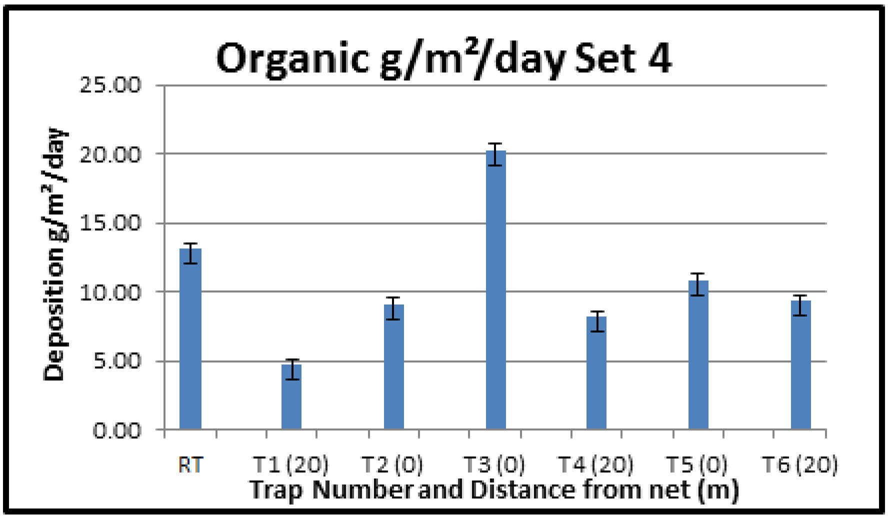

Figure 16: Average daily organic accumulation per m² during sample set 4(25/08/11 – 22/09/11). T1, T2, T3 and T4 are traps located around cage A1 (see figure 7). T1(20m) and T2(0m) are up current from cage A1 and T3(0m) and T4(20m) are down current. T5(0m) and T6(20m) are located around cage A2 and are both down current. RT is located 275m north east of the farm.

3.2 Location of Accumulation

For all sample sets with the exception of sample set 1 traps that were closest to the cages (0m) collected the most organic material (figure 17 and 18). With the exception of set 1 total organic weight for each sample also increases from one set to the next. The reference site samples remained constant throughout the study around 1.00g with an increase during sample set 4 to 1.42g.

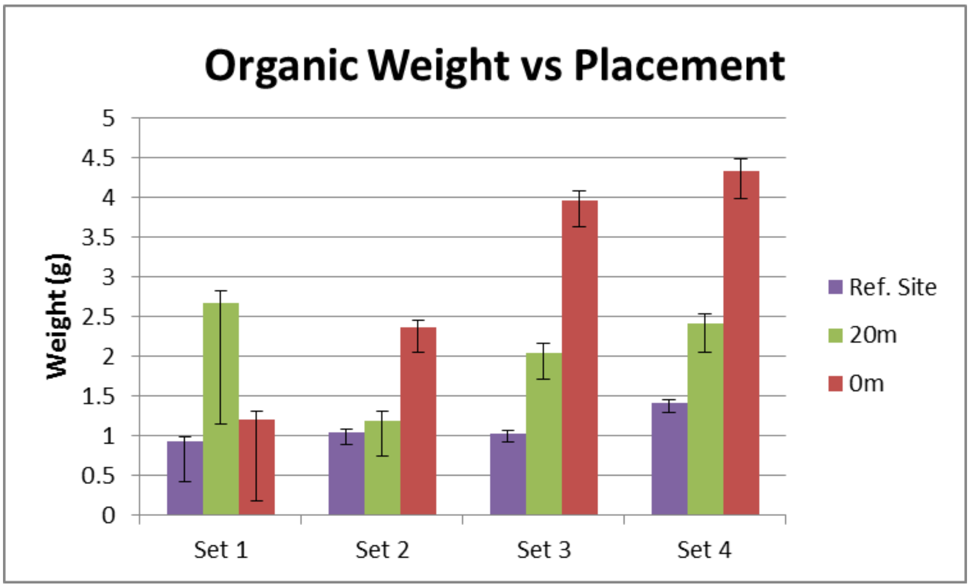

Figure 17: Total organic weight collected for each set separated into trap distances of 0m and 20m from cage as well as the reference site (275m north east of farm).

With the exception of the reference site and sample set 1 there is a trend that accumulation is much higher at locations close to the net. Traps at 0m continuously have a higher accumulation rate than traps a 20m (figure 18). The total average of organic accumulation rate for sample sets 2, 3, and 4 also illustrates this trend (figure 18). Sample set 1 is not included in the average because it has such a large amount of error.

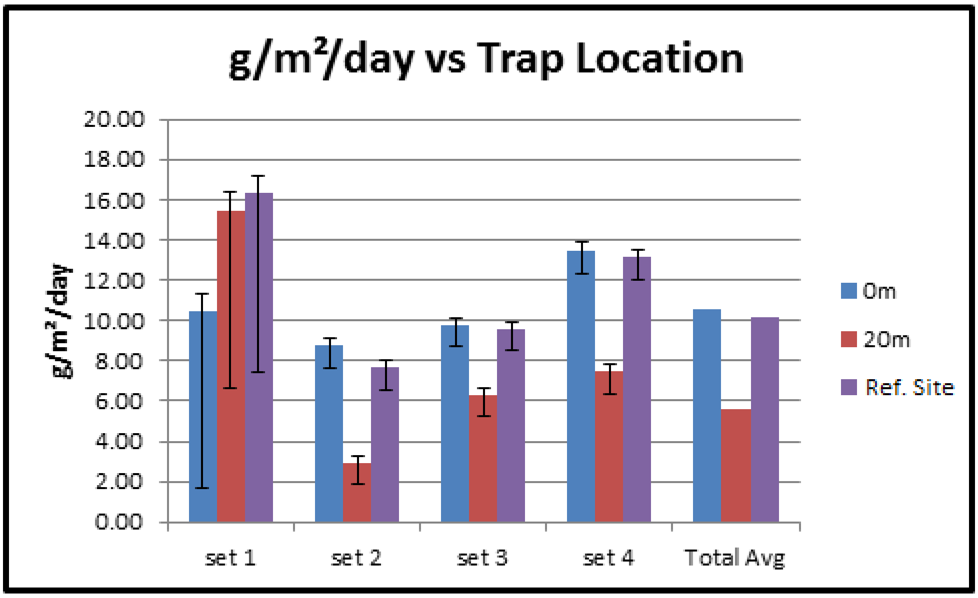

Figure 18: Average total set accumulation (g/m²/day) of organic material for trap locations of 0m and 20m from cage as well as the reference site (275m north east of farm). As well as total study average.

3.3 Feed Analysis

3.3.1 Feed Usage

There was a continuous increase in the amount of feed used throughout the study. When looking at one sample period to the next the amount of feed used increased from June to late august when it began to decrease slightly. During September food usage is more unevenly distributed and decreases slightly towards the 4th sample collection date (figure 19 and 20).

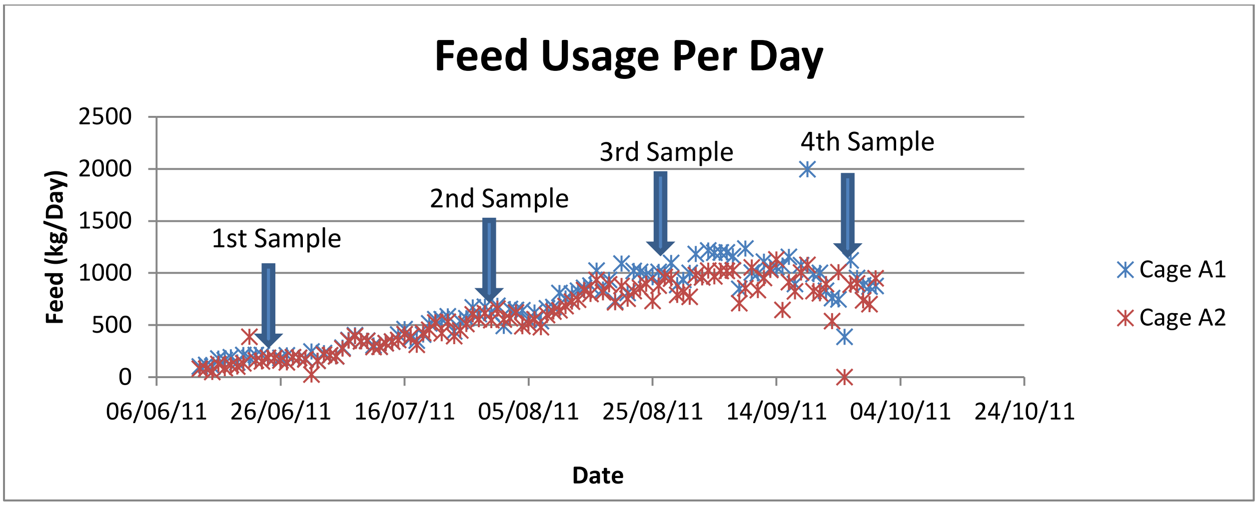

Figure 19: Feed usage in kg for cages A1 and A2 as well as sample collection periods.

Total feed usage increases over time with the least amount of feed used during sample set 1 and the most used during sample set 4. Over time cage A1 consistently receives slightly more feed than cage A2 (figure 20).

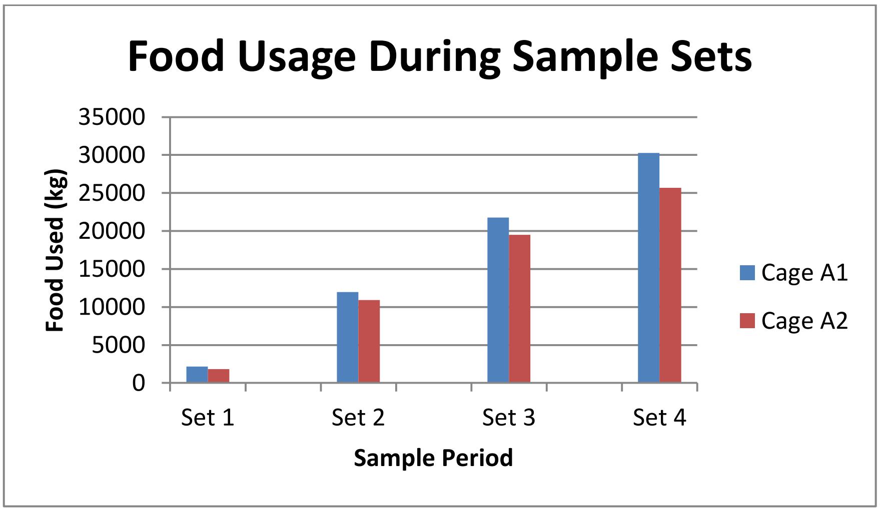

Figure 20: Total amount of feed used during each sample period in kg for cages A1 and A2

3.3.2 Feed Parameters

Organic weights were found to be 2.53g for 3.76g of 4mm feed and 2.11g for 3.36g of 3mm feed. Organic %s was similar for both samples with 67.29% for the 4mm feed and 62.80% for the 3mm feed. Lab tests for settling rates found that 3mm feed settled at a rate of .086m/s and 4mm feed settled at 0.074m/s in salt water. In freshwater 3mm feed settled at .088m/s and 4mm settled at 0.087 m/s. When feed pellets entered the water they had small bubbles attached to the pellets. When the pellets reached around 30cm the bubble was released at the pellet picked up speed. This characteristic occurred on every pellet of both sizes but the point at which the bubble was released varied slightly. It was noticed that 4mm pellets sank faster when the bubble was released than the 3mm. A dispersion equation from Shakouri, 2003 was then used to calculate dispersion. 4mm feed spread 28.2m and 3mm spread 24.3m.

Table 6: Dry weights, organic weights, organic percent, settling rates and dispersion for different sizes of feed.

Feed Size	Dry Weight (g)	Organic Weight (g)	Organic %	Settle Rate m/s	Dispersion (m)
4mm	3.76	2.53	67.29	0.086	28.2
3mm	3.36	2.11	62.80	0.074	24.3

3.4 Field Characteristics

There were also other field characteristics noted during sample collection as present or absent. All traps with the exception of reference trap were marked present for a rotten egg smell (H_2S) when they were removed from the water. Traps closer the cages had a stronger egg smell than the traps 20 m away. All traps with the exception of the reference trap were also marked present for food pellets being inside the sample tubes. Traps that were closer to the cage had more food pellets. All traps directly underneath the cages during sample sets 2, 3, and 4 were also marked present for white stringy mucus (*Beggiatoa sp*) in the traps. All cage site trap samples had dark brown to black sediment present in the tubes. Reference site trap samples had large amounts of broken shells and grey sand present.

4. Discussion

The goal of this study was to study the organic output directly related to the salmon cages in Fossfjördur and if so can a rate be determined. One thing to consider from this goal is how this study and its method can be utilized as a tool for the management and monitoring of organic output and its impact on the environment.

The methods used for this study evidently provided adequate results when used to determine organic output and accumulation rates. Using sediment traps to collect sediment under cages and using sodium hypochlorite to oxidize organic material provided comprehensible results. The reference trap used in this study failed to provide results on background accumulation rates in Fossfjördur. However there are various spatial and temporal trends for organic output that can be interpreted through the results meaning the failed reference trap has little impact on the outcome of the study.

There is an exception to the trends stated below which is sample set one. It should be noted that this sample set also has the highest amount of error. Sample set 1 was only in the water for 2 weeks while sample set 2 was in the water for 5weeks. In theory sample 2 should have more organic matter. However this is not the case and is likely due to issues with the methodology. Sample set 1 did not receive the same salt dilution method as the other sets which mean the lower end of the error bars are likely the true values. Initial testing of the methods was also tested separately on only a few trap samples rather than full monthly sets. This could also cause more error within the sample set 1.

4.1 Feed Analysis

4.1.1 Feed Parameters

There were 3 different sizes of feed used by Fjardalax during the study 3mm, 4mm and 6mm. The 3mm feed was used from 13/06/11 to 10/07/11 4mm feed was used from 11/07/11 to 08/09/11 and 6mm feed was used from 09/09/11 to the end of the study 22/09/11. The lab tests for settling rate found that as feed size and density of water increased settling rate decreased. However, there was a significant sinking rate increase when bubbles that had attached at the surface left the pellet. As air bubbles were released the speed of pellets increased and the larger feed sank faster.

Feed samples that were analyzed for organic material showed that only around 65% of the feed was actually organic. However, while the feed was being oxidized in bleach it was noticed that the fat/oil separated from the sample and floated to the surface. When fats are oxidized by sodium hypochlorite they are converted to fatty acid salts and glycerol (soap and alcohol) (Estrela, 2003). Fish feed use by Fjardalax has 23 %, 26% and 32% fish oil respectively for 3.0mm, 4.0mm and 6.0mm feed. The various sizes of feed also have an amount of ash that would not be dissolved in bleach. The 3.0mm feed has 8% ash and the 4.0mm and 6.0mm have 7% (Laxa Feedmill specifications Appendix 5). When you combine the percentages of oil and ash for each feed size they account for the dry weight of that residue left behind after the bleach oxidation. In situ the feed present in the traps would likely not have fat and oils present in the samples. This was seen in a study by Rapp et al, 2006. While the pellets breakdown in the trap the oil and fat would float out of the trap. Feed pellets were present in the traps throughout this study. If this situation occurred in the traps then organic material would have exited the sample reducing the organic content found and increasing the error.

4.2 Reference Site

It should also be stated that the attempt at acquiring a background accumulation with the reference trap failed. The placement provided contaminated samples for all four sample sets and did not represent background organic accumulation in Fossfjördur. Recorded field characteristics of the samples state there was a large portion of sand and white shells in the trap samples. This is likely a result of resuspension of benthic floor sediment into the trap. Traps located at the cage site didn`t have these characteristics. Having a failed reference value only impacts the study negatively by preventing the study from attaining a background accumulation rate. Figures 17 and 18 still illustrate that organic output and accumulation rates are higher closer to the cages in traps at 0m than traps that are at 20m.

4.3 Spatial Trends

For sample sets 2, 3, and 4 there is more organic material found to accumulate closer to the cage than at distances of 20 m (figure 17 and 18). Although trap samples around the cages very throughout the study traps at 0m receive more organic material than traps at 20m. It should be noted that sample sets 1 and 2 do not have data for trap 3. This means these figures show 3 traps worth of accumulation for traps 20m from cages and only 2 traps worth of accumulation for traps 0m from cage. Accumulation closer to cage can be correlated to feed sinking parameters. Feed pellets will sink at a rate much quicker than salmon feces (Rapp et al, 2006; Giménez et al, 2011).When feed enters the cage it will sink rapidly and accumulate on the ocean floor closer to the cage (around 27m downstream). The traps that were place directly at the cage (0m) accumulated more organic material during sample sets 2, 3, and 4than the traps at a 20m distance. These results have been found in other studies by Rapp et al, 2006. Although feed was found in traps at 20m there was more feed in traps at 0m. This could be explained by the feeding system. The feed pellets are distributed in the cage through an air powered central centrifugal sprayer. The feed is spread over the entire surface of the cage making the dispersion zone somewhat predictable (figure 21). Traps at 0m distance from cages are directly in the middle of the dispersion zone and are likely to receive to most waste feed. Traps at 20m distance from cages are likely located on the edge or out of the dispersion zone are will likely receive less or no feed.

Only the average currents for Fossfjördur are available so the current in the opposite direction is unavailable. If total current values were available average current in each direction would have been calculated. There is obviously some sort of current that moves in the opposite direction during periods of the study because traps T1 and T2 have organic content and waste feed in them. It should also be noted that the settling times were also done in the lab. The dispersion equation may not represent the exact settling rates. Bubbles slowed the initial settling rate in the lab tests. When bubbles left the pellets 4mm feed actually sank faster than 3mm and thus the dispersion areas shown below are maybe less than that.

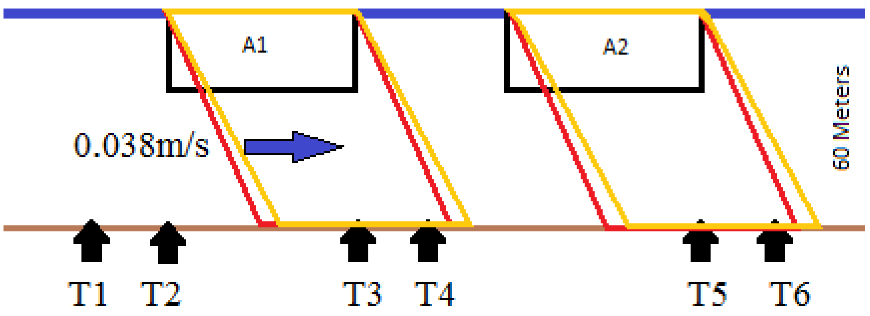

Figure 21: Scaled diagram of the dispersion of the two types of feed and trap locations. The yellow represents 6mm and red 4mm. Current direction and average speed indicated by blue arrow. Scale of 1cm: 20m

When looking at figures 12, 14 and 16 you can see that traps placed at 20 m from cages have a similar accumulation rate trend for sample sets 2, 3 and 4. In each of these sample sets traps T1 collects the least amount of organic matter. Out of the three traps closest to the cage trap T6 collects the most. Trap T4 accumulates similar amounts to trap T6 but always slightly less. This pattern can likely be explained by trap placement in respect to currents. The current in Fossfjördur was calculated measured to travel from the north to south direction flowing directly through the cages (See figure 7 and table 1 in methods). Organic material from the cages will likely disperse along the current in a southern direction. Trap T1 is up current from the cages making it least likely to receive organic material and thus having the lowest amount of organic material (figure 21). Trap T4 was 20 m down current from cage A1and trap T6 is down current from both cages A1 and A2. Although feed may accumulate closer to the cages feces will disperse farther. T4 and T6 both received feed pellets but T6 is likely to receive more slow settling feces from cage A1 (figure 21).

There are no studies on the expected organic sedimentation rates in Icelandic fjords. However other sedimentation studies by Morrisey et al. 2000 and Stucchi et al, 2005 found that their reference sites accumulated 0.89 to 1.01g of Total Volatile Solids/m²/day and 1.0 g/m²/day respectively. All of these reference sites are much lower than the reference site values attained in this study. There is no information of the carrying capacity for Icelandic fjords for organisms to breakdown organic input. There was however a study done in 2009 by Eiríksson et al. that looked at an experimental cage site to determine organic accumulation and benthic impacts. They tested benthic fauna after 3 months and then again after 3 years. What they found was that with only slight increase in rate of accumulation under aquaculture cages changes will begin to occur to the benthic fauna.

The reference failed to determine background accumulation rates in Fossfjördur. This prevents the study from comparing accumulations between background levels and Fjardalax's cages. Having no reference rate does not take away from the outcome that there is an obvious increase in accumulation when considering the proximity to cages. A study by Hargrave, 1994 proposed that any organic deposition under cage sites at an accumulation rate greater than 1.0g of organic C/m²/day was greater than benthic communities could decompose. This would lead to organic enrichment and the impacts associated with organic accumulation discussed earlier in section 1.2.3. According to this rate both 20 m and 0 m traps indicate that there is a reason to believe the benthic community is being negatively impacted. In all four sample sets accumulation rates were higher than 1.0g/m²/day. Traps that were placed at 0 m had an average accumulation rate of 10.61g/m²/day and reached accumulation levels as high as 20.29g/m²/day. This could potentially cause a very drastic change in the benthic community. However site specific rates of decomposition vary and as stated are unknown in Fossfjördur.

4.4 Temporal Trends

The trend of overall accumulation increasing over the 4 sample sets can be correlated to feed usage. One of the field characteristics recorded was the presence of feed pellets in the traps. Traps that were closer to the cages had more pellets than those at distance of 20 m. Organic weight thus includes these pellets. Over time during 4 sample periods feed usage increased for both cages (figures 19 and 20). The increase in the amount of feed used during the accumulation of each sample set can explain why there is an increase in organic sediment found in traps. This trend also suggests that as production continues at this site that organic accumulation will continue to increase. As these salmon continue to grow more feed will be required and thus more feed will enter into the immediate area. This could be a major impact that this study is unable to monitor. The planned harvest time for cage A1 is August 2012 and Cage A2 will not be harvested until

November 2012. If the current rate of accumulation continues or what is more likely increases, the potential for an alteration in the benthic community greatly increases.

4.5 Physical Characteristics

The sediment traps have given this study insight into the rate and location of accumulation. They have proved to be a useful tool in understanding dispersion and show that there is an abundance of organic material in the area. Other than this observation there is little known about the current state of the environment around these cages. One of the most important objectives of this study was to use literature to try and determine the potential impacts of this accumulation. Comparing literature and the physical characteristics can provide insight into the impact of accumulation. The physical traits varied among the various traps.

Black sediment and a rotten egg (H_2S) smell were found in traps around the cages but not in reference trap. Although the reference trap failed at acquiring background levels of accumulation the physical characteristics noted during sampling can still be utilized. The black sediment and the smell of rotten eggs are typical characteristics from sediments under aquaculture sites. The black soils indicate anoxic sediment conditions (Wildish, et al 2004). These characteristics that are present in the cage traps likely represent anoxic conditions which in turn are being colonized by sulphide oxidizing bacteria (Brooks and Mahnkin, 2003 Burridge et al, 2010). This impact is likely also localized to the surrounding area of the cages because the reference trap did not present similar characteristics. The extent of these anoxic conditions is unknown because only a distance of 20 m from the cage was studied.

Traps at 0 m from the cage for sample sets 2, 3, and 4 had white stringy mucus present. This mucus is believed to be produced by *Beggiatoa sp.* This bacteria is commonly found in low oxygen conditions and oxidizes H_2S (Wilding and Hughes 2010; Brooks and Mahnken, 2003). This would also explain the smell of rotten eggs found in the samples. However levels of organic accumulation may only be high enough to promote this stringy mucus in the 0 m range of the cage. Traps at 20 m distance still had the odor but no visible colonies of *Beggiatoa sp.* It should be noted that these characteristics were found within the trap. The traps are isolated from further resuspension and bioturbation and impacts from organisms. Rapp at al, 2006 noticed that once organic material such as feed reached the ocean floor its horizontal dispersion continued. This means that the samples represent trap accumulation but may not represent the actual accumulation rate on the ocean floor.

4.6 Utilization of the Study

When looking at aquaculture in Iceland from a managerial and environmental perspective there are gaps in the industry. There are few regulations for continuous environmental impact monitoring. Aside from an initial EIA and a benthic analysis of the site before, during and after production there is no assessment of organic output or accumulation. There are no organic output/accumulation rates or levels which are referred to in order to assess environmental impacts. This leaves a major gap in the overall impact on the site as well as a timeline of accumulation. This study found that there are potentially significant levels of organic output accumulating in the immediate area of the cages. Other than this study the major benthic impacts of this site will only be measured after production when the potential degradation has already occurred. This study showed that using this methodology, adequate insight into current accumulation rates is possible. If a monitoring program was developed traps could be placed at strategic locations to gather a greater gradient of accumulation. The current Environmental licensing system could be used to develop and implement a monitoring program using sediment traps. If monitoring phase was developed specific data into accumulation and output would be attained. This data could then be used to develop site footprints for areas that will be impacted around sites. This monitoring could also be used to determine maximum production levels. If accumulation rates were too high regulations could be developed that required companies to reduce production until a desired level of output was attained. If production cannot be decreased other options could include mitigation such as multi-trophic systems or increase fallowing frequency. This study would be further utilized when deciding on mitigation. Providing insight into the dispersion of organic output would allow for proper mitigation techniques to be utilized.

4.7 Sources of Error within Experiment

There are a few sources of error that should be mentioned. The depth of the experiment prevented the knowledge of the exact placement of the traps. This means that although the traps were placed at 0 m and 20 m from the cage. If they actually were located that distance on the ocean floor is unknown. Current meter data is also from December 2010 to January 2011. The current speeds during the study are unknown so the dispersion model created (figure 21) may not be exact. Settling rates for the feed test were also done in the lab in a 40cm tube. The actual settling rate for the various types of feed as it sinks through various densities of ocean water at the site is unknown. The physical parameters noted during sample collection are only for the trap samples. The actual status of the ocean floor is unknown and only assumed through the state of the samples. It should also be noted that the amount of decomposition during sample time is unknown. We were unable to place a known amount of organic material to measure how much decomposition occurs naturally in the trap over the time it is in the water. This means that when traps first begin to accumulate organic material by the end of the sample period some of the organic material collected may have already begun to decompose. Although cages A3 and A4 were not sampled in this study it is possible that during our sample periods organic output from these cages could have ended up the traps.

5. Conclusion

5.1 Recommendations

5.1.1 Management

Taking this study and using the methods as a tool for management would be very beneficial. This study has showed that there is a potential need to begin monitoring organic output from large scale aquaculture in Iceland. With current regulations only monitoring the impacts from cages when production has ceased there is a gap in the knowledge.

Understanding the dispersion and the rate of accumulation in the surrounding environment is the first key step in understanding the ongoing impact. Using this study as a tool to develop a monitoring of aquaculture for new or current production would provide more insight into the issue.

Organic accumulation in the benthic zones needs to be understood in order to determine the amount of impact a salmon farm will have on the environment. If site decomposition can be determined then this information combined with hydrodynamic data and accumulation rates, proper carrying capacity can be determined. By doing this, the amount of benthic impact can be minimized by different mitigation options. Using mussels or sea weed in and multi-trophic system to remove organics from the water column can further reduce the impact on the surrounding environment. Fjardalax does not use any chemicals or products such as anti-biotics, anti-fouling agents or pesticides allowing them to sell their product as organic/natural. This means that the possibility to cultivate mussels and seaweed for mitigation as well as profit could also provide an economic incentive. Other options may include more frequent fallowing. This would allow systems that are enriched with organic output to recover. Having frequent fallowing would let systems more often and would reduce the amount of continuous accumulation affecting them.

5.1.2 Further Research

There are many areas of research that are required before the complete impacts of aquaculture can be understood. This study only focused on the organic output related to salmon aquaculture. This was also only a 3.5 month study that was done at the beginning of production. With production ending in August and November 2012 the increase in accumulation from now until production end is unknown. A benthic analysis of the surrounding area around the cages would allow one to see the actual impact of this farm on the benthic sediment and community. A study with more traps would also create a bigger picture of the total dispersion of the organic output from this farm. More traps placed down current would create a longer transect to compare dispersion over and create an accumulation gradient. The use of oxygen meter to measure dissolved oxygen would be interesting to see the profile change in dissolved oxygen as depth increases. It would also allow for interpretation into whether or not there are anoxic conditions in the benthic zone. This is something that this study assumed from physical characteristics but unable to truly determine.

5.2 Final Remarks

All of the goals and objectives were achieved during this accumulation project. Organic accumulation rates were successfully calculated using our methodology. The accumulation was also correlated with feed data to determine that it was an output from the salmon cages. Traps that are closer to the cages are collecting more organic material from the cages which have been correlated with dispersion models for the various types of feed. Findings were also compared to other research to determine the potential impact of the current organic accumulation.

There are numerous outcomes to this study that suggest there is an environmental impact occurring as a result of these cages. Both the spatial and temporal trends found suggest there is a high accumulation rate that is likely causing changes in the benthic community under these cages. The black sediment, presence of white mucus thought to be *Beggiatoa sp* and the strong smell of H_2S are all physical characteristics of typical aquaculture sites. These characteristics as well as the high accumulation rate around the cages means the environment is likely anoxic, with the presence of bacteria. This being said, further study into the benthic environment and the impact of this accumulation is required before these conclusions can be made. Lastly this study has provided insight into the benefits of using this method as tool for management. It could be used to play a key role in the development of a monitoring program. This would permit Iceland to take a step closer to understanding the environmental impacts of organic accumulation from aquaculture.

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Appendix 1

Table 1.1: Trap totals for sample set 1. Includes deployment and retrieval time; dates and number of days deployed. All dry weights have an error of 0.51g calculated from a control sample of 15.00g of salt water. All organic weights have an error of .05g calculated from a bleach control of 0.03g from 10.00g of bleach water; and .02g from a filter control.

Sample set 1				
12:00 PM	12:00 PM			
08-Jun-11	23-Jun-11	15 days		
Trap #	Dry Weight	Organic Weight	Organic %	g/m²/day
RT S1	3	0.4	13.33	6.93
RT S2	8.71	1.48	16.99	25.65
T1 S1	0.85	0.68	80.00	11.79
T1 S2	1.66	1.45	87.35	25.13
T2 S1	1	0.48	48.00	8.32
T2 S2	0.9	0.7	77.78	12.13
T3 S1	0	0	0	0.00
T3 S2	0	0	0	0.00
T4 S1	1.03	0.64	62.14	11.09
T4 S2	0.82	0.46	56.10	7.97
T5 S1	1.08	0.68	62.96	11.79
T5 S2	0.98	0.56	57.14	9.71
T6 S1	1.68	1.08	64.29	18.72
T6 S2	1.32	1.05	79.55	18.20

Table 1.2: Trap totals for sample set 2. Includes deployment and retrieval time; dates and number of days deployed. All dry weights have an error of 0.15g calculated from a control sample of 12.02g of salt water. All organic weights have an error of .04 g calculated from a bleach control of 0.02g from 10.00g of bleach water; and .02g from a filter control. Samples with * have organic weight errors of .05g calculated from a bleach control of 0.05g from 10.01g of bleach water; and 0.00g from a filter control. Sample with ** had a shrimp in the trap during sampling.

Sample set 2				
12:00 PM	10:00 AM			

23-Jun-11	28-Jul-11	35 days		
Trap #	Dry Weight	Organic Weight	Organic %	g/m²/day
RT S1	23.44	1.23	5.25	9.14
RT S2	14.34	0.84	5.86	6.24
T1 S1	0.47	0.31	65.96	2.30
T1 S2	0.41	0.22	53.66	1.63
T2 S1	1.76	1.02*	57.95	7.58
T2 S2	1.78	1.19*	66.85	8.84
T3 S1	0	0	0	0.00
T3 S2	0	0	0	0.00
T4 S1	1.7	0.59	34.71	4.38
T4 S2	1.41	0.31	21.99	2.30
T5 S1	3.02	1.29*	42.72	9.58
T5 S2	3.02	1.23*	40.73	9.14
T6 S1	1.86	0.45	24.19	3.34
T6 S2	1.9	0.5	26.32	3.71

Table 1.3: Trap totals for sample set 3. Includes deployment and retrieval time; dates and number of days deployed. All dry weights have an error of .11g calculated from a control sample 15.01g of salt water. All organic weights have an error of .04g calculated from a bleach control of 0.02g from 10.00g of bleach water; and .02g from a filter control.

Sample Set 3				
10:00 AM	2:00 PM			
28-Jul-11	25-Aug-11	28 days		
Trap #	Dry Weight	Organic Weight	Organic %	g/m²/day
RT S1	14.38	0.87	6.05	8.08
RT S2	19.59	1.19	6.07	11.05
T1 S1	2.05	0.61	29.76	5.66
T1 S2	1.83	0.46	25.14	4.27
T2 S1	2.19	0.95	43.38	8.82
T2 S2	2.67	1.53	57.30	14.21
T3 S1	3.32	1.05	31.63	9.75
T3 S2	3	1.12	37.33	10.40
T4 S1	3.62	0.81	22.38	7.52
T4 S2	3.28	0.55	16.77	5.11
T5 S1	5.15	1.5	29.13	13.93
T5 S2	5.44	1.8	33.09	16.71
T6 S1	4.23	0.89	21.04	8.26
T6 S2**	4.35	0.76	17.47	7.06

Table 1.4: Trap totals for sample set 4. Includes deployment and retrieval time; dates and number of days deployed. All dry weights have an error of 0.12g calculated from 15.00g of salt water. All organic weights have an error of 0.05g calculated from a bleach control of 0.04g from 10.00g of bleach water; and .01g from a filter control. Samples with * organic errors of .05g calculated from a bleach control of 0.05 from 10.01 g of bleach water; and .00 from a filter control. Sample with ** had a shrimp in the trap during sampling.

Sample set 4				
2:00 PM	12:00 PM			
25-Aug-11	22-Sep-11	28 days		
Trap #	Dry Weight	Organic Weight	Organic %	g/m²/day
RT S1	45.08	1.14	2.53	10.58
RT S2	47.05	1.69	3.59	15.69
T1 S1	2.82	0.52	18.44	4.83
T1 S2	3.5	0.5	14.29	4.64
T2 S1	4.53	0.96*	21.19	8.91
T2 S2	4.89	1*	20.45	9.28
T3 S1	6.51	2.47*	37.94	22.93
T3 S2	5.01	1.9*	37.92	17.64
T4 S1**	5.33	0.79	14.82	7.34
T4 S2	5.42	0.98	18.08	9.10
T5 S1	3.95	0.98*	24.81	9.10
T5 S2	5.52	1.36*	24.64	12.63
T6 S1	6	1.09	18.17	10.12
T6 S2	5.29	0.94	17.77	8.73

Appendix 2

Table 2.1: Daily feed data for sample site cages A1 and A2. Including daily amounts in kg as well as feed size. Sample dates are **Bolded.**

Date	Feed (kg)	Feed Type	Feed (kg)
13/06/2011	100	3 mm	78
14/06/2011	115	ECO 3 mm	80
15/06/2011	100	ECO 3 mm	50
16/06/2011	179	ECO 3 mm	125
17/06/2011	162	ECO 3 mm	85
18/06/2011	190	ECO 3 mm	115
19/06/2011	140	ECO 3 mm	101
20/06/2011	210	ECO 3 mm	130
21/06/2011	185	ECO 3 mm	385
22/06/2011	210	ECO 3 mm	160
23/06/2011	210	ECO 3 mm	150
24/06/2011	185	ECO 3 mm	185
25/06/2011	185	ECO 3 mm	180
26/06/2011	185	ECO 3 mm	160
27/06/2011	208	ECO 3 mm	140
28/06/2011	190	ECO 3 mm	190
29/06/2011	185	ECO 3 mm	185
30/06/2011	175	ECO 3 mm	168
01/07/2011	245	ECO 3 mm	24
02/07/2011	155	ECO 3 mm	155
03/07/2011	229	ECO 3 mm	215
04/07/2011	207	ECO 3 mm	207
05/07/2011	198	ECO 3 mm	198
06/07/2011	282	ECO 3 mm	273
07/07/2011	354	ECO 3 mm	349
08/07/2011	402	ECO 3 mm	393
09/07/2011	344	ECO 3 mm	344
10/07/2011	350	ECO 3 mm	346
11/07/2011	303	ECO 4 mm	287
12/07/2011	292	ECO 4 mm	292
13/07/2011	325	ECO 4 mm	326
14/07/2011	340	ECO 4 mm	340
15/07/2011	409	ECO 4 mm	357
16/07/2011	461	ECO 4 mm	412
17/07/2011	372	ECO 4 mm	386

18/07/2011	350	ECO 4 mm	310
19/07/2011	409	ECO 4 mm	423
20/07/2011	514	ECO 4 mm	455
21/07/2011	555	ECO 4 mm	523
22/07/2011	555	ECO 4 mm	419
23/07/2011	583	ECO 4 mm	531
24/07/2011	437	ECO 4 mm	393
25/07/2011	538	ECO 4 mm	448
26/07/2011	563	ECO 4 mm	509
27/07/2011	669	ECO 4 mm	600
28/07/2011	603	ECO 4 mm	556
29/07/2011	676	ECO 4 mm	614
30/07/2011	617	ECO 4 mm	546
31/07/2011	683	ECO 4 mm	656
01/08/2011	492	ECO 4 mm	552
02/08/2011	652	ECO 4 mm	563
03/08/2011	645	ECO 4 mm	620
04/08/2011	641	ECO 4 mm	486
05/08/2011	552	ECO 4 mm	516
06/08/2011	618	ECO 4 mm	554
07/08/2011	537	ECO 4 mm	478
08/08/2011	658	ECO 4 mm	596
09/08/2011	673	ECO 4 mm	630
10/08/2011	808	ECO 4 mm	641
11/08/2011	753	ECO 4 mm	681
12/08/2011	802	ECO 4 mm	725
13/08/2011	829	ECO 4 mm	742
14/08/2011	855	ECO 4 mm	835
15/08/2011	878	ECO 4 mm	798
16/08/2011	1021	ECO 4 mm	933
17/08/2011	840	ECO 4 mm	812
18/08/2011	932	ECO 4 mm	888
19/08/2011	731	ECO 4 mm	717
20/08/2011	1089	ECO 4 mm	874
21/08/2011	808	ECO 4 mm	751
22/08/2011	1019	ECO 4 mm	826
23/08/2011	1008	ECO 4 mm	857
24/08/2011	981	ECO 4 mm	897
25/08/2011	957	ECO 4 mm	731
26/08/2011	1009	ECO 4 mm	877
27/08/2011	991	ECO 4 mm	960
28/08/2011	1095	ECO 4 mm	946
29/08/2011	882	ECO 4 mm	788
30/08/2011	933	ECO 4 mm	817

31/08/2011	1000	ECO 4 mm	770
01/09/2011	1181	ECO 4 mm	977
02/09/2011	958	ECO 4 mm	957
03/09/2011	1215	ECO 4 mm	1022
04/09/2011	1192	ECO 4 mm	967
05/09/2011	1197	ECO 4 mm	1018
06/09/2011	1197	ECO 4 mm	1019
07/09/2011	1161	ECO 4 mm	1025
08/09/2011	845	ECO 4 mm	708
09/09/2011	1233	ECO 6 mm	854
10/09/2011	1002	ECO 6 mm	1051
11/09/2011	994	ECO 6 mm	833
12/09/2011	1107	ECO 6 mm	952
13/09/2011	1040	ECO 6 mm	1027
14/09/2011	1054	ECO 6 mm	1128
15/09/2011	1072	ECO 6 mm	644
16/09/2011	1153	ECO 6 mm	912
17/09/2011	891	ECO 6 mm	823
18/09/2011	1074	ECO 6 mm	1002
19/09/2011	1994	ECO 6 mm	1076
20/09/2011	987	ECO 6 mm	826
21/09/2011	1000	ECO 6 mm	804
22/09/2011	827	ECO 6 mm	891
23/09/2011	759	ECO 6 mm	537
24/09/2011	745	ECO 6 mm	1006
25/09/2011	386	ECO 6 mm	0
26/09/2011	1120	ECO 6 mm	887
27/09/2011	952	ECO 6 mm	900
28/09/2011	879	ECO 6 mm	735
29/09/2011	867	ECO 6 mm	700
30/09/2011	874	ECO 6 mm	948

Appendix 3

Table 3.1: Table of negative and positive error bar values for total organic vs distance from cage figure (figure 19).

Set #	**0 meters**		**20 meters**		**Total**		**Reference Site**	
	-	+	-	+	-	+	-	+
set 1	1.02	0.1	1.53	0.15	2.55	0.25	0.51	0.05
set 2	0.3	0.1	0.45	0.12	0.75	0.22	0.15	0.04
set 3	0.33	0.12	0.33	0.12	0.66	0.24	0.11	0.04
set 4	0.36	0.15	0.36	0.12	0.72	0.27	0.12	0.04

Table 3.2: Table of negative and positive error bar values for Average organic out per meter^2 per day (figure 20)

Set #	**0 meters**		**20 meters**		**Reference Site**	
	-	+	-	+	-	+
set 1	8.84	0.87	8.84	0.87	8.84	0.87
set 2	1.11	0.37	1.11	0.30	1.11	0.30
set 3	1.02	0.37	1.02	0.37	1.02	0.37
set 4	1.11	0.46	1.11	0.37	1.11	0.37

Appendix 4

LAXA FEEDMILL Ltd - FISHFEED

Akureyri 12. September 2011

Laxa Feedmill Ltd. Iceland.

Compliance Statement – Whole Food Market.

Laxa Feedmill Ltd are sole supplier of fish feed for farmed salmon from Fjardalax in Iceland.

I herby confirm that fish feed from Laxa Feedmill comply with all EU regulations regarding production and distribution of fish feed.

I also confirm that feed from Laxa Feedmill comply with all standards from Whole Food Market, including use of non-synthetic colorants in form of natural enriching Aquasta astaxanthin made from *Phaffia rhodozyma* yeast.

Ingredients used in fish feed from Laxa Feedmill Ltd contains only fish meal, fish oil, whole wheat, vegetable meals, non-synthetic colorants and premixed vitamin mixture.

Fish meal and fish oil are from sustainable sources in North Atlantic (FAO-027) and produced domestic in Iceland.

All vegetable raw material used in fish feed from Laxa Feedmill Ltd are GMO free according to EU regulations and industry standards.

Origin of wheat and rapeseed are Danish and are GMO free as it is grown within EU according to agriculture regulations. Origin of corn-meal and soy-meal are from S-America and Asia, both with purchasing/shipping trough traders in Rotterdam and documented GMO free for importing to EU.

In behalf of Laxa Feedmill.

Gunnar Örn

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Appendix 5

Akureyri, June 2010

LAXA FEEDMILL Ltd - FISHFEED

ECO
ECO is special made grower feed for salmon and contains natural pigment.

Description:
ECO is extruded grower feed in pellets, containing fat from 23% to 32% and protein from 38% to 49%.

Composition:
Superior fish meal (NSM), fish oil, rapeseed oil, whole wheat, corn meal, soy meal, rapeseed meal, premixed vitamins and minerals, natural colorant from *Phaffia* yeast.

Feed analysis (%)

Pellet size	3,0 mm	4,0 mm	6,0 mm	9,0 mm
Protein	49	46	42	35
Oil	23	26	32	32
Carbohydrates	9	8	8	12
Ash	8	7	7	6
Dry matter	91	92	92	92
Astaxanthin mg/kg from Phaffia	18	42	42	42
Digestible energy MJ/kg	19,6	20,0	21,3	21,0
Gross energy MJ/kg	22,2	22,5	23,9	23,5

Energy distribution, % of DE	%	%	%	%
Protein	51	47	40	36
Oil	43	48	55	56
Carbohydrates	6	5	5	8

Vitamins pr kg feed				
Vitamin A IU	2.500	2.500	2.500	2.500
Vitamin D3 IU	1.500	1.500	1.500	1.500
Vitamin C mg (stay C)	300	100	100	100
Vitamin E mg	115	110	110	110

Feeding guide	3,0 mm	4,0 mm	6,0 mm	9,0 mm
Salmon grams	30-150	100-500	400-1100	1000 <

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