

Master's Thesis



***Do Artificial Reefs Reduce the
Accumulation of Feeding Remains Around
Mariculture Cages in Skutulsfjörður?***

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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.

Dafna Israel

Abstract

It is essential that mariculture continues to expand in order to meet the needs of the growing global demand for fish supply. As a result of industrial growth, there has been an increase in negative impacts on the environment near mariculture netpens. Such negative impacts include organic effluents, which are the feeding remains and feces that are released from the netpens. One possible solution for this problem is the use of artificial reefs below the netpens. Artificial reefs intend to attract various organisms that feed off the excess of the organic matter and reduce its accumulation.

In this research two artificial reefs were built and deployed, one below the mariculture netpen: artificial reef farm (ARF), and one in a control site 240 meters away: artificial reef control (ARC). In order to assess their biofiltration capability, the organisms that were associated with the artificial reefs were examined. During each sampling dive, wild stock assessment of bigger fauna was conducted and four plates that were made from the same material as the reefs' tubes were removed. The species that grew on the plates were then identified and quantified. In total, there were thirty-two plates for eight sampling dives.

Our results show that the reefs attracted both invertebrates, sessile and motile, as well as wild fishes. The succession of sessile species appeared from the fourth sampling dive onwards. During the research, the presence of sessile species increased in number and size. Motile species were also present in both reefs. Their succession was early, appearing in the first sampling dive. The number of motile species was greater in the farm site. Wild fishes were present only in the farm site, while Hydrozoa was present only in the control site and grew extensively on the reef. Overall, species richness was greater at the farm site. Standard ANOVA test could not be applied as it was unsuccessful in finding a significant correlation between the two sites. Instead, Repeated Measures ANOVA was used to show that there was a significant difference in plate (fouling) cover between ARF and ARC. Also, the effect of time on growth indicates that time had a significant influence on this factor, and that there was a significant difference in growth rate between the sites.

It can be concluded that the organisms found on the reefs, and the wild fish around it, showed the reefs' capability of being used as biofiltration as they successfully attracted organisms that fed off the feeding surplus from the netpens. However, the full extent of their filtration capability is still to be determined.

KEY WORDS: mariculture, netpens, artificial reefs, biofiltration, organic effluents

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Acronyms

ARC – Artificial Reef Control

ARF – Artificial Reef Farm

EIA - Environmental Impact Assessment

FAO – Food and Agriculture Organization

EQOs - Environmental Quality Objectives

EQSs - Environmental Quality Standards

GDP - Gross Domestic Product

NPA - National Planning Agency

SEPA - Scotland the Scottish Environment Protection Agency

TAC - Total Allowable Catch

TIAA - The Icelandic Aquaculture Association

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1. Introduction

Nowadays the importance of mariculture as source of fish is well recognized (Ottolenghi et al., 2004; Holmer et al., 2008; FAO, 2010c), yet fish farming has been known to generate negative impacts on the environment near mariculture netpens (Wu, 1995; Goldberg et al., 2001; CBD, 2004). One of the negative impacts is organic effluents from fish feces and feeding remains that are released from the netpens. Such effluents can cause local eutrophication as well as anoxia in the water column and sediment. This can result in loss of biodiversity (Karakassis, Tsapakis, Hatziyanni, Papadopoulou & Plaiti 2000; Angel et al., 2002; CBD, 2004; Cook et al., 2006). The magnitude of this impact depends on many factors: the type of fishes being cultivated, the feed used, fish stocking density in the cages, physical features of the site (e.g. bathymetry, sediment type) and hydrography (Wu, 1995).

It has been proposed that artificial reefs may help deal with some of the negative effects of aquaculture (Angel et al., 2002; Cook et al., 2006; Gao, Shin Paul, Xu & Cheung, 2008). So far, only a few farms have attempted to use artificial reefs in order to reduce environmental impacts from excess feeding remains. Moreover, such research has not been conducted in higher latitude regions or in fjord environments. The success of such research may provide a partial solution for fish farm organic enrichment. This project could therefore support further growth in mariculture by answering the main research question: *Do Artificial Reefs Reduce the Accumulation of Feeding Remains Around Mariculture Cages in Skutulsfjörður?* In addition, this study addresses more specific questions, such as: What groups of organisms would the reefs attract? What is the effectiveness of the reefs in reducing accumulation of farm effluents? How do artificial reefs of this sort perform in high-latitude and cold waters?

This project provides an overview of the mariculture sector in Iceland. It analyzes how mariculture is practiced, the negative ecological impacts it generates and some possible solutions. It focuses in particular on the effectiveness of artificial reefs, several of which were deployed and tested during this research.

2. Literature Review

2.1 The Cause for the Recent Global Growth in Mariculture

Historical records describe various practices, mainly minor household production, of aquaculture as early as the 19th century. In the 1900s, the use of aquaculture to enhance fish production received some interest, but overall production at that time was negligible (Holmer et al., 2008). Until the late 1970s (apart from Asia) aquaculture did not draw the attention of developers in the fishing industry, as it did not seem to be cost-effective. Fishing was customary practice and was favoured by most nations as a means to harvest fish. As a result, aquaculture as an industry developed rather late compared to other animal protein production methods. In the 1970s it was confirmed that some fish stocks were rapidly depleting and the long held belief that fish was a never-ending resource was proven to be unfounded (Katavias, 1999; Brown, 2004; Tacon & Matthias, 2007). As a result, more effort was invested in developing intensive aquaculture farms (Fig. 1). The turning point of this industry in the late 1970s arose from the success of salmon cultivation in Norway, leading to a worldwide expansion and growth in mariculture production (Katavias, 1999; Tacon & Matthias, 2007). At the beginning of the 21st century annual aquaculture production amounted to half a billion tons, as compared to the overall production of about 1 million tons per year fifty years earlier (FAO, 2010c). Production of aquaculture increased from 0.7 kg per capita in 1970 to 7.8 kg in 2008, with an average growth in production of nearly 7% per year as compared to wild capture fisheries that had an average growth of 3.6% per year (FAO, 2010c) for this period.

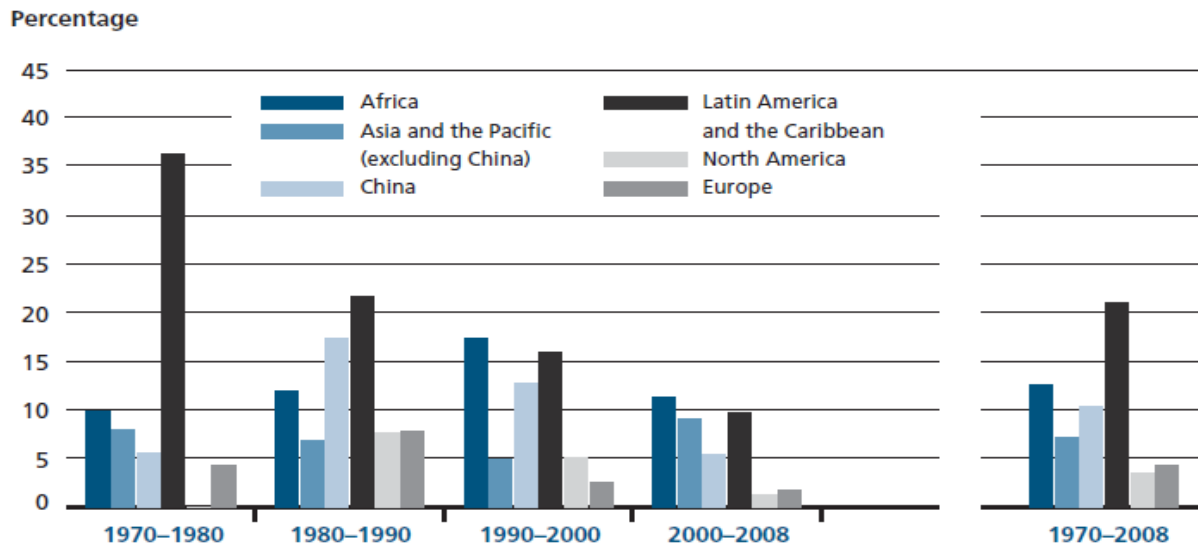


Figure 1: Growth of aquaculture by continent since 1970 (data excluding aquatic plants) (FAO, 2010c).

Nowadays, 50% of the worldwide fish supply (both freshwater and marine aquaculture) is from aquaculture practices (Bimal, Mohanty, Sahoo and Sharma, 2010) and more than half of the coastal countries have established mariculture industries (Ottolenghi, Silvestri, Giordano, Lovatelli & New, 2004; FAO, 2011). It is predicted that the total production of aquaculture will exceed the landings from wild fisheries as the main source of fish. In some countries, fish production from aquaculture is already higher than capture fisheries (FAO, 2010c). The cultivation of aquatic plants has also experienced vast growth. The yearly growth rate of this industry has been 8% since the 1970s and in 2006 the industry supplied nearly 95% of the world aquatic plants consumption, with China producing more than 2/3 of the total supply (FAO, 2011).

In order to supply the global demand for fish, the FAO estimates that aquaculture will need to supply 80 million tons per year by 2050. Each region experiences a different growth rate and cultivates different species. The Asia-Pacific region is a global leader in aquaculture, producing almost 90% of global yield of quantity and about 75% of global aquaculture profits (FAO, 2011). Such supremacy is mainly the result of China's immense aquaculture production that accounts for 2/3 of the world's production and about half of the world's revenue of this industry (Fig 2). China is the world leader in seafood and seaweed production while Norway and Chile are leaders of salmonids production.

Together, they account for about 65% of the world's marine finfish production (FAO, 2011).

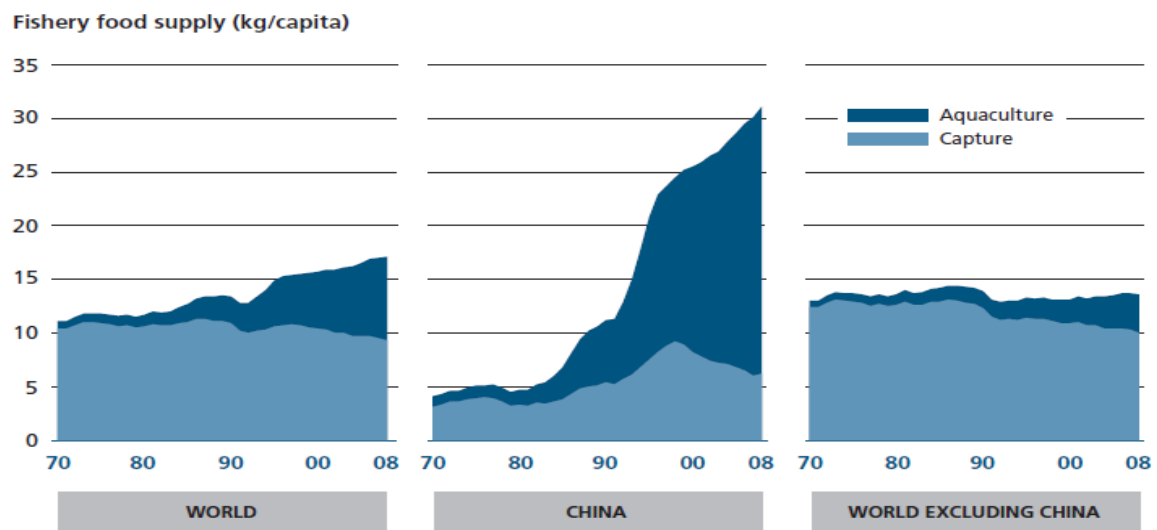


Figure 2: Relative contribution of aquaculture and capture fisheries to food fish consumption (FAO, 2010c).

The continuous and extensive growth in aquaculture over the past three decades is the result of: overexploitation of fish stocks, human population growth, increasing demand for fish and economic growth (Naylor et al., 2000; Neori et al., 2004; Ottolenghi et al., 2004; Asche, Roll & Tveteras, 2008). Current data shows that even with greater efforts from fishery management to reduce pressure on endangered fishes by establishing Total Allowable Catches (TAC) and Maximum Sustainable Yield (MSY), the available fish stock will not be able to provide an adequate amount of food for the world's growing population. The prediction is that the dependence on aquaculture (fresh and marine) for fish production will increase (Wu, 1995; Holmer et al., 2008; FAO, 2010c). In addition, nowadays, only about 1/6 of aquatic species used for human utilization are cultivated. Therefore the prediction is that production will increase in both quantity and type of cultivated species (Holmer et al., 2008).

2.2 Practices of Mariculture

Aquaculture is the generic name for cultivating aquatic fauna such as finfish, shellfish (mollusks and crustaceans) and flora such as aquatic plants in brackish, fresh or salt water (Fig. 3)(Goldburg, Elliot & Naylor, 2001; CDB, 2004). The cultivation of

marine species is known as marine aquaculture, or mariculture, and spans a wide range of salinities from brackish to full strength seawater (Goldburg et al., 2001). Aquaculture is practiced either in artificial closed systems, such as tanks and ponds, or in natural environments such as rivers, lakes, bays, estuaries or open marine systems (Goldburg et al., 2001).

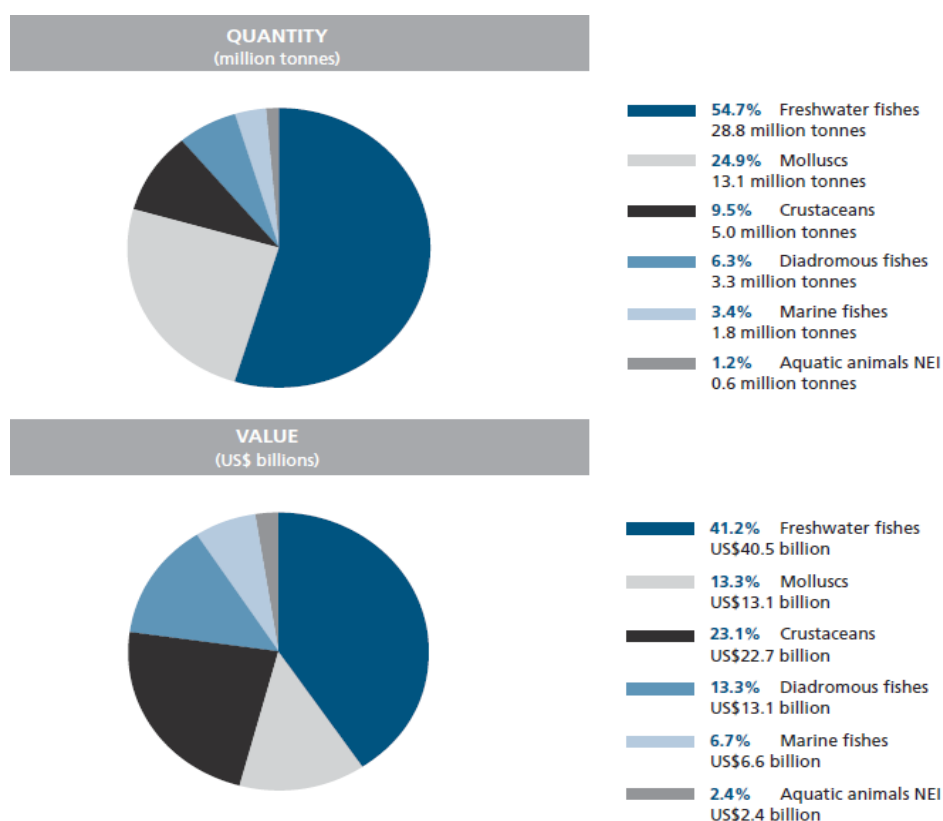


Figure 3: World aquaculture production: major groups in 2008 (FAO, 2010c).

Marine finfish aquaculture is generally carried out in net cages at sea and may be situated in either inshore or offshore locations. Inshore cages are closer to land, generally in shallower water and in protected locations that are less susceptible to damage by storms. Offshore net pens are generally situated in more exposed sites, farther from shore. As a result, the offshore farms are more susceptible to damage from storms, but in many cases these have better water quality conditions than onshore farms. Both offshore and inshore cages are moored to the seafloor and may occupy a variety of depths in the water column, but they also float on the surface (CBD, 2004). Marine Finfish aquaculture may be performed in extensive, semi-intensive or intensive manners. Extensive mariculture implies minimal human intervention, such as cultivation of fish in reservoirs. Semi

intensive farming involves feeding the cultivated species, but the investment in feed production and husbandry is not high. Intensive aquaculture involves a large investment in all aspects of fish cultivation to maximize the yield in minimal time and generally focuses on relatively high value species such as salmonids, seabream, seabass and cod (Naylor et al., 2000). This review will focus on intensive finfish mariculture.

2.3 Finfish Mariculture

Finfish mariculture relies on juveniles that are either captured (through fishing) or produced in hatcheries. Unlike regular fisheries, the main aim of capture-based mariculture is to cultivate high quality fish in controlled conditions so that they reach market size in the most economic way possible. It is noteworthy that capture-based aquaculture is fully dependent on the natural breeding patterns of wild fish. Stress is common in the juvenile capture process. Hence, there is greater emphasis on the manner in which juveniles are captured as it has an influence in determining the captured juvenile mortality rate (Ottolenghi et al., 2004).

The more technologically-advanced, complex and costly alternative to capture-based aquaculture is rearing of fish in hatcheries and nurseries. The cultivated juveniles may subsequently be released to natural systems for restocking or they may be transferred to tanks, ponds or net cages where they are reared to the desirable size. This approach is also known as “culture-based fisheries” (FAO, 1997) or closed life-cycle aquaculture (Ottolenghi et al., 2004). Such closed systems involve a detailed comprehension of the species being cultivated; their life cycle stages and dietary requirements during each of those stages, behaviour in captivity, environmental requirements, and immunity levels (Ottolenghi et al., 2004).

Capture-based aquaculture is employed for those species that we are unable to induce spawning in artificial systems. Many species are being studied in an attempt to provide them with the necessary conditions needed for spawning and juvenile growth. In certain cases, hatchery-based cultivation is receiving more attention due to overexploitation of various species, pollution near spawning grounds and climate change. Capture-based aquaculture is fully dependent on wild stock availability, but overfishing diminishes the natural populations of larvae and juveniles. Pollution, especially near spawning grounds, can eliminate a whole generation. For example, the recent BP oil spill

in the Gulf of Mexico severely damaged the spawning grounds of the western blue fin tuna (Upton, 2011), jeopardizing future generations. In addition, increasing seawater temperatures may greatly influence the natural productivity of marine systems, threatening the survival of certain species (Bimal et al., 2010).

2.4 Fishing Technology for Capture-based Mariculture

In order to apply suitable fishing techniques to capture juveniles for mariculture, there is a need to understand their behaviour and to be acquainted with their average body size for specific stages of their life. This is to ensure that they are not caught too early while still frail. According to previous research, the majority of marine finfish drift in plankton during their first few weeks after hatching. Following this, the larvae then search for a suitable habitat (such as seagrass beds) where they can hide and feed as they grow to the juvenile phase. In order to capture the juveniles alive in good physical and psychological condition, suitable fishing gear is needed. This plays a great role in determining juvenile mortality rate after being caught. Moreover, it is important to note that some species experience soaring psychosomatic stress during capture or while in captivity and therefore are not suitable for cultivation (Ottolenghi et al., 2004). In many cases juveniles are harmed during the fishing process and subsequent transportation to farm facilities. In order to capture juveniles at the desirable age/size, their growth rate is calculated along the hatching season to determine the best fishing time. (Ottolenghi et al., 2004).

2.5 Mariculture in Iceland

2.5.1 History and Development of Mariculture in Iceland

Icelanders began fish farming as early as the end of the 19th century. Their first practice was stocking salmon-free rivers and lakes by relocating the fishes. By the end of the 19th century, they tried to increase the salmon stock by enhancing fertilization of female eggs while restocking the rivers (Gunnarsson, 2009a). Until the middle of the 20th century, Icelandic aquaculture involved mainly stocking rivers and streams with salmonids. At this point, the rainbow trout was introduced in Iceland and was reared in both tanks and netpens (Gunnarsson, 2009a). With the growth of the European aquaculture industry in the late 1970s, Iceland increased production of fish, however, on a smaller scale. In response

to the increasing interest in aquaculture, The Icelandic Aquaculture Association (TIAA) was established in the early 1980s to unify the industry and provide help with technical, social, political and economic issues (TIAA, 2011).

Icelandic aquaculture development increased in the 1990s as commercially important species such as Arctic char, halibut, turbot, abalone and cod were introduced (Gunnarsson, 2009a), peaking in 2006 at a total production of 9,931 tonnes. In the following years Iceland experienced a reduction in aquaculture production, mainly because of a decrease in salmon prices, however there was a concomitant increase in both Arctic char and cod (Table 10)(FAO,2010b).

Table1: Icelandic finfish aquaculture production, in tonnes (FAO, 2010b).

Year	2009*	2008	2007	2006	2005	2004	2003	2002	2001	2000
Salmon	500	283	1 158	6 895	6 094	6 020	3 700	1 471	2 645	3 370
Arctic char	3 200	3 006	2 145	1 426	977	1 336	1 670	1 540	1 320	1 364
Rainbow trout	100	0	10	10	50	142	180	248	105	95
Halibut	50	19	31	141	129	123	95	120	93	30
Turbot	80	41	70	47	115	62	32	9	3	0
Cod	1 200	1 502	1 467	1 412	1 050	595	445	205	70	11
Total	5 130	4 851	4 881	9 931	8 415	8 278	6 122	3 593	4 236	4 870

By 2009, forty-five fish farms were registered: thirty of the farms produced salmonids, four farms cultivated marine species, and eleven farms produced mainly cod (Fig. 4). Moreover, there were ten mussel farms and twenty-five land tanks for Arctic char. Since 2009 Arctic char, salmon and cod have been the main cultivated species and predictions indicate that by 2015 production will be twice as much as current levels (Gunnarsson, 2009a).

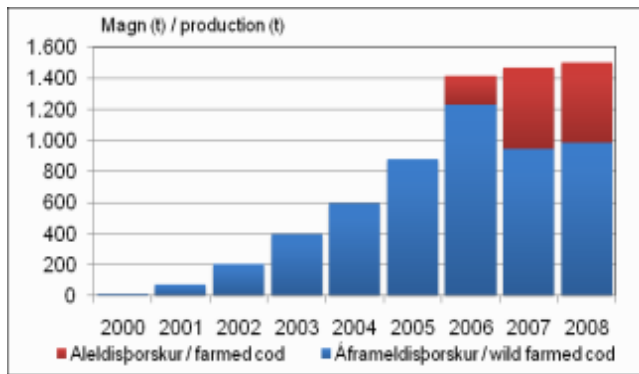


Figure 4: Production of farmed and wild farmed cod (Gunnarsson, n.d.c).

The unpolluted waters provide a premium habitat for fishes and consequently give Iceland a great advantage for having high quality mariculture products. In addition, Iceland's geothermal energy can be used in order to cultivate "warmer" water species such as the turbot. Iceland is also a leading nation in the development of hatcheries, having succeeded in hatching traditionally difficult species such as halibut (Gunnarsson, 2009).

2.5.2 Icelandic Cod

The cod population, *Gadus morhua*, is widely spread across the Atlantic Ocean, from the Canadian East Coast to the Barents Sea and to the southern part of the Atlantic. The average size of mature Icelandic cod is between 50 and 100 cm, with weight ranging from 1 to 4 kilograms (Valtýsson, n.d.). The growth rate of cod is heavily dependent on food availability and varies at different locations. The Northern cod reach maturity at the age of six while Southern cod reach maturity at the age of three years. The Icelandic cod population has a slower growth pace than southern cod populations due to the colder environment (Codtrace, n.d.). The cod is an omnivorous carnivore that feeds on zooplankton as a juvenile (Valtýsson, n.d.) and small fish such as capelin, herring, and even juvenile cod as well as various invertebrates as it grows. (Codtrace, n.d.).

The Icelandic cod lives mostly near the sea in waters ranging from only a few meters deep down to a few hundred meters (Codtrace, n.d.). The Icelandic cod's main spawning ground is in south-western Icelandic waters (Fig. 5). From the beginning of March until June, the pre-hatched eggs and newborn larvae travel with the north-east Irminger Current (Fig. 6), along the Icelandic coast and fjords toward the north-west of Iceland to Greenland (Begg & Marteinsdottir, 2000; Vilhjálmsson & Hoel, 2005). In

recent years, additional spawning grounds were discovered on the west, north and east coasts of Iceland, however the main spawning grounds remain in the south-west (Begg & Marteinsdottir , 2000; Valtýsson. n.d.).

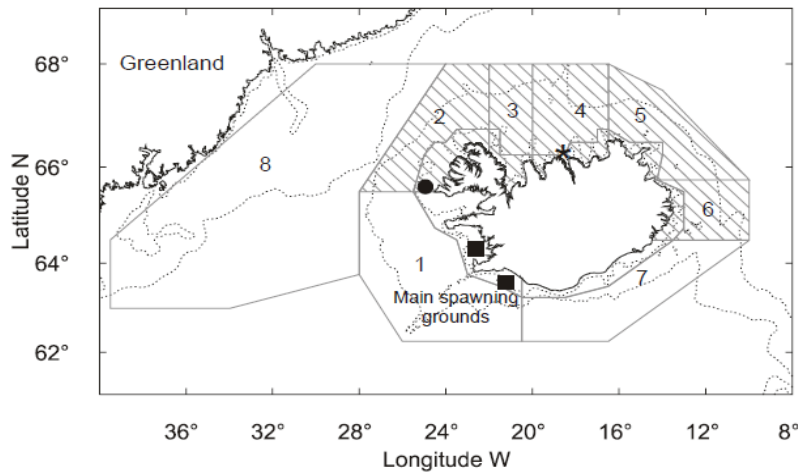


Figure 5: Main spawning grounds in Iceland (Begg & Marteinsdottir, 2000).

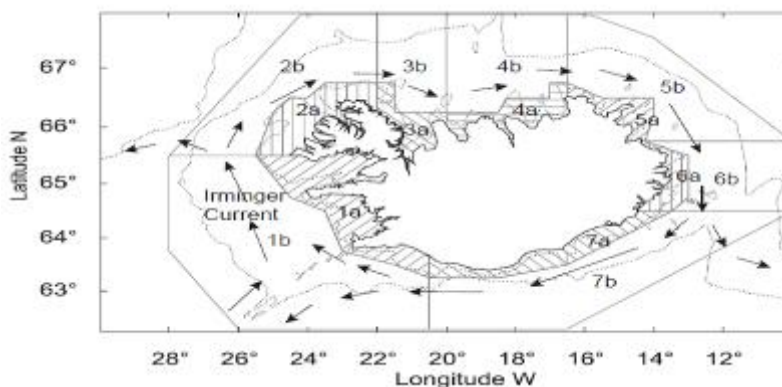


Figure 6: Irminger Current (Begg & Marteinsdottir , 2000).

The female cod is highly productive and may release 2.5 to 9 million eggs during a spawning season (Jensen, 2009). The spawning season takes place throughout winter, ending sometime between January and March. The ideal temperature for spawning ranges from 0-12° C, when the oxygen level in the water is high. This is essential for the eggs' survival. The cod maintains positive buoyancy throughout its embryonic stage and will therefore float with the current. After hatching, the newborn cod larvae are even lighter than the eggs, which allow them to float along with the phytoplankton in the upper water layer for the first few weeks. Thereafter, the larval cod move into deeper and more

offshore water (Jensen, 2009). When mature, cod is capable of living in deeper water throughout a wide range of water temperatures from near freezing to 20 °C, including the continental shelf at depths of 150-200m.. Cod are also extremely euryhaline and able to adjust to waters from nearly fresh water to oceanic salinities (FAO, 2011; Marine Bio Organization, n.d.).

The cod stock decreases in size along the Icelandic coast, from the southwest toward the east. The southeast stock spawns and hatches first, followed by northwest, north, and then east. The strength of water currents has been recognized as the most influential factor in determining the juveniles' location, stock density, and size. Moreover it seems that during their early life stages, the ocean's physical properties are the most influential factors determining larval survival rates, dispersion along the coasts and their success in reaching a safe habitat (Begg and Marteinsdottir, 2000).

2.5.3 Cod Mariculture in Iceland

In the past three decades, the cod fishery around Iceland has averaged 150,000-300,000 tonnes per year, generating roughly 1/3 of the national income of Iceland. As a result of its high economic value, cod is at a constant risk of being overexploited. In the past several years, the cod stock assessment determined that the natural stocks were at risk of overfishing. As a result, the Total Allowable Catch (TAC) was set at 130,000 tonnes per year. The first attempt to cultivate cod took place in the beginning of the 1990s and was a success. As a result, the Ministry of Fisheries and Agriculture provided a higher quota for aquaculture fishing to encourage this and the quota was set for half a million cultivated cod per year. From 2003 to 2008, 1 million juvenile cods were captured and cultivated in the northwest coast. However, in 2009 this practice was stopped due to decline in cod stocks (Gunnarsson, n.d.c).

The largest and most economically important mariculture practice in Iceland is Cod farming (Gunnarsson, n.d.c). Atlantic cod is especially amenable to capture-based mariculture because the fish do not show signs of major stress when captured and transferred to tanks and netpens. In addition, they spawn in aquaculture facilities off shore and in land-based tanks (Brown, O'Brien-MacDonald & Parrish, 2006). Icelandic cod culture is mostly capture-based. Larvae between 3 to 5 grams are reared in inland tanks for

about eight months before being transferred to netpens at sea. Large juvenile cod (1 to 2 kg) are directly transferred to net pens, where they are reared for six to twelve months until they achieve the desirable (market) weight of 3 to 4 kg (Fig. 7). In southwest Iceland, there are hatcheries where 100,000-200,000 cod were hatched between 2004 to 2007. Those juveniles were transferred to netpens (Figs 8&9)(FAO, 2010b).

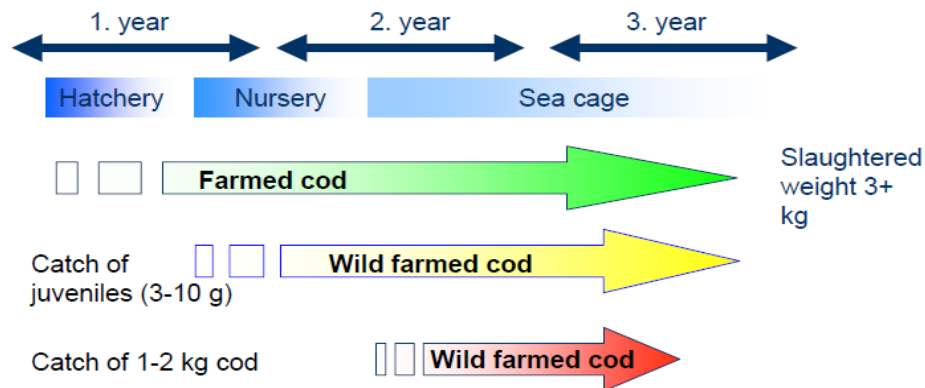


Figure 7: Cod farming in Iceland (Gunnarsson, 2008b).

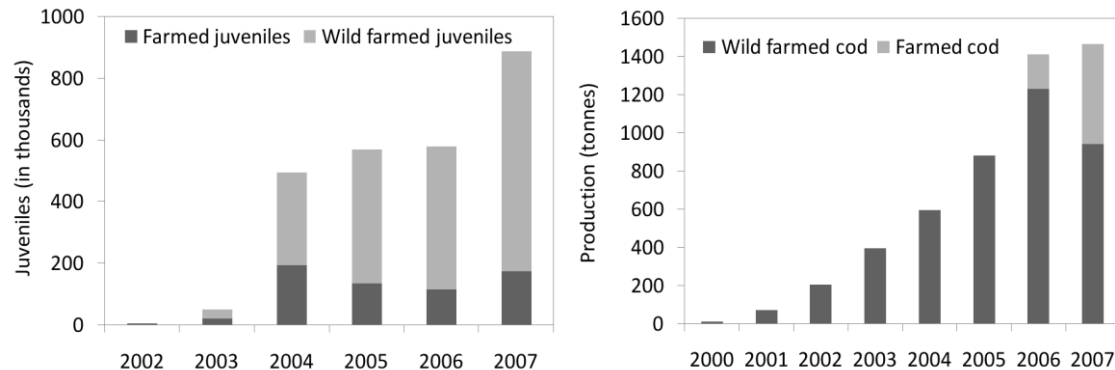


Figure 8: Numbers of juveniles (in thousands) from hatcheries (farmed) versus capture-based (wild farmed) sources in sea cages, between 2002-2007 (Gunnarsson, 2008b).

Figure 9: Production (in tonnes) of cod from capture based vs. hatchery-produced mariculture, between 2000-2007 (Gunnarsson, 2008b).

To date, a total of eleven Icelandic farms practice both capture-based and hatchery-produced cod farming. Within seven years, cod production increased from 10 tonnes in 2000 to 1,450 tonnes in 2007 (Gunnarsson, n.d.a). Capture-based mariculture of cod is more cost-effective than hatchery-production and has therefore remained the preferred

practice in Iceland (FAO, 2010b). Nonetheless, companies such as Icecod Ltd. continue to develop new hatchery methods and technology in the southern part of the country. It is expected that hatcheries will dominate in the future due to the increasing depletion of cod stock (Gunnarsson, n.d.c).

This section of the literature review explored the general concept of mariculture by looking at industry growth, forms, and practices. It also provided a more detailed description of finfish mariculture, particularly the Icelandic cod, *Gadus morhua*, and the different forms of its cultivation. The following section provides an overview of the positive and negative aspects of the mariculture industry.

3. Pros and Cons of Mariculture

3.1 Advantages of Mariculture

Mariculture has the potential to resolve some of the major problems that the world's population is facing in the new millennium. Mariculture can enhance food security, decrease pressure from overfished wild stocks, increase job availability and lead to economic growth- all of which fuel the constant growth of this sector (Naylor et al., 2000).

3.1.1 Food Security

Nowadays, the assumption is that wild fish stocks will not be able to provide an adequate amount of food or protein for the world's growing population. Aquaculture provides an alternative source of fish to address this concern (Naylor et al., 2000; Yu Feng, Hou, Nie, Tang, & Chung, 2004). It reduces the growing gap between fish demand and supply, thereby contributing to global food security (Naylor et al., 2000). This is one of the main mandates of the United Nations Food and Agriculture Organization (FAO) (FAO, 1997).

Fish has high nutritional value, providing protein, minerals, vitamins and essential fatty acids. It is therefore considered to be one of the healthiest protein foods (FAO, 1997; Sugiyama, Staples & Funge-Smith, 2004). 150 grams of fish can satisfy more than half of the daily adult protein requirements (FAO, 2010c). About 1/7 of the world's population are dependent on fish as their main protein supply (Fig. 10)(Tidwell & Allan, 2001). Many developing countries have a daily diet based on vegetables and rice, with a clear lack of protein. Fish can provide an essential element to such protein-deficient diets and are especially rich in essential amino acids such as lysine (Sugiyama et al., 2004). Fish are also a great source of essential fatty acids that are especially necessary during pregnancy for fetal development and health. Therefore the availability of fish is vital in developing countries (Sugiyama et al., 2004).

In addition to nutritional benefits, fish is an important source of income in many nations. In many parts of Asia (especially the coastal regions) seafood is a major

component of human diet and annual production can be as high as 25 kg per capita or more. In sub-Saharan Africa fish provide almost $\frac{1}{4}$ of the human population's protein consumption, whereas in the west coast of Africa, fish comprise up to 50% of the population's protein intake (FAO, 1997). Fish has been recognized in developing countries as a relatively accessible and inexpensive source of protein. The contribution of aquaculture to the world's fish supply has raised the food security level. The successful cultivation of many fish species has led to greater accessibility and price reduction. This provides populations with lower income access to fish (FAO, 2005).

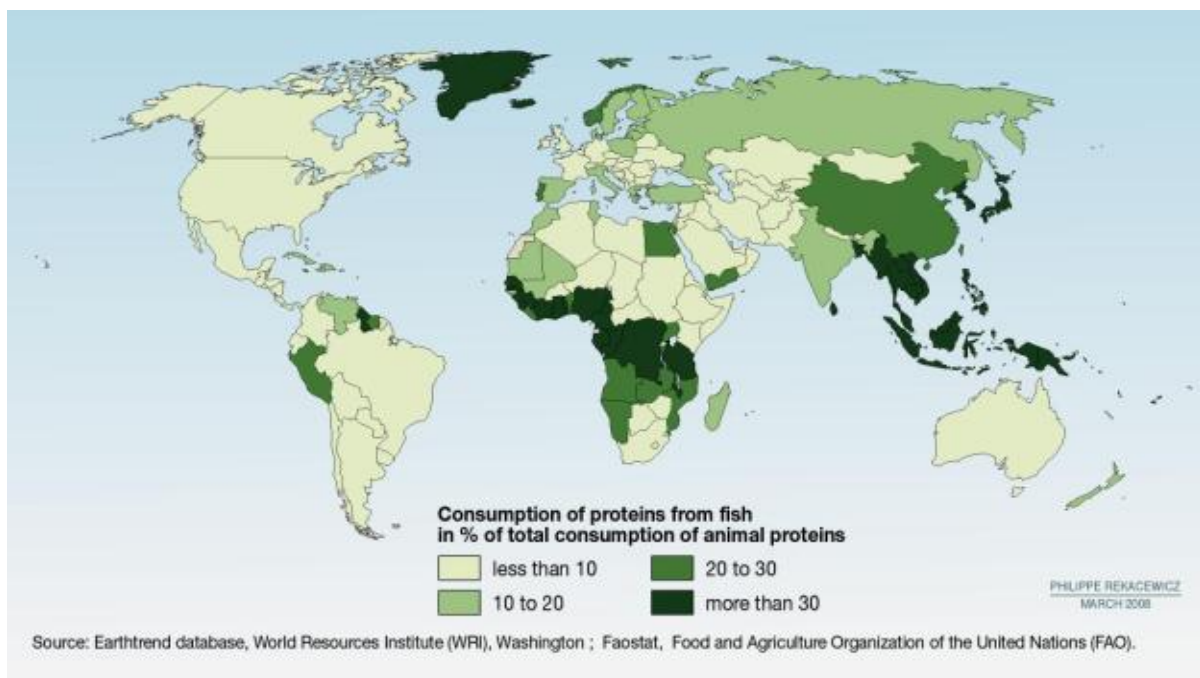


Figure 10: Consumption of fish proteins in % of total consumption of animal proteins (FAO, 2010c).

3.1.2 Decrease Pressure from Wild Stocks

Aquaculture production also has the ability to reduce the pressure of exploiting wild fish stock. Nowadays many economically important aquatic species are almost fully exploited and can no longer sufficiently reproduce offspring to maintain its stock (Fig. 11) (Williams, 2004). According to the States of the World Fisheries and Aquaculture report of FAO for 2010, marine capture-based fisheries attained its highest catches in the mid 90s and have since experienced a constant decline as a result of overexploitation of the fish stock (FAO, 2010c). During that same time, the amount of nearly exploited fish stock has increased from 10% to 30% and the percentage of overexploited fish stocks is now 50%.

As a result of such figures, it is clear that in order to try and restore these fish stocks there is a need to reduce TAC and to increase our reliance on fish produced by aquaculture and mariculture, in particular with increased production in hatcheries (FAO, 2010c).

Global trends in the state of world marine stocks since 1974

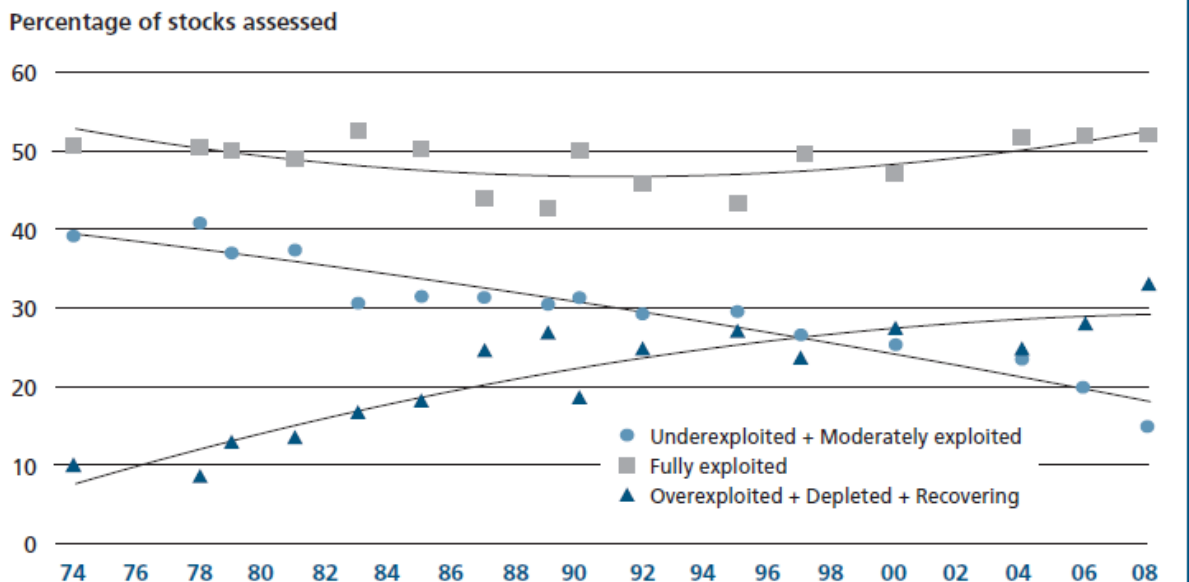


Figure 11: State of the world's fish stocks (FAO, 2010c)

Even though decreasing pressure from wild fish stock is more evident when using hatcheries to produce eggs, capture-based mariculture can also promote pressure reduction. In capture-based aquaculture, mostly juveniles are captured. The proportion of juveniles that survive in captivity is higher than in nature. Capturing juveniles and feeding them results in a higher survival rate of juveniles reaching adulthood, which in turn leads to a gain of biomass (Hreinsson, 2011). Hatchery-based aquaculture has a greater contribution to preservation of wild stocks (FAO, 2010b). In hatcheries a few individuals can produce many offspring, which makes such technology very efficient (CBD, 2004). As a result of such effectiveness, there is a growing investment in promoting hatchery technology and production (FAO, 2010b).

Finally, fish that live in captivity have less energy output, as they do not spend energy on searching for food, escaping from predators or finding a mate. Therefore, unlike wild fish, the feed is mostly invested in growth (Simpson, 2011). As a result, cultivated

fish reach market size at a younger age, which implies that they probably consume less food throughout their life cycle. In addition, the widespread problem of mercury and persistent organic pollutant accumulation (bioaccumulation) found in wild fish is reduced as the cultivated fish spend less time in the sea while growing to market size (Simpson, 2011).

3.1.3 Creating Jobs and Economic Growth

Traditional fishing provides jobs for millions of people globally. Since the 1980s there has been a great increase of employees from nearly 17 million to about 50 million by 2009, all of which were engaged directly with this industry. In addition, it is estimated that this industry provides about 3 times more jobs indirectly and to related fields (FAO, 2010c).

Aquaculture increases not only fish availability but also generates jobs and increased revenues. There are nearly 400 cultivated species around the world and twenty of these have high economic value. A flourishing fish farm is a profitable industry which attracts investors and developers who ultimately increase production.

Food production industries have contributed to the growth of fisheries and aquaculture, as well as overall employment rates and economic value. Asia experienced the highest growth in this industry and constitutes about 85% of the total global employment of fishermen and aquaculturists. So far wild fisheries still have higher employment than aquaculture; however, aquaculture provides many new opportunities for employment as well. By 2008, a quarter of the total employees in the fishing industry were aquaculturists, and the numbers continue to increase, while employment in the wild fisheries sector is decreasing (FAO, 2010c). In developing countries (e.g. sub-Saharan Africa), most of the aquaculture production is generated by small scale household production, which implies that with the growth of this industry there is a great potential for increasing sources of income and revenue and has a positive correlation to food security (Fig.12)(FAO, 2005).

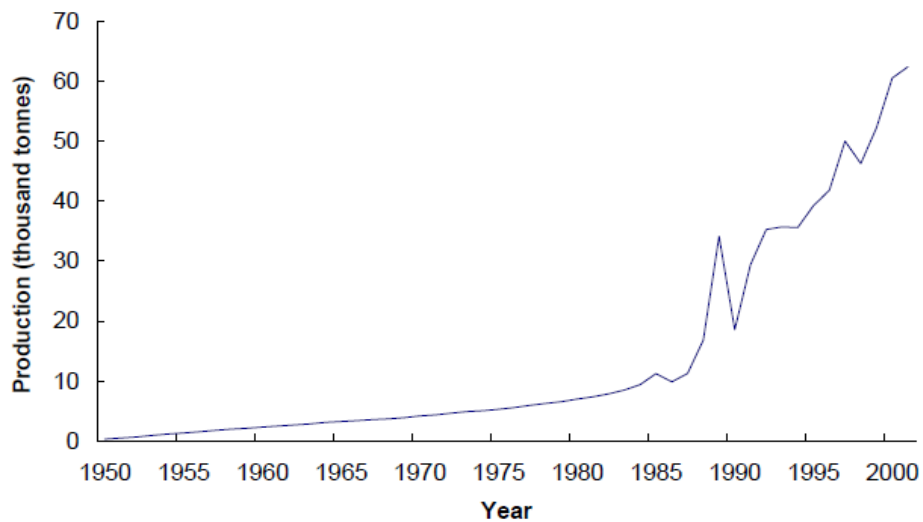


Figure 12: Evolution of the total aquaculture production in the Sub-Saharan Africa region (FAO, 2005).

The contribution of aquaculture to economic growth can be viewed when Gross Domestic Product (GDP) is measured. In Asia there are seven countries that mariculture production is more than 1% of the states' total GDP (Sugiyama et al., 2004).

Table 2: Contribution of Aquaculture to the nation's GDP (Sugiyama et al., 2004).

Production value as percent of GDP ²			
Capture fisheries		Aquaculture	
Kiribati	33.549	Lao PDR	5.775
Marshall Is.	28.378	Viet Nam*	3.497
Maldives	17.294	Bangladesh	2.688
Cambodia	10.030	Philippines	2.633
Solomon Is.*	7.787	China PR	2.618
FSM	6.603	Thailand	2.071
Samoa	4.239	Indonesia	1.662
Viet Nam*	3.702	Cambodia	0.893
PNG	3.306	Kiribati	0.752
Vanuatu	3.294	India*	0.540
Tonga	2.865	Sri Lanka	0.468
Indonesia	2.350	Malaysia	0.366
Philippines	2.184	Nepal	0.345
Fiji Islands	2.046	Taiwan POC	0.324
Thailand	2.044	New Zealand	0.189
Bangladesh	1.884	Myanmar	0.167
Lao PDR	1.432	Korea RO	0.145
Sri Lanka	1.428	Japan	0.108
China PR	1.132	Iran	0.105
Malaysia	1.128		

3.2 Negative Aspects of Mariculture

As a recent newcomer to the food industry in the late 1970s (Karavias, 1999; FAO, 2004), mariculture's negative effects have only begun to be genuinely addressed in recent years (Naylor et al., 2000). The negative ecological impacts can be divided into the three different types of effluents: biological, chemical and organic (Goldburg et al., 2001). The extent of the impact is generally site specific and is dependent on various factors, such as: the species of fishes being cultivated, their feed, the density in the cages, bathymetry and composition of the seafloor, and the direction and strength of the currents (Wu, 1995; CBD, 2004). The growing demand for fish leads to increased production which tends to intensify the negative ecological effects of mariculture.

3.2.1 Biological Impacts

In mariculture, biological “pollution” consists of: introducing non-native species to a new environment, interaction between escapees, and the parasites and pathogens that arise in the native populations. It can also include overfishing to supply feed for the cultured stocks (Goldburg et al., 2001). Many mariculturists import exotic species and cultivate them in their non-native environment. For example, in recent years mariculturists from higher latitudes have begun to cultivate temperate, non-native species because of rising seawater temperatures in their region (FAO, 2010a). The risk is that some of the cultivated fishes will escape from the cages and affect not only wild stocks but also the marine community. When exotic predator species invade an ecosystem, the prey stocks may be severely impacted, affecting the entire food web (CBD, 2004; FAO, 2011). Escapees may consume the native population’s prey, compete with them over available resources, transfer diseases and parasites, as well as interbreed with the native population (Goldberg et al., 2001; FAO, 2011; Jensen, Dempster, Thorstad, Uglem & Fredheim, 2010). Direct interbreeding is when cultivated fish breakout from the netpens, while indirect interbreeding is when cultivated fish spawn in the netpens and their eggs are then released into the environment. The extent of such occurrences and their impact has not yet been fully understood (Jensen et al., 2010).

Escapees

One of the risks associated with escaped farmed fish, which tend to have a fairly limited gene pool, is that these may interbreed with wild stocks and eventually reduce the natural genetic diversity in the wild populations (Goldburg et al., 2001). A loss in genetic diversity may lead to a suite of problems including reduced reproductive success, resilience and fitness (FAO, 2011, CBD, 2004). Moreover, escapees may introduce pathogens, and directly compete with natural populations (Jensen et al., 2010).












Another risk of cultivated escapees is the spread of exotic diseases and parasites. In some cases new parasites can have no impact, while in others it can overwhelm a whole ecosystem. The escapees’ capacity to transmit diseases or parasites to the native population is dependent on various factors including the interaction between native and cultivated species, the duration of the interaction and the species’ age during the interaction (Jensen

et al., 2010). In their new ecosystem, exotic species can have a greater resistance to disease which give them an advantage over the native stock (FAO, 2011).

Fish Food

Another type of biological impact is the overfishing of natural stocks to supply fish meal and fish oil to the fish-feed industry. The steady growth of mariculture has led to a growing need for fish food. Many fish farmers use captured wild fishes to feed the cultivated fishes, e.g. the use of mackerel to feed farmed tuna. Overfishing creates an imbalance in the ecosystem and may have catastrophic effects (Goldburg et al., 2001). The following table presents the estimated amount of wild fishes that are needed in order to nourish cultured fishes. The greatest market demand is for marine finfish, which also require the most fish meal and oil from wild fish. Such high requirements illustrate the magnitude of the problem of extracting wild fishes for feeding cultured stocks (Goldburg et al., 2001).

Table 3: Fish meal and fish oil use in world aquaculture (Goldburg et al., 2001).

Fish	Production (million pounds)	Production Using Compound Feeds (million pounds)	Wild Fish Used in Compound Feeds (million pounds)	Ratio of Wild Fish to Fed Farmed Fish*
 Marine Finfish	2,083	1,250	5,157	4.13
 Eel	492	392	1,843	4.69
 Salmon	1,953	1,953	4,762	2.44
 Marine Shrimp	2,707	2,220	4,996	2.25
 Trout	1,168	1,168	1,709	1.46
 Tilapia	2,363	970	545	0.56
 Milkfish	829	331	311	0.94
 Catfish	1,060	913	273	0.30
 Fed Carp	22,167	8,201	3,075	0.38
 Filter-feeding Carp	12,169	0	0	0
 Mollusks	20,150	0	0	0

In addition, capture of mature fishes for spawning in captivity reduces the size of the reproductive population of that species, which can eventually lead to a reduction of its total wild population (CBD, 2004).

3.2.2 Chemical Pollution

Chemical pollution of mariculture refers to the industry's reliance on chemical substances for production. As with any intensive cultivation that has a high density of

living organisms, there is a risk of spreading diseases. There is a growing use of chemical substances such as antibiotics, vitamins, antifoulants, and pesticides, as well as hormones to induce growth (Wu, 1995; Goldburg et al., 2001; CBD, 2004). The use of antibiotics and vitamins is a common practice in mariculture, especially when the fish are fed with artificial feeds. However in many cases the farmed fish are fed with bycatch, trash fish, or purposely-captured fishes. When cultivated fishes are fed by other wild fish, the risk of chemical contamination is reduced. However, other types of pollution such as organic pollution (see below) might appear due to the excessive feeding remains and their accumulation below the netpens (Wu,1995).

Hormones used to encourage growth and reproduction are administered by injection or inserting them into feed. Injections are more controlled and ensure delivery to the targeted species. One risk of adding hormones, as well as antibiotics and vitamins, to feed is that these substances may reach non-target species (Goldburg et al., 2001; CBD, 2004) such as local meiofauna and macrofauna. Both meiofauna and macrofauna are consumed by various marine species. Biomagnification may cause chemicals to spread within the food web and have widespread effects (Goldburg et al., 2001).

Table 4: Chemicals used in aquaculture, their source and their environmental impacts (CBD, 2004)

Pollutant	Source / Uses	Impact
Antibiotics	Hatcheries, culture ponds	Accumulation in sediments and living organisms, genetic diversity of benthic microflora
Pesticides	Cages, algal beds	Invertebrate mortality
Disinfectants	Hatcheries, culture ponds	Hypoxia, mortality
Antifoulants	Cages	Invertebrate mortality
Hormones	Hatcheries	Unknown

3.2.3 Organic Pollution and Eutrophication

Organic pollution and eutrophication are the most visible consequences of feeding remains and waste discharge from mariculture. Discharge leads to a concentration of organic matter around and below the cages (Angel et al., 2002; CBD, 2004). The amount of waste being released via feed and feces from the nets, and its consequences depends on the type of feed and a range of environmental features (Wu, 1995).

Changes in benthos composition are the most well recognized and documented impacts of mariculture discharges. Soon after a fish farm begins operation, it is possible to detect increases in the sediment's total organic carbon. An increase of organic carbon leads to a decrease in availability of oxygen for benthos species. This can affect micro and macro organisms that may metabolize the fish farm discharges (Karakassis et al. 2000; Pusceddu, Frascchetti, Mirto, Holmer & Danovaro, 2007). Lower oxygen levels mean fewer species can survive. This causes a reduction in biodiversity of benthic species (Karakassis et al. 2000). In addition, there are often changes in the biochemical composition of the sea bottom as a result of various discharges from the fish farm, such as feeds which often contain a high percentage of lipid (Karakassis et al. 2000; Pusceddu, 2007).

Removal of fouling from fish farm surfaces can also add to the organic loading of the environment (Wu, 1995). The major effect associated with intensive cage farming is an accumulation of particulate organic matter on the seafloor, leading to benthic hypoxia, anoxia and sediment sulfide accumulation (Angel et al., 2002; Yu Feng et al., 2004; Gao et

al., 2008; Holmer, Hansen, Karakassis, Borg, & Schembri, 2008). Such changes in the sediment's chemistry generally lead to two processes: 1- Disappearance or extinction of macrofauna and meiofauna in heavily impacted sediments which results in biodiversity loss (Angel et al., 2002; Cook et al., 2006). 2- Increase in biomass and abundance of opportunistic species that benefit from the extensive food availability in slightly less impacted regions (Karakassis et al., 2000). In such cases, organic accumulation increases near the cages as the species that process and break apart the organic matter diminish. This is more common in areas where the current is weak and the accumulation of feeding remains is greater (Angel et al., 2002; Dempster & Sanchez-Jerez, 2008).

Poorly flushed marine systems are more vulnerable to organic accumulation and benthic anoxia as a result of slow water flow and exchange. The extent of the impacted sediments may range as far as 50-100 meters from the netpens (CBD, 2004).

In the next section, few solutions are reviewed for their negative biological and chemical impacts. The paper delves into the possible solutions for organic discharges, focusing primarily on the use of artificial reefs as a potential mitigation system. The following research was conducted in *Skutulsfjörður*.

4. Mitigation of Negative Effects

4.1 Reducing the Negative Ecological Impacts of Mariculture (Biological and Chemical)

Since the importance of aquaculture as a means of food security is well recognized, there have been growing efforts to address the negative ecological impacts in order to increase the sustainability of this sector. Solutions to some of the impacts of mariculture include better management, improved habitat conditions for cultivated fishes and feeding types, investment in hatchery development, and reducing unnecessary substances.

4.1.1 Better Management

Better management involves procedures such as environmental assessments prior to the construction of fish farms. An Environmental Impact Assessment (EIA) assesses the possible effects on the area as well as the ecosystem's carrying capacity (how many netpens can be deployed, choice of species, stocking densities, etc.). EIA gives both the potential negative and positive outcomes of the fish farm environmentally, economically, and socially. Only with a good understanding of the surrounding environmental conditions and physical features, can the suitable technology and prevention systems be applied in order to minimize negative ecological outcomes. For example, using records of tidal range and strength can provide essential data when assessing the accumulation of feedings and waste underneath the netpens. Netpens in areas that have a better water flow can reduce the above mentioned side effects (CBD, 2004).

In recent years there has been a growing awareness of international regulations in order to promote the development of conscientious aquaculture. This includes an international code of sustainable development and implementation of fish farms that considers environmental, economic, and social effects (FAO, n.d.c). Many countries who practice mariculture are now using Environmental Quality Objectives (EQOs) and Environmental Quality Standards (EQSs) to promote and regulate the industry. Many also assess the ecosystems' carrying capacity to minimize potential negative impacts (Holmer et al., 2008).

In the last decade Iceland has seen more regulations of sustainable aquaculture. In May 2000 Act No. 106 was introduced. This act requires the EIA to be an obligatory practice for fish farms. In addition, any mariculture farm that discharges waste into the sea, produces above 200 tonnes per year needs to obtain a license as well as any aquaculture farm that pours waste into freshwater and produces over 20 tonnes per year. This license is obtained by the National Planning Agency (NPA) after the farm EIA has been reviewed. If the NPA is not satisfied with the EIA, they carry out an environmental pollution assessment as well as look at transferable diseases and genetic variability of the cultivated fish. In addition, the Environment Agency, the Directorate of Fisheries and the Icelandic Food and Veterinary Authority are all participants in the evaluation process for granting a license to a fish farm (EU Aquis, 2011). Such a process can ensure that fish farmers make an effort to produce fish in a sustainable manner and minimize any possible negative environmental impacts.

On July 1st, 2008 another new legislation came into place in Iceland: Act 71. The new act refers to aquaculture and mariculture as well as ranching. The Act promotes growth while focusing on sustainable development (EU aquis, 2011). Obtaining a license became stricter under the newer legislation and three main components were viewed: the species being cultivated, netpens' density and locality (Gunnarsson, 2009b). If a license is granted, the new farm needs to ensure the cultivation of the registered species prior to operation. It cannot exceed the quantity that was granted to them and must have a complete plan in case of netpen breakout (Gunnarsson, 2009b).

4.1.2 Alternative for Fish Meal

One of the fears associated with mariculture growth is the impact on wild fish populations that provide fish meal and oils for fish feed. Researchers are investigating new feeds in an attempt to find alternatives to wild-caught fish for mariculture practices. The idea is to achieve satisfactory feeds for cultivating fishes without changing the cultivated fish health, growth rates, quality or taste. Some advanced feed formulas are already seen in the market, for example Kona Blue, a fish farm near Hawaii, reduced wild fish consumption from 80 to 30% over 3 years (Simpson, 2011).

Another aquacultureist/mariculturist aim is to reduce the amount of fishes used to feed the cultivated fish so there is little to no discharge. This has already been achieved

with fresh water species such as tilapia and catfish, but not yet with marine species. The amount of feeding invested per fish has already minimized because of new feeding technology. Another recent advancement includes extracting desirable omega 3 from algae's DHA. This substance can both fill carnivorous species and reduce the use of alternative protein rich feedings such as soybeans (Simpson, 2011). There are also new attempts to reduce nitrogenous discharge by modifying feedings to the species' dietary needs. Today, feedings include more fat and less protein which reduces nitrogen accretion that result from feeding discharges (CBD, 2004).

4.1.3 Development of Hatchery

Nowadays, there are growing efforts to produce eggs by hatchery. This field is receiving great attention, as it will decrease the pressure from wild fish stock and promote greater food security as the reliance on the availability of wild fish is reduced. The present technology is undergoing improvements in order to produce undisturbed eggs (FAO, n.d.b).

4.1.4 Decreased Use of Antibiotics

Unmonitored use of antibiotics in aquaculture led to concerns regarding the development of resistance among pathogenic bacteria (CBD, 2004). As a result, there is a growing effort to align international regulation in regards to the use of antibiotics in mariculture. Nowadays it is recommended that frequent inspections of the cultivated species be conducted in order to detect infections at an early stage. Some nations already began to reduce the use of antibiotics while improving the water quality and living conditions in the nets (e.g. reduced density in netpens). The public resistance to the use of antibiotics led to enhanced research on how to prevent disease outbreaks in netpens without consistently relying on antibiotics. Vaccination showed successful results among some species. For example, in salmon mariculture in Norway the use of vaccination to prevent furunculosis was discovered to be efficient and hence the overall use of antibiotics was seventy-five times less in 1995 than 1987, from 585 gr. per ton to 8 gr. per ton respectively (CBD, 2004).

4.1.5 Prevention of Damages Related to Escapees

Despite careful netpen maintenance and management, escapes can occur. Cultivating native species is one way to limit ecological damage. Cultivation of native species does not eliminate possible negative impacts, but does reduce biological pollution effects on the local population as it removes the risk of invasive, exotic cultivated species. In addition, the magnitude of cultivated escapees can be minimized if the genetic pool of the cultivated species remains rich. As a result, much attention is given in hatcheries to maintaining genetic diversity of the stocks. In addition, cultivation of sterile species can prevent genetic contamination of native populations in cases of escapes. Good management and an "escape management plan" are both useful in minimizing the impact of escapees on the natural environment.

A thorough examination was conducted in Norway, a leading mariculture nation, in order to evaluate the impact of escapees from mariculture. The Norwegian Escapees Commission was established to research escapee cases in order to prevent and better handle such incidents. The regulatory tools they use include: notifying the fishery and aquaculture commission in case of a breakout; inform both mariculturists and equipment providers; regulate the equipment being used for mariculture and the manner they are set up; ensure that the equipment being used is suitable for the local oceanic physical processes; invest in improving sea cage structures and maintenance; and lastly, provide guidelines for mariculturists in case they are confronted with a breakout. All of the above precautionary measures reduce the possibility of escapees and, in the case it does occur, allows mariculturists to follow a comprehensible guideline (Jensen et al., 2010).

4.2 Reducing the Ecological Impact of Mariculture (Organic Pollution)

In order to reduce the impact of organic enrichment in the surrounding area of the netpens, a few solutions have been generated and are already being used in some fish farms. Among those possible solutions are: polyculture of species, fallowing and rotation, and artificial reefs.

4.2.1 Polyculture

Polyculture implies that there is potentially less discharge to the environment while increasing the production of protein (CBD, 2004). Though this practice has existed in China for many years, mainly in cultivation of fresh water species, marine polyculture is fairly new. The concept is to integrate various species: “bivalves, seaweed, and marine finfish,” so the cultivation process of the species is complementary and minimizes discharges to the environment (Fig. 13)(CBD, 2000). The supplementary species consume and are nourished on the excess of plankton and feeding remains that is discharged from the netpens. As the supplementary species consume the excess of plankton, they reduce overloads in nutrients such as phosphorus and nitrogen(Wurtz, 200).

Integrated aquaculture is also economical. In fact, cultivating supplementary species was first done in order to increase production and was only later discovered to have the ability to reduce nutrient accumulation (De Silvia, 1993). Nowadays, the supplementary species are also consumed and have great economic value. For example, in Chile, the red alga *Gracilaria chilensis* is cultivated near salmon farms. Such algae may recycle both nitrogen and phosphorus at the same time being economically valuable (CBD, 2004). Another example of polyculture is salmon and the mussels *Diplodon chilensis*. The mussels were used as filter feeders and successfully removed organic enrichment (Gao et al., 2008). Lastly, mariculture of some species such as carp and mollusks that are filter feeders has minimal ecological impacts and can greatly increase food supply (Naylor, 2004).

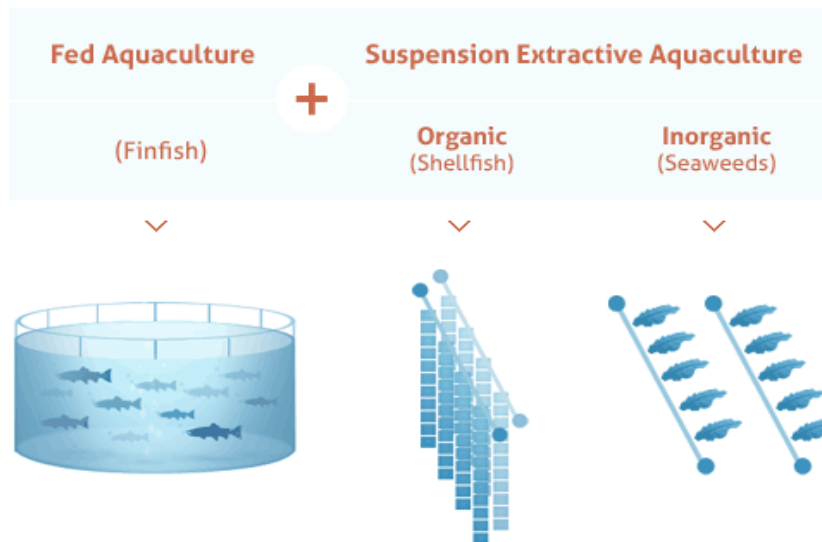


Figure 13: an example of integrated multi-trophic aquaculture (IMTA) in Canada of Salmon along shellfish and seaweeds (Chopin, 2006).

4.2.2 Fallowing and Rotation of Netpens

Another solution is fallowing and rotation of netpens. Fallowing implies that netpens are left empty for some time while rotation implies that the cultivated fish are farmed in other nearby netpens on site while the former active netpens are emptied. Such a management strategy allows the sediment below the netpens to recover and avoid extensive accumulation of waste (Edwards & Cook, 2001; Porrello et al., 2005). In Scotland the Scottish Environment Protection Agency (SEPA) decided that fallowing and rotation should be performed in any netpens that are located at sea, where the water current is not substantial enough to remove both feeding remains and faeces. Such a decision was taken after the realization that even if an ecosystem's carrying capacity examination is made and quantities of farmed fish are adjusted accordingly, some unpredicted changes might occur; for example, unexpected changes in species' biodiversity at the site as a result of the organic enrichment (Edwards & Cook, 2001). Therefore, in order to avoid organic enrichment, fallowing and rotation are required as they were found to be the best solution to avoid accumulation of discharges on the sea bottom (Carroll, Cochrane, Fieler, Velvin & White, 2003).

4.2.3 Artificial Reefs

In past years, a number of projects were conducted to examine the effectiveness of artificial reefs as underwater structures that reduce the accumulation of feeding remains below mariculture netpens. The artificial reefs were placed underneath mariculture netpens with the intention of attracting various organisms that feed off the feeding remains and excess nutrients. So far, artificial reefs have demonstrated their ability to attract various organisms and as a result have led to a reduction of organic matter (Cook et al., 2006) as well as changes in the benthos composition (Gao et al., 2008). By attracting filter feeders that process the surplus of the organic matter, the filter feeders function as a mixer between the water and the sea bottom (Gao et al., 2008). Their capability of filtering the feeding remains will greatly depend on the amount of discharges and the quantity of the filter feeders themselves (Gao et al., 2008). The diversity of the species and biomass attracted to the artificial reefs will greatly differ depending on the physical characteristic of the area, water temperature, salinity, current strength, and existing species (Cook et al., 2006). The artificial reefs not only attract smaller species, as bigger species were found near and within the reefs as well. Bigger species greatly add to the filtration process of the netpens' discharges and have the capacity to process greater amounts of feeding remains (Gao et al., 2008).

When current speeds are low, there tends to be a greater accumulation of particulate discharges near the netpens (Angel et al., 2002; Cook et al. 2006). One of the attributes of artificial reefs is that at low current speeds some filtering species are able to "capture" farm wastes more efficiently than at higher speeds (Angel et al., 2002). In addition to their ability to reduce organic accumulation, artificial reefs are fairly simple, cost effective and can be constructed from various materials. As a result, artificial reefs were suggested to be a solution, or at least a supplementary solution, for the organic enrichment as they can be used as biofiltration agents and allow the ecosystem to process greater nutrient load (Angel et al., 2002; Cook et al., 2006; Gao et al., 2008). Our hypothesis is that the artificial reefs will attract various organisms and that recruitment of species will be higher in farm site than the control site due to higher nutrient availability and food residual at the farm site.

The next section describes the methodology of this research. It begins with an overview of Iceland's topography, coastal waters (temperature, current and salinity) and climate. This will be followed by an in-depth description of the study site, the netpens, cultivated cod and the construction of the artificial reefs.

5. Methodology

5.1 Topography

Iceland is situated in the midpoint of two underwater ridges, the Mid-Atlantic Ridge and the Greenland-Scotland Ridge, and surrounded by few seas: to the west the Irminger Sea, to the north the Icelandic Sea, to the east the Norwegian Sea and to the south the Iceland Basin (Malmberg, , 2004). Iceland is well-known for its fjords and bays that circle its coastline in the southern part of the country. Most of the fjords are characterized by having steep elevations with an even sediment floor. As the fjords open up toward the bay, the water becomes deeper, ranging between 100-200 meters (Jonsson, n.d.a).

5.1.1 Water Composition

The Icelandic waters consist of three water masses: the North Atlantic Ocean to the south with an average ocean salinity of 35‰ and water temperature that ranges between 5 to 9°C, the Labrador Sea to the west with waters ranging between 3 to 4 °C and salinity nearly 35‰, and to the east the Iceland-Scotland Overflow that brings water from both the Norwegian and the Nordic Seas with a water temperature close to zero and salinity below 35‰ (Malmberg, 2004). Icelandic waters are classified as “cold water” as they remain chilly during the entire year in most parts. However, water temperatures vary in the western and southern coasts, rising from about 2 °C during the winter and can reach beyond 10 °C during summer time (Ingólfsson, 2008).

5.1.2 Water Temperature

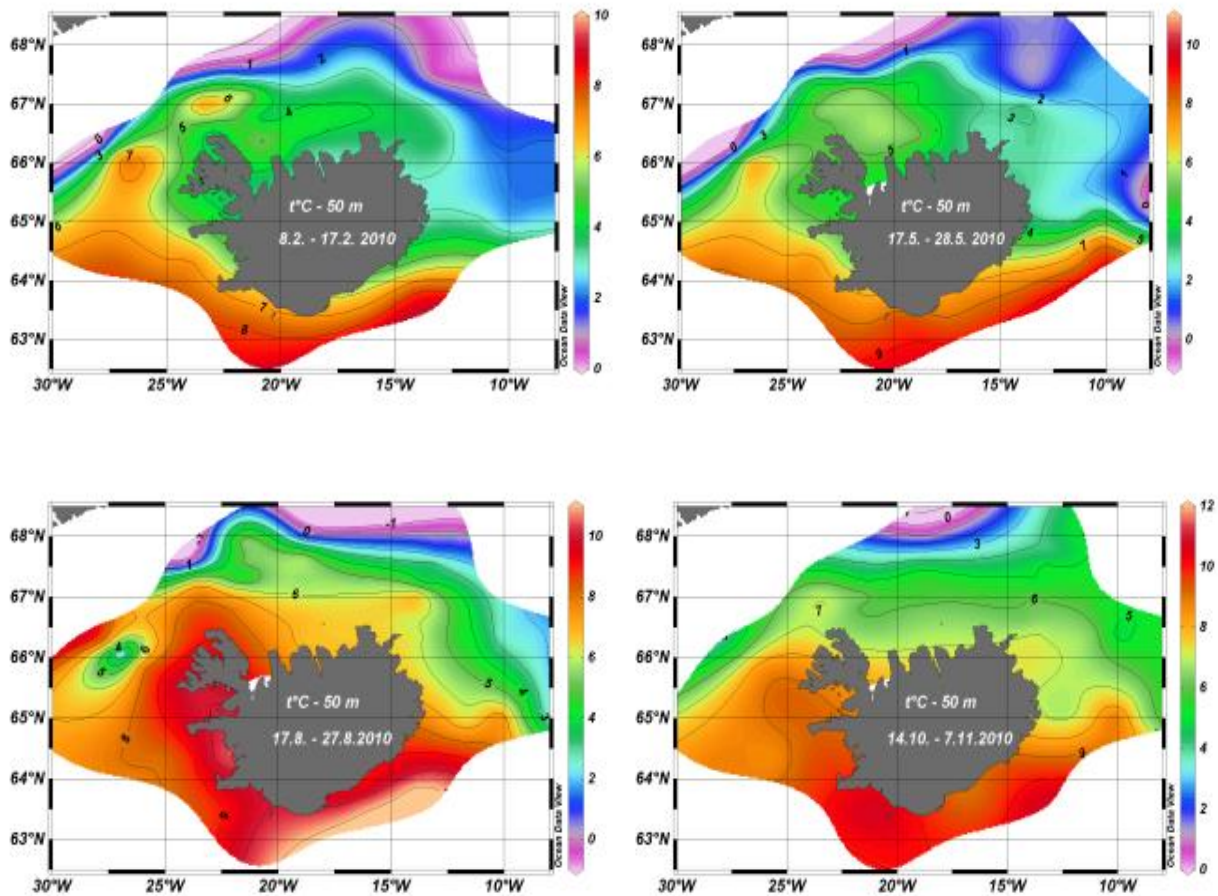


Figure 14: water temperature variation throughout the year at 50 meters depth going clockwise from the upper left side: February 2010, May 2010, August 2010 and October/November 2010 (Hafro-The Icelandic Marine Institute, 2010).

5.1.3 Water Circulation

Iceland water circulation is affected by three main currents: The North Atlantic Drift, the Irminger Current and the East Greenland Current (Jonsson, n.d.a).

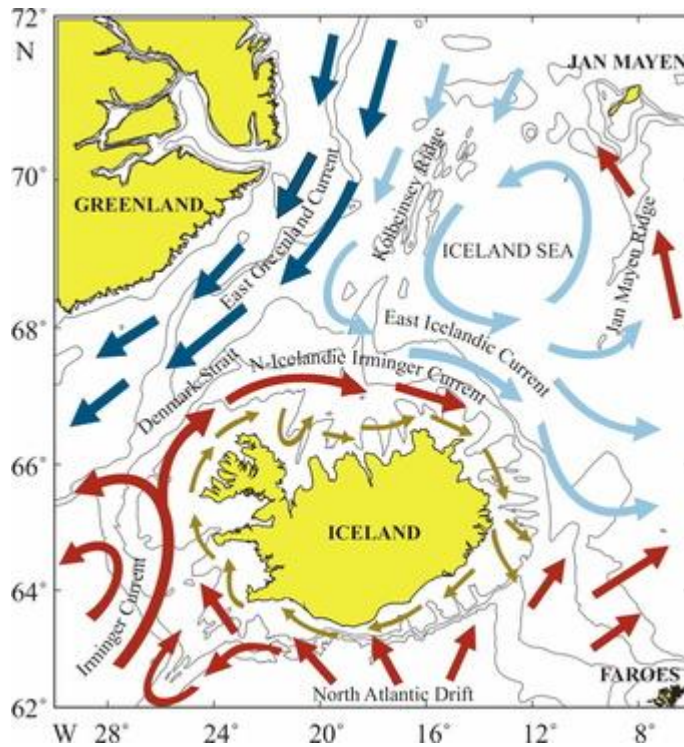


Figure 15: The currents affecting the Icelandic water (Jonsson, n.d.a)

The North Atlantic Drift approaches the Icelandic coast and then diverges, moving east and west (Fig. 15). The western flow continues all the way to the north-western part of Iceland and then splits again: east to the Iceland-Faroe Ridge and west, which is the Irminger Current. The north-western current is the East Greenland Current, only a small amount of this water mass reaches the Icelandic Sea. The East Icelandic current approaches the coast from the North Icelandic Sea and heads from north to east along the north-eastern part of Iceland. The Icelandic currents are more powerful at depth, as a result of water accumulation in the Faro Ridge and the Denmark Strait. As the water flow fills up the ridge, a great pressure builds up, which ends up spilling over the Greenland-Scotland Ridge toward the North Atlantic (Jonsson, n.d.a).

5.1.4 Salinity

Salinity level is influenced by mainly two water sources: The part of the Atlantic Ocean that reaches Iceland and the polar waters of the North Atlantic Drift. The Atlantic water has a fairly constant salinity of 35.2‰ while the Polar water salinity is lower with an average of 34.5‰ (Jonsson, n.d.b). Salinity is lowest near the coastline during spring and summer as ice in the mountains melts and fresh water flows directly to the sea (Fig. 16).

Most of these low salinity waters move from the western fjords along the Irminger current and are dispersed around Iceland (Jonsson, n.d.a) As a result, the water circulation in westerns fjord is counter clockwise. Looking from outside the western fjords toward land, the inflow of water is coming from the right side (west) and is circulating to the left side (east) where the water outflow circulates back to the open ocean, creating a horizontal circulation (Fig. 17)(Jonsson, 2010).

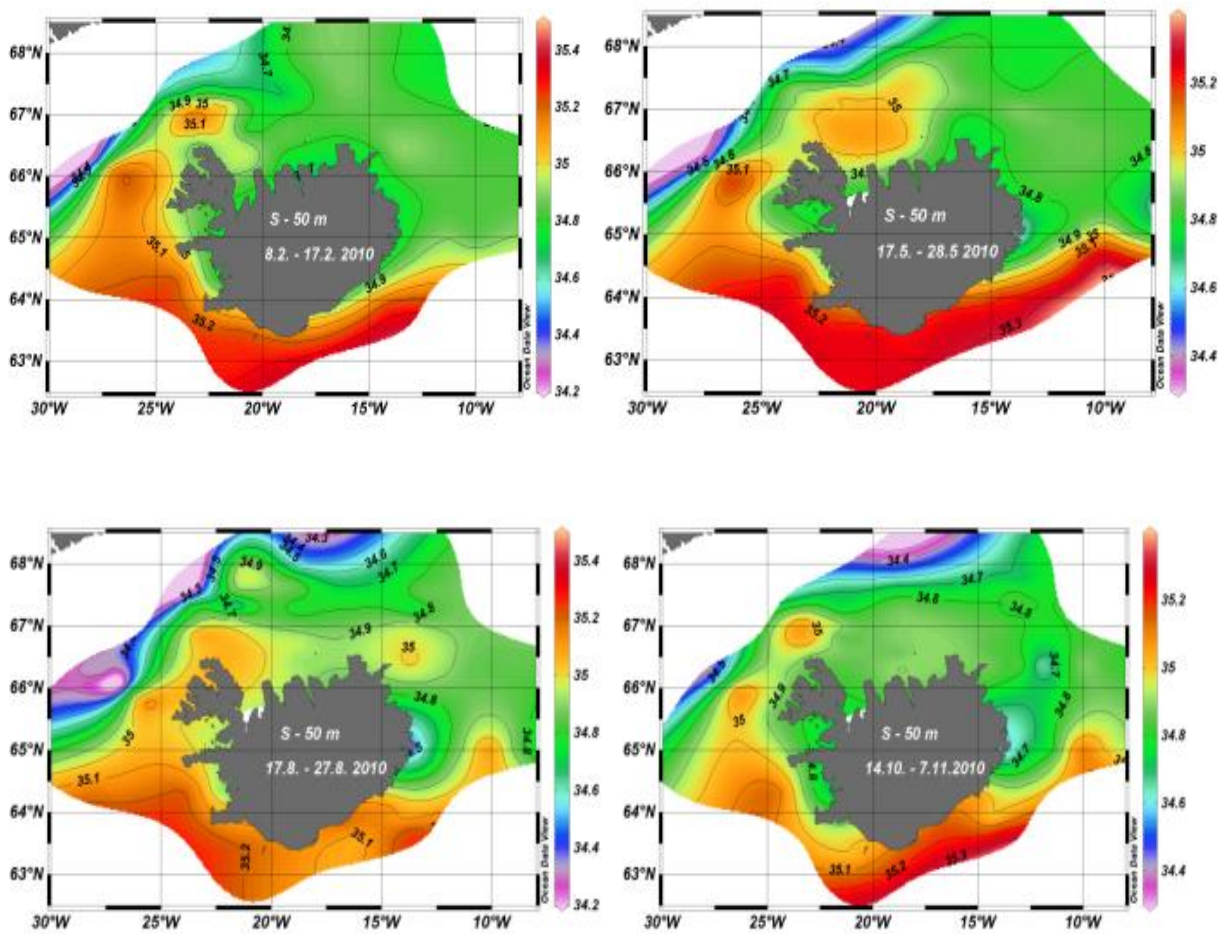
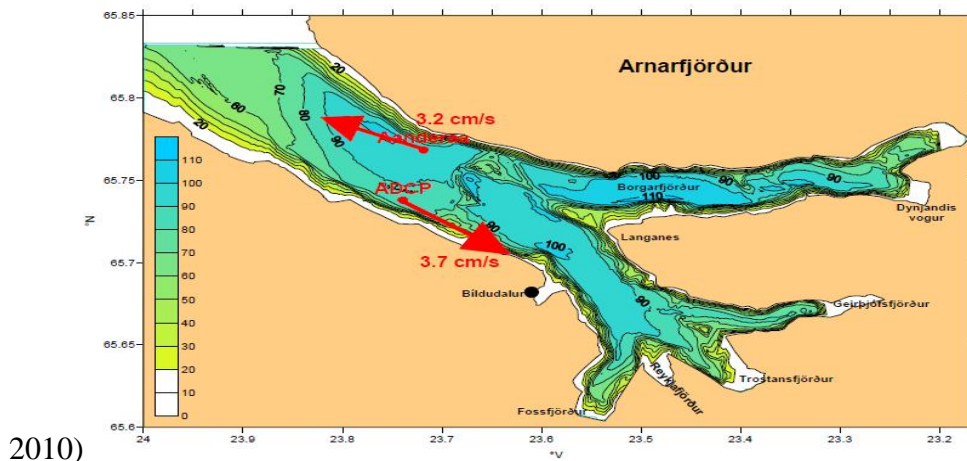


Figure 16: Salinity variation throughout the year going clockwise: February 2010, May 2010, August

2010 and October/November 2010 (The Icelandic Marine Institute -Hafro,



2010)

Figure 17: The common current direction of Icelandic fjords: Arnarfjordur (Jonsson, 2010).

5.1.5 Climate

The Icelandic climate is fairly mild and is influenced by the cold Arctic wind as well as the temperate Gulf Stream flows. The interaction between these two different factors results in recurrent changes in the weather. The temperature variation between summer and winter does not differ greatly, the difference is about 8 to 10 C°(Fig. 18)(Vedur- Icelandic Metrologic Office, n.d.).

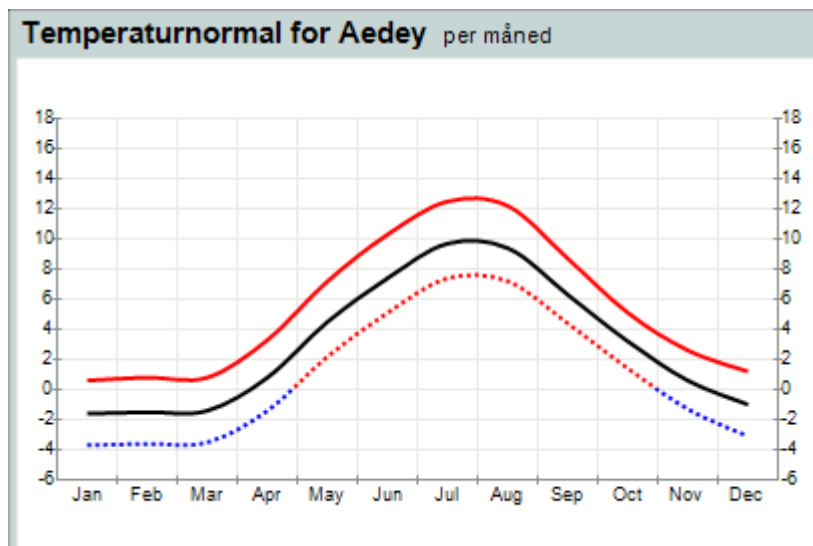


Figure 18: Average monthly temperatures - measured from 1961-1990. Red - maximum averaged temperature; black – minimum averaged temperatures (Yr - Metrologic Institute of Norway, n.d.)

5.1.6 Light Availability

Light has a great impact on marine productivity and Iceland is known for its drastic changes in light availability over the course of the year. There are between 18-24 hours of light during the summer and only 3-6 hours in winter. However, even during the summer the sky is often covered by clouds and temperatures do not exceed an average of 8-13 degrees (Einarsson, 1984).

Table 5: Light availability throughout the year in Ísafjörður (travelnet.is, n.d.)

Daylight (Sunrise/Sunset)				
	Reykjavík		Ísafjörður	
Month	Sunrise	Sunset	Sunrise	Sunset
Jan	11:19 am	03:44 pm	12:01 pm	03:11 pm
Feb	10:09am	05:14 pm	10:15 am	05:19 pm
Mar	08:37 am	06:45 pm	08:31 am	06:59 pm
Apr	06:47 am	08:18 pm	06:43 am	08:31 pm
May	05:01 am	9:51 pm	04:26 am	10:35 pm
June	03:24 am	11:29 pm	Daylight 24 hours a day	
July	03:04 am	11:57 pm	02:34 am	10:40 pm
Aug	4:32 am	10:33 pm	4:34 am	10:40 pm
Sept	06:08 am	8:45 pm	6:12 am	8:50 pm
Oct	7:35 am	6:59 pm	7:41 am	7:02 pm

Nov	9:09 am	5:13 pm	9:41 am	4:50 pm
Dec	10:44 am	3:49 pm	11:25	3:18 pm

5.2 Site Description

5.2.1 Skutulsfjörður

Skutulsfjörður is located in the Northern part of the Westfjords, Iceland; N: 66° 06' 00" and W: 23° 06' 00". It is a narrow fjord surrounded by Rocky Mountains that reach an elevation of 700 meters. The fjord is part of a group of glacier-origin fjords. Fresh water runs from the surrounding mountains to the fjord and forms gullies that spill into the fjords (Meidinger, 2011). Skutulsfjörður is 8.29 km long and 1.8 km wide. The fjord splits into two parts as it reaches land: a shoreline, which is the town of Isafjordur, and an inner fjord which leads to Isafjordur's harbor. The outer part of Skutulsfjörður is connected to Ísafjardardjup (Fig. 19), a bay that connects several fjords (Gharibi, 2011).



Figure 19: Ísafjardardjup and Skutulsfjörður (marked as Ísafjordur) (Google map, 2012).

Skutulsfjörður is a shallow fjord with a maximum depth of 25 meters. As the fjord opens up to Ísafjardardjup, the water becomes deeper. The water current moves counter clockwise (Jonsson, 2010). The water flow enters from Ísafjardardjup and flows toward the ending point of the fjord. Looking from Ísafjardardjup to sea, the current is moving from

the right hand side and as it reaches the ending point of the fjords it flows out on the left hand side back to Ísafjardardjup (Jonsson, 2010).

5.2.2 Fish Farm and Netpens that were Studied

The fish farm *Álfsfell* began its activities in 2002. Production has increased slowly and reached 118,245 kg in 2010. In 2009, production was 95,657 and the estimated production for 2011 is 105,000kg. *Álfsfell*'s netpens are made from polyester pipes and a nylon matter net (Egersund net A/S Norway). The cage's net is 12 meters deep. The circumference is 60 meters and the total size is 3,400 m³.

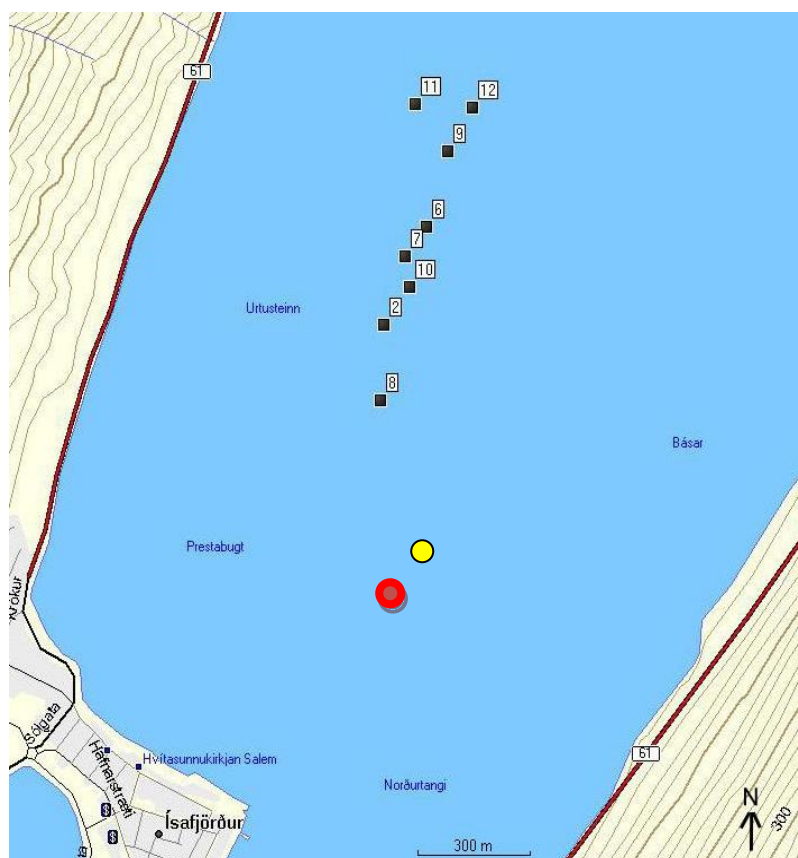


Figure 20: Location of study sites: ARF, cage number 6, marked in yellow, and ARC, near cage number 7, marked in red (Kjartansson, 2011).

5.3 The Cultivated Cod

The cod in cage number six were captured between August 15th and September 15th (mean: August 31st) 2010 in Aðalvík, a northern fjord in the Westfjords. A total of 19,693 cod were captured using a pure seine net. After the cod were caught, they were placed in a special cage off shore for two to four weeks before being transferred to their netpens in Skutulsfjörður. The cods were placed in the sits' netpens on the 15th of September 2010.

When the cod were in the netpen they were only fed with frozen herrings captured by Síldarvinnslan, an east coast fishing company. The frozen herring takes about six to eight hours to melt. The cods are fed twice a week throughout the winter and three times a week throughout the summer. During spawning season, which takes place between April until May, feeding is reduced to approximately 25%. Such reduction is made in order to minimize stress, and/or infections (which could lead to death) in the fish during that period. After spawning season, the quantity of feedings is increased again for the rest of the feeding months, which is in most cases until September.

Table 6: amount of feeding per month (Kjartansson, personal communication, August 2 2011)

Month	Amount of frozen herring in kg.
September	12,600kg
October	13,800kg
November	15,160kg
December	8,000kg
January	5,100kg
February	6,400kg
March	9,600kg

April	6,400 kg
May	3,620 kg
June	18,040 kg
July	12,000kg
August	5,390kg
September	12,000 kg
October	14,000 kg

The cods' weight was about 1.7 kg when captured in Aðalvík and their desired market weight was 3.2 kg (Kjartansson, personal communication, October 1, 2011).

5.4 Construction of the Reefs

Two artificial reefs were constructed for this research. The collected material included: plastic nets (PVC); pipes made from standard steel LSI 316 and Iron coated with sink; and four 12 meter-long sticks made of typical steel 37 mixed with iron and cable ties. The plastic nets were 125cm in length. The metal pipes' diameter was 25 cm and they were cut into 3 cm rings. The 3cm pipes, the plastic nets and the cable ties were used to construct the tubes. To construct one tube, four metal rings were looped over with the plastic nets and fastened with cable ties.



Picture 1: PVC net



Picture 2 & 3: Plastic net rolled over the metal ring and held by cable ties in order to construct the tubes.

The reefs were shaped as triangular pyramids by constructing tubes and placing them one on top of the other in diminishing sequence, with five tubes forming the base. Each reef was made out of fifteen tubes. In order to hold the structure together, a frame was shaped with two of the 12 meter steel lines. The lines were smelted and bent into a three dimensional triangle shape (Picture 4). Fifteen tubes were placed within the frame and attached with cable ties (Pictures 5, 6).



Picture 4: Steel frame.



Pictures 5 & 6: The tubes are placed on top of each other, creating a pyramid shape and placed within the steel frame.

Sixty-six plates (18 cm/16 cm) were cut from the same material as the reefs' tubes. These plates were removed during each sampling dive to measure growth of organisms. The plates' surface was 288cm^2 on one side with a total surface area of 456cm^2 , or 0.0456m^2 , calculating both sides. All plates were measured, weighed and tagged; 33 plates were attached to each reef with cable ties. The distribution of the plates on the reef was made to obtain the most accurate representation of growth. During each sampling dive, four plates from both sides were removed, as well as from the lower and upper parts

Table 7: Distribution of plates on the reefs.

Side A:

1A	3A	4A	7A
5A	2A	8A	6A
3A	1C	7C	4C
6C	5C	2C	8C
X*			

Side B:

2B	5B	6B	8B
7B	4B	1B	3B
8D	4D	5D	2D
7D	6D	3D	1D
X*			



Pictures 7 & 8: Cut plates from plastic nets and tagged plates.

In order to secure the reefs in place after their deployment, an old anchor chain was cut into eight kg pieces and attached with ropes to the base of each corner of the reefs. In order to moor the reefs, 30 cm steel hooks were attached manually to the frame and inserted into the seafloor upon deployment. Those hooks were eventually used only in the ARF, as the seafloor at the ARC site was too rocky and it was impossible to push the hooks into the sea floor manually.



Picture 9: Steel hooks and anchor chain attached to the reef's corner.

6. Methods

6.1 Deployment of Artificial Reefs and Sampling Program

Two locations were used for the research: a study site and a control site. The study site was below active fish farm, cage number six, which will be referred to as Artificial Reef Farm (ARF.) It is located at N 66°05.220 W 23°06.025 with sea floor depth of 23 meters. The control site will be referred to as Artificial Reef Control (ARC) and is located near empty cage number seven. It is 240 meters southeast to ARF and is N 66°05.127 W 23°06.083 with sea floor depth of eighteen. Both reefs were deployed on the 11th of May, 2011. ARF was tied with a rope to the netpen and ARC was marked with a buoy. Although the two sites were a short distance from each other (240 meters apart), the sea bottom features differed greatly, as a result of the fish farm activity. The ARF's sea bottom was muddy, soft and had some dispersed vegetation. The ARC's sea bottom was rocky and covered with marine vegetation.

Both reefs were deployed on May 11th, 2011. Every two weeks a sampling dive was conducted.

Table 8: Date of sampling dives.

Dive	Deployment	1	2	3	4	5	6	7	8
Date	11/5/2011	25/5	8/6	24/6	13/7	26/7	7/8	21/8	5/9/

For every sampling dive, wild stock assessment was conducted by the divers to assess attraction of bigger fauna to the artificial reefs. So as not to scare the fish off, one diver descended earlier than his partner and counted the number of large fauna within and near the reefs. The zone where large fauna (mainly fishes) were counted was about half a meter to one meter from the reef and within the reef's tubes.

6.2 Processing of Samples

In order to assess the benthic sessile and motile invertebrates, four plates were removed from each reef every sampling dive. Each plate that was removed was placed directly in a sealed box. After collecting the plates, the boat headed to the harbour and the plates were transferred to the Natturustofa Vestfjarda (West fjords Natural History Institute) for laboratory analysis of motile and sessile organisms. The water from the sampling boxes was passed through a 125 mm sieve. The filtered content was transferred to plastic petri plates for microscope analysis that included identification and enumeration of the motile organisms. In order to assess the total sessile species' areal cover a metal grid (mesh; Fig 35) was used. The metal net was placed on top of the plate and the number of covered squares counted for each sessile organisms.



Picture 10: Metal grid used to calculate cover.

Following the calculation of plate areal coverage, the plate's tag was removed and the plate was photographed and weighed for wet weight. Then the plate was taken for a microscope analysis, where the sessile species were identified and quantified. The remaining organisms on the plate were removed gently with a brush and added to the motile species total count. Finally, the organisms were transferred to containers and were placed in a freezer for the dry and ash biomass analysis. The biomass of both sessile and

motile species from all the plates were calculated together resulting in one measurement of weight for a reef per dive.

The samples were transferred to an oven in order to measure dry biomass and were dried at 65 °C for eighteen hours. Following, the samples were weighed and then returned to the oven for six more hours at 250 °C in order to estimate the organic matter content, calculated as the % weight loss between the drying and burning at 250 °C.

6.3 Processing of Results

After faunal data were processed, these were converted to abundances of species on the reefs on a per m² basis. This was achieved by dividing the abundances of individuals on the plates by the mean plate surface area (456 cm² (both sides) = 0.0456m²) to calculate abundances per m². In addition to measuring abundances of individuals per m², the surface coverage of sessile species was determined by placing a metal net over each plate and recording the number of "covered" cells/plate and subsequently converting this to cover per m².

In order to examine the recruitment of dominant species individually in ARF and ARC over time, the total number of individuals of each species in each site was calculated. This was done by adding their numbers from the four sampling plates collectively. The number of individuals of each species was then plotted over time. Average, standard deviation of the number of individuals of each species at each sampling time, and coefficient of variation (CV) of the number of individuals of each species and time were all calculated and tabulated. Each graph presents the overall growth of the dominant species from all plates. The table below each graph elucidates the graph and charts the growth on each plate, the average, standard deviation, and Coefficient of Variation (CV) . The CV represents the ratio of the standard deviation to the mean.

Repeated Measures of ANOVA was performed when assessing the changes in the total abundance of organisms between plates, between sites and over time. This analysis was performed for the dominant species, with the exception of Hydrozoa, which appeared only at the reference (ARC) site, and of *Phyllodoce maculata* and *Mytilus edulis* as the data for these two species could not be analyzed by this statistical test. Repeated Measures ANOVA was performed using the statistical package R.

Finally, the recruitment data for the remaining (less abundant) species were tabulated separately for reference.

7. Results

7.1 Presence of Wild Fish on the Artificial Reefs

Though the artificial reefs were located 240 meters apart from each other, there was a great difference in visibility at the two sites. Visibility at the ARF was generally reduced, at times only about one meter, while the visibility at the ARC was on average about five meters. As a result of limited visibility at the ARF site, divers reported difficulty in accurately counting the number of fishes that were swimming around and within the reef as well as trouble in identifying other smaller fishes that might have inhabited the reef. Regardless of the differences in visibility, wild fishes were only observed by the divers below the ARF. The only species that was observed and counted throughout the eight sampling dives was cod (*Gadus morhua*), and these were mostly juveniles. During the last sampling dive, when the ARC was pulled out of the water, several lumpsucker (*Cyclopterus lumpus*) juveniles were brought up with the reef.

7.2 Overall Species Richness

Throughout the course of the project the species richness at ARF was greater than at the ARC (Fig 21, Table 9 and Table 27 from Appx). The following graph presents the number of species found on each reef during each sampling dive.

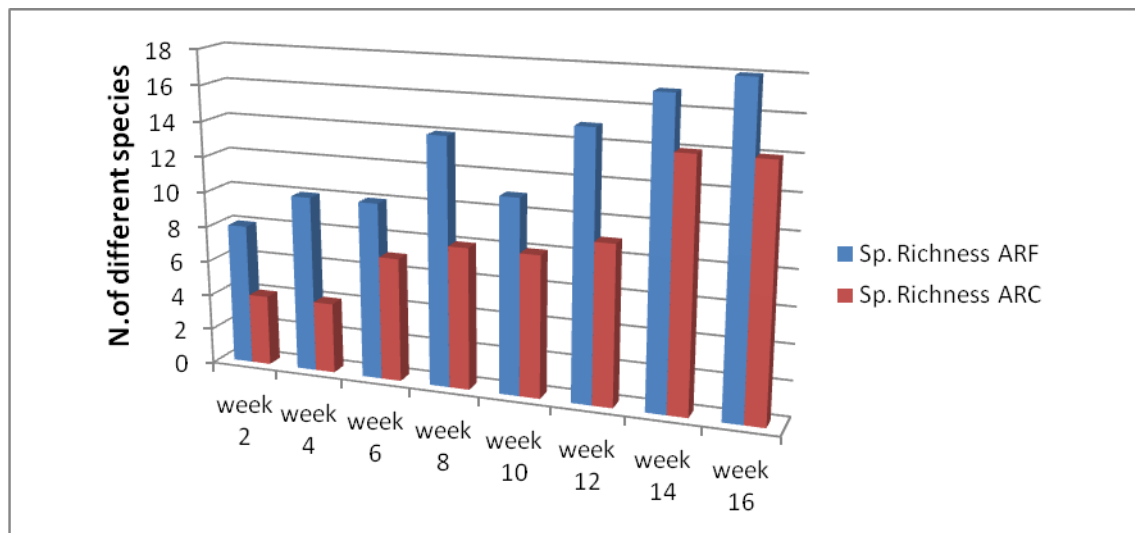


Figure 21: Total numbers of species by weeks.

Table 9: Mean abundances, standard deviation and CV (STDEV/AVERAGE) of total number of species.

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	3.500	4.750	7.000	8.000	8.500	9.750	10.500	11.000
STDEV	0.577	0.957	0.816	1.414	1.915	1.708	2.082	2.944
CV	0.165	0.202	0.117	0.177	0.225	0.175	0.198	0.268
ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	2.500	3.500	5.250	6.000	5.000	6.000	9.500	10.750
STDEV	1.291	1.000	2.062	2.000	1.414	2.828	2.082	1.708
CV	0.516	0.286	0.393	0.333	0.283	0.471	0.219	0.159

Results from Repeated Measures ANOVA indicate that there is no interaction between reefs and time for species richness ($P = .937$) and change in species richness over time exhibited similar variance at the 2 reefs (Table 10). However, there was a significant difference ($P < 0.05$) in the temporal change in species richness at the 2 reefs; ARF has higher species richness than ARC (table 10& Fig.21).

Table 10: repeated measures ANOVA for total number of species

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Time	1	381.44	381.44	218.2134	6.05e-06
Site*time	1	0.01	0.01	0.0068	0.937
Error	6	10.49	1.75		
Site	1	52.562	52.562	11.416	0.04313
Error	3	13.813	4.604		

In addition to the difference in species richness, the overall abundances of organisms associated with the ARF were higher than the abundances at the ARC (Fig 22, Table 11 and 28 Appx). It is noteworthy that this does not include one species of Hydrozoa *Obelia longissima*, which will be discussed below. The following graph presents the mean number of individuals (abundance) per m² for each reef.

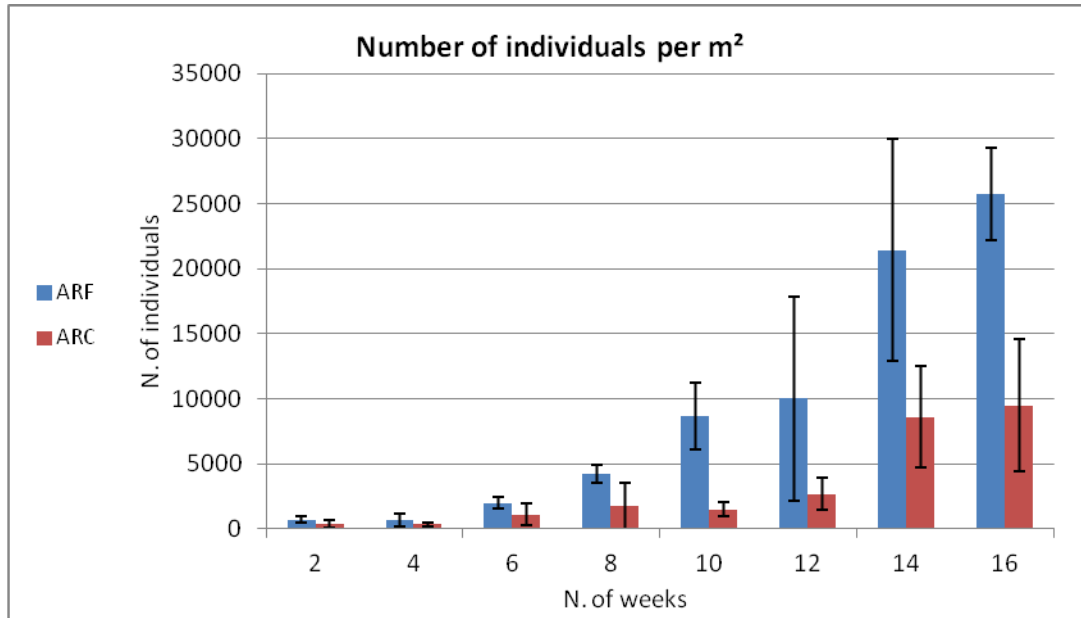


Figure 22: Mean abundances (+/- standard deviation) of organisms per m² on settling plates.

Table 11: Mean abundances, standard deviation and CV (STDEV/AVERAGE) of organisms per m² on settling plates.

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	706.9	663.1	2016.6	4274.4	8696.8	10028.4	21437.8	25750.5
STDEV	247.6	505.4	414.0	675.1	2547.8	7813.9	8517.7	3545.8
CV	0.4	0.8	0.2	0.2	0.3	0.8	0.4	0.1
ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	383.6	361.7	1117.9	1770.0	1523.4	2701.6	8625.5	9518.8
STDEV	332.2	119.4	815.3	1743.7	520.4	1228.0	3909.9	5084.0
CV	0.9	0.3	0.7	1.0	0.3	0.5	0.5	0.5

Results from Repeated Measures ANOVA indicate that the temporal variances in the total abundances of organisms on plates from ARC and ARF were not significantly different ($p = 0.3643$, Table 12). However, the abundances of organisms on the two reefs

(ARF and ARC) throughout the research period were significantly different ($p < 0.05$), Table 12).

Table 12: repeated measures ANOVA of total number of organisms

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Site	1	62.01562500	62.01562500	16.29	0.0274
Plate	3	17.67187500	5.89062500	1.55	0.3643
Error	3	11.42187500	3.80729167		

7.3 Benthic Invertebrates

Benthic invertebrates were present on the reef surfaces as early as week two, the first sampling dive after the reefs' deployment. The invertebrates were divided into two groups: sessile invertebrates (attached to the reefs/plates) and unattached invertebrates (motile species). The dominant groups of sessile invertebrates were: Bryozoa *Lichenoporidae*, Crustacea *Semibalanus balanoides*, Polychaeta *Spirorbis*, Bivalvia *Mytilus edulis* and Hydrozoa *Obelia longissima*, which colonized only the ARC. The dominant groups of motile invertebrates were *Corphium bonelli*, polychaeta (*Phyllodoce maculata* and *Harmothoe imbricata* were the most dominant) and the gastropod *Margarites spp.* Other invertebrates like *Hyas arnaeus*, *Lacuna vincta* and *Pandalus borealis* were not very abundant but their presence had an important effect on species dynamics.

Patellogastropoda and *Pagurus bernhardus* were observed on the reefs only in the last dive.

7.4 Sessile Species

7.4.1 Sessile Species Coverage

There was a significant difference in growth of sessile species on the plates between the two reefs (Fig. 23). There was a disparity in both the time the sessile species appeared on each reef and in their growth rate (Table 29 Appx). ARF had a more extensive coverage of sessile species, but had no Hydrozoa or algae. The community associated with ARC included sessile invertebrates among them extensive Hydrozoa *Obelia longissima* growth and slight algal growth recorded only in the first eight weeks: *Polysiphonia lanosa*, *Chordaria flagelliformis*, *Dictyosiphon foeniculaceus* and *Ceramium rubrum*. Sessile

species cover, which includes the above mentioned Bryozoa, Crustacea, Polychaeta and Bivalvia, was evident from week six in ARF and from week ten in ARC. The increase of sessile species growth was particularly evident in ARF, which by week sixteen had tripled the cover observed during the previous sampling dive. There was a constant growth of sessile species in ARC, though slower than the growth in ARF. At both sites, sessile invertebrates settled on both sides of the plates. However, there was a greater settlement (apart from the Hydrozoa) on the inner part of the plates that was attached to the reef.

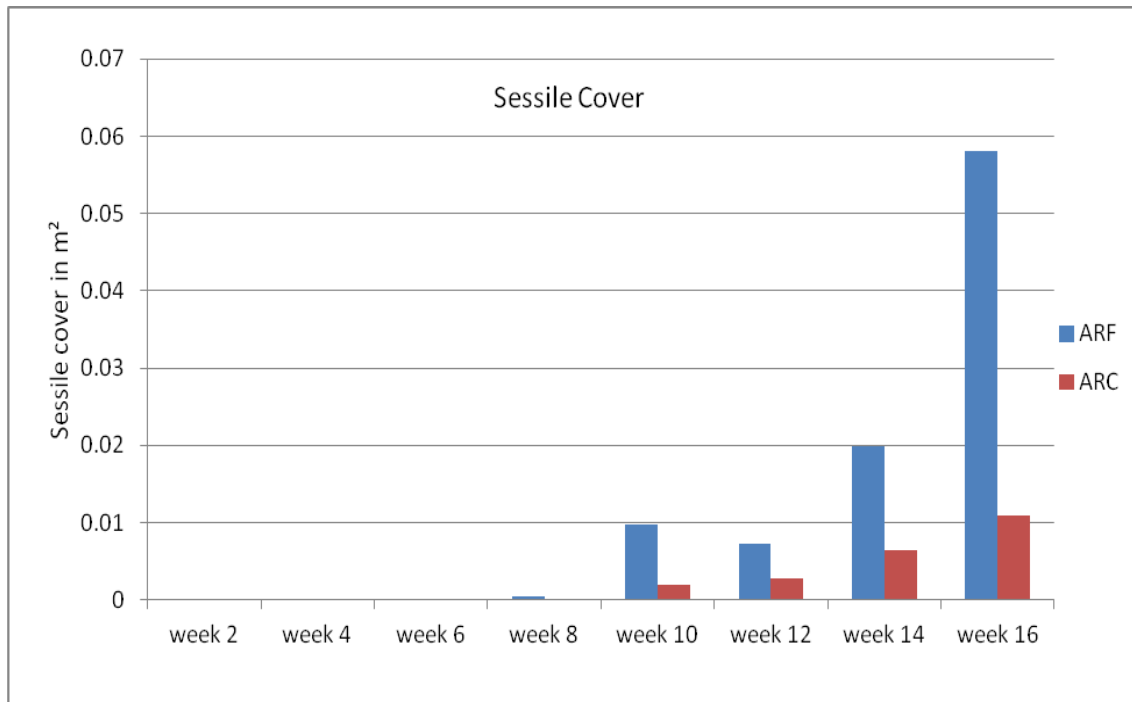


Figure 23: Temporal development of the fouling community (sessile species cover) on both of the reefs.

Table 13: Mean abundances, standard deviation, CV (STDEV/AVERAGE) of sessile species cover per plate in m² over the 16 week period

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	0	0	0	0.000025	0.00045	0.000313	0.000913	0.002663
STDEV	0	0	0	2.04	0.0004021	0.000111	0.000312	0.001247
CV				0.816497	0.893507	0.354777	0.341826	0.46845
ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	0	0	0	0	0.0000875	0.000125	0.000338	0.0005
STDEV	0	0	0	0	0.00010	0.00013	0.00009	0.0009
CV	0				1.17803	1.058301	0.28044	0.182574

Results from Repeated Measures ANOVA indicate that there is a significant interaction between sessile cover in the two reefs and time ($P < 0.05$). In Figure 23 we see that rate of recruitment of sessile species in ARF is higher than ARC.

Table 14: repeated measures ANOVA of sessile cover per plate in m^2

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Time	1	1.0865e-05	1.0865e-05	35.844	0.0009756
Site*time	1	4.2570e-06	4.2570e-06	14.044	0.0095372
Error	6	1.8187e-06	3.0310e-07		

7.4.2 Sessile Invertebrates

The first member of the sessile species community that appeared on the reef surfaces at ARF (within two weeks of reef deployment) was the barnacle, *Semibalanus balanoides* (Fig. 24). Although it appeared early on, its abundance on ARF did not increase until week eight, whereafter it grew and spread rapidly until week sixteen (Table 15&30 Appx). In addition to rapid growth in abundance, *S. balanoides* also grew in size from 1 to 5 mm within the sixteen weeks. On the ARC, *S. balanoides* appeared only around week fourteen in rather low numbers.

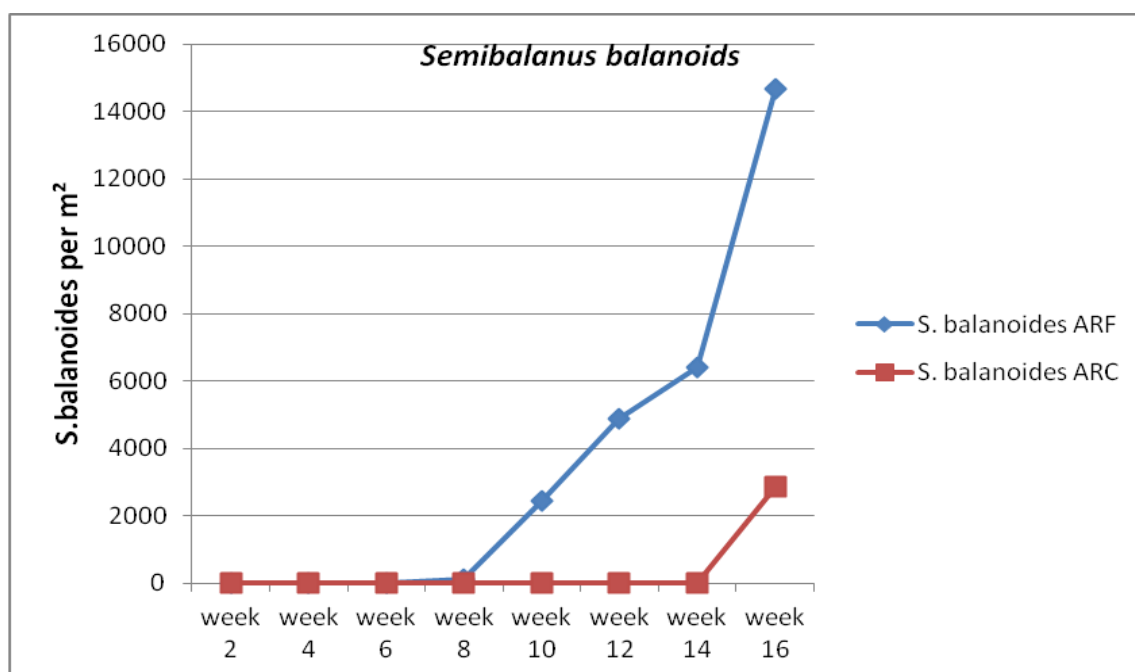


Figure 24: Abundances of *Semibalanus balanoides* (per m^2) on the reefs

Table15 : Mean abundance, standard deviation, CV (STDEV/AVERAGE) of *Semibalanus balanoides* (per m²) on the reefs.

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	0	0	10.96	109.6	2449.56	4882.68	6406.12	14659
STDEV	0	0	21.92	219.2	1910.22	3682.1	4475.13	7268.04
CV			2	2	0.77982	0.75411	0.69857	0.49581
ARC								
AVERAGE	0	0	0	0	0	0	0	2860.56
STDEV	0	0	0	0	0	0	0	3159.65
CV								1.10456

Repeated Measures ANOVA indicate that there is a significant interaction between site and time for *S. balanoides* ($P < 0.05$). In Figure 24 we see that rate of recruitment of *S. balanoides* in ARF is higher than ARC.

Table 16: repeated measures ANOVA of *Semibalanus balanoides*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Time	1	350646792	350646792	15.9783	0.007141
Site*time	3	206094381	350646792	1.55	0.022096
Error	6	131671009	21945168		

Bryozoa occurred at both sites after week eight (Fig. 25, table 17& 31 Appx). The Bryozoa showed constant growth, both in size (from 1 – 5mm diameter) and abundance on both reefs, with a greater number of individuals on the ARF.

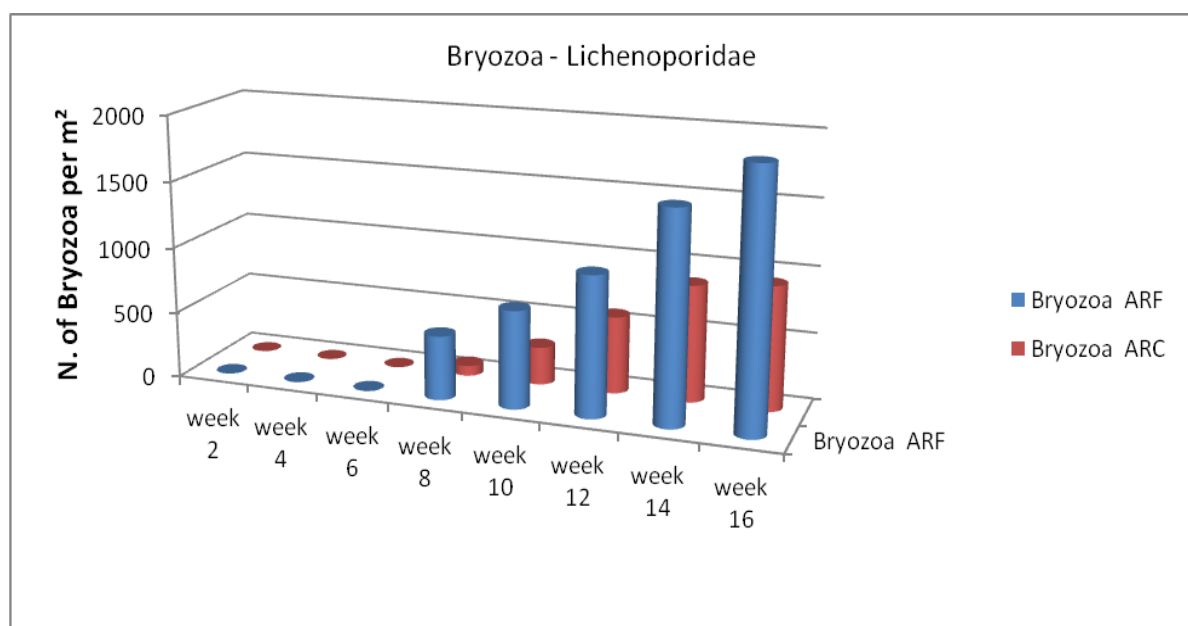


Figure 25: Abundances of Bryozoa per m² on the reefs

Table 17: Mean abundances, standard deviation, CV (STDEV/AVERAGE) of Bryozoa per m² on the reefs.

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
STDEV	0	0	0	94.7052	145.951	329.287	529.116	93.6423
AVERAGE	0	0	0	482.24	734.32	1216.56	1578.24	1923.48
CV				0.19639	0.19876	0.27067	0.33526	0.04868
ARC								
STDEV	0	0	0	65.76	152.917	460.668	344.267	632.396
AVERAGE	0	0	0	76.72	284.96	580.88	876.8	931.6
CV				0.85714	0.53663	0.79305	0.39264	0.67883

Repeated Measures ANOVA indicate that there is a significant interaction between site and time for bryozoa ($P < 0.05$). In Figure 25 we see that the rate of recruitment of bryozoa in ARF is higher than in ARC.

Table 18: repeated measures ANOVA of bryozoa

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Time	1	17293229	17293229	90.7966	7.622e-05
Site*time	1	1830842	1830842	9.6127	0.02110
Error	6	1142768	190461		

The polychaete *Spirorbis* sp. was observed on both reefs after week six (Fig. 26, Table 17 & 32 Appx) and its population grew constantly over the course of this study, with a larger population at ARF. The diameter of *Spirorbis* sp. ranged between 1-2 mm.

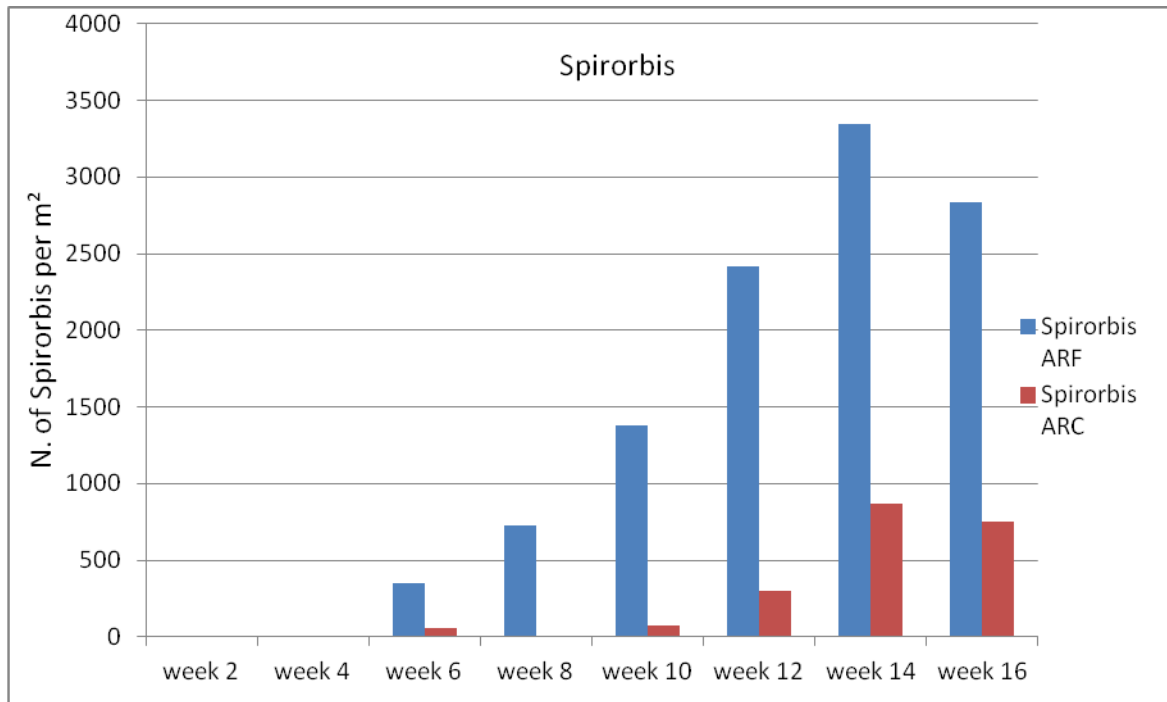


Figure 26: Abundances of *Spirorbis* sp. per m² on the reefs.

Table 19: Mean abundances, standard deviation, CV (STDEV/AVERAGE) of *Spirorbis* spp. per m² on the reefs.

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	0	0	405.52	723.36	1320.68	2416.68	3342.8	3386.64
STDEV	0	0	344.5	241.452	973.139	1519.12	1080.47	1035.82
CV			0.84953	0.33379	0.73685	0.6286	0.32322	0.30586
ARC								
AVERAGE	0	0	60.28	0	71.24	263.04	865.84	504.16
STDEV	0	0	45.1892	0	93.6423	414.746	817.335	497.605
CV			0.74966		1.31446	1.57674	0.94398	0.987

Repeated Measures ANOVA indicates that there is a significant interaction between site and time for the polychaete ($P < 0.05$) and that its rate of recruitment in ARF was higher than in ARC (Fig. 26).

Table 20: repeated measures ANOVA for *Spirorbis* sp.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Time	1	35116950	35116950	41.948	0.0006434
Site*time	1	16506719	16506719	19.718	0.0043736
Error	6	5022873	837145		

The mussel *Mytilus edulis* was present on the reefs in relatively low numbers throughout the study, increasing considerably only toward the end (Fig 27, table 21 & 33 Appx). However, the size of *M. edulis* increased substantially, from 1-2 mm in the first weeks to 1.5 cm by week sixteen. This great increase in size was a considerable addition to the total sessile cover and biomass.

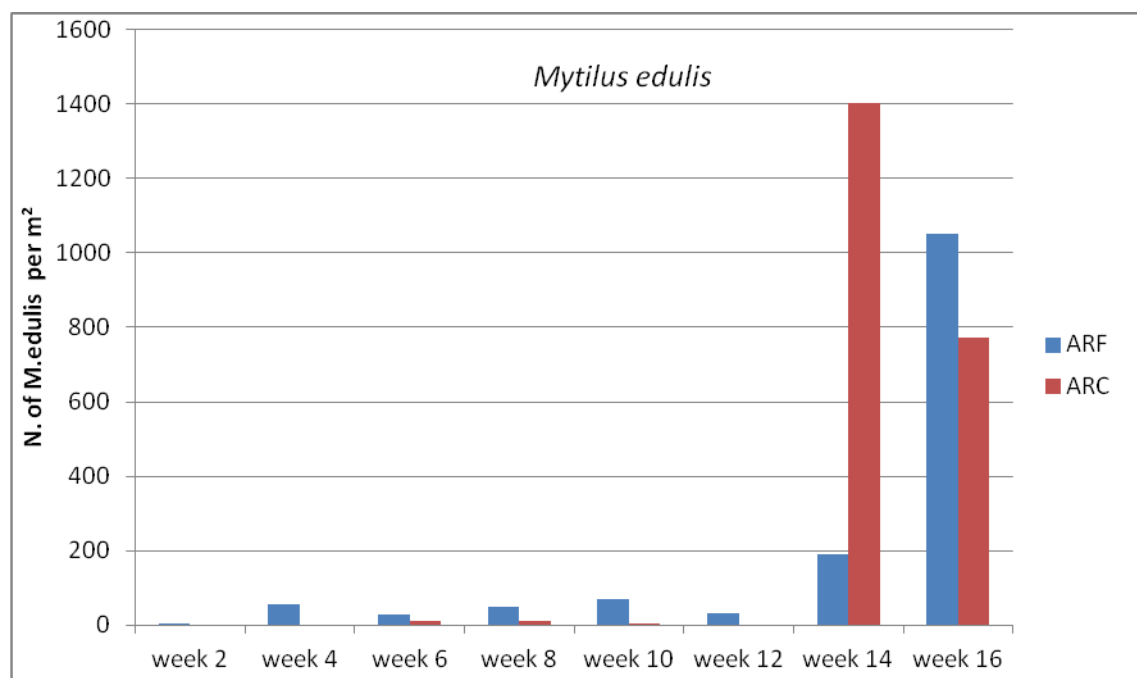


Figure 27: Abundances of *Mytilus edulis* on the reefs, individuals per m².

Table 21: Mean abundances, standard deviation, CV (STDEV/AVERAGE) of *Mytilus edulis* per m².

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	5.48	32.88	27.4	49.32	71.24	71.24	191.8	734.32
STDEV	10.96	37.9665	27.5820	41.49389	57.64863	54.8	147.9938	500.01309
CV	2	1.1547	1.00664	0.841320	0.809217	0.769231	0.7716	0.680920
ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	0	0	10.96	10.96	5.48	0	1676.88	789.12
STDEV	0	0	21.92	12.655518	10.96	0	2553.688	932.223
CV			2	1.1547005	2		1.52288	1.181345

The Hydrozoa *Obelia longissima* grew only on the ARC, with the exception of week eight (Fig. 28. table 22 & 34 Appx), when it appeared on the ARF in small numbers and was not found again. Its appearance on the ARC was observed in week eight, whereupon it covered nearly 13% of reef surfaces. Hydrozoa coverage of ARC continued

to grow, peaking at week fourteen with 27.1% coverage. Unlike the other sessile species, *O. longissima* grew preferentially on the outer side of the plate surfaces. The Hydrozoa's length varied from 1 to 10 cm, with maximum length of 20 cm by week fourteen.

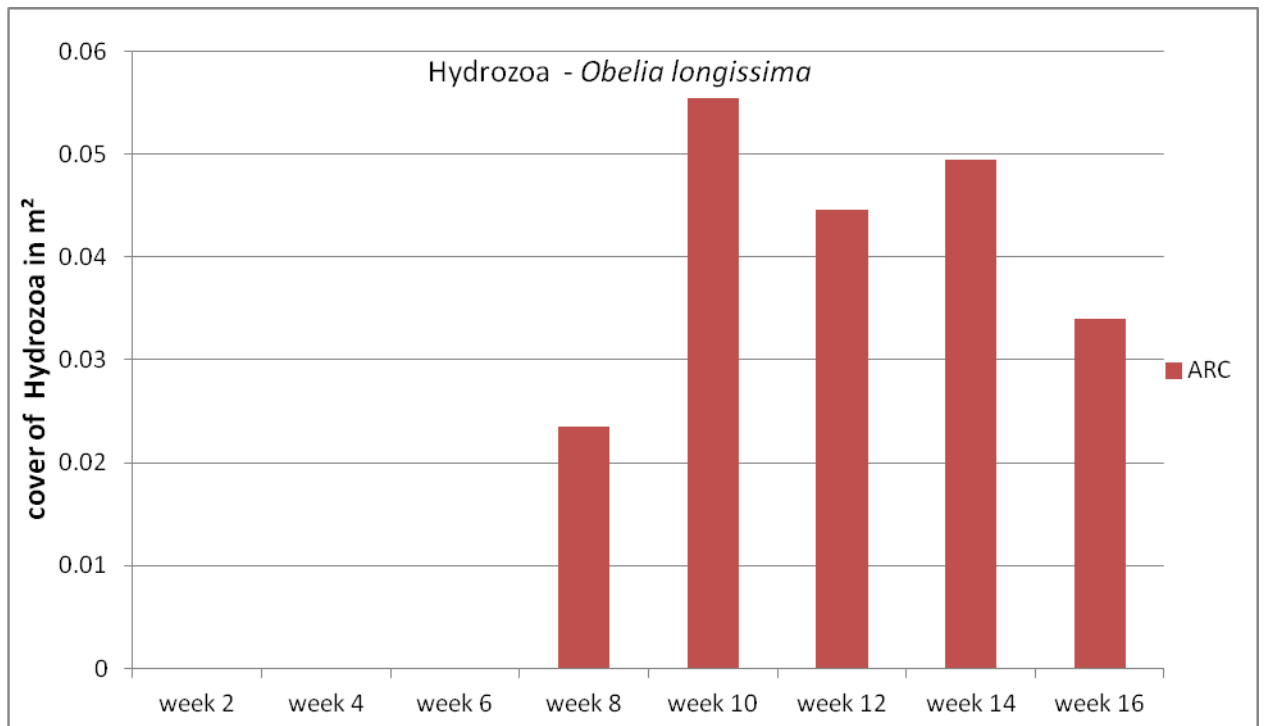


Figure 28: Coverage of *Obelia longissima*, individuals per m².

Table 22: Mean abundances, standard deviation and CV (STDEV/AVERAGE) of *Obelia longissima*, per m².

ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
AVERAGE	0	0	0	0.00591	0.01394	0.0112	0.01245	0.00869
STDEV	0	0	0	0.00335	0.00567	0.0024	0.00283	0.00514
CV				0.56634	0.40703	0.21432	0.22735	0.59172

7.5 Motile Species

One of the motile species that occupied the reefs shortly after deployment was the amphipod *Corophium bonelli*. This was the most abundant motile species on the reefs from the first sampling dive and thereafter (Fig 29, table 23 & 35 Appx). During the first sampling, most of the *C. bonelli* on the reefs were easily identified because they were adults. Between week ten and twelve, many of the *C. bonelli* were juvenile and many of the adults carried eggs. Between weeks fourteen and sixteen there was a decrease in the number of individuals.

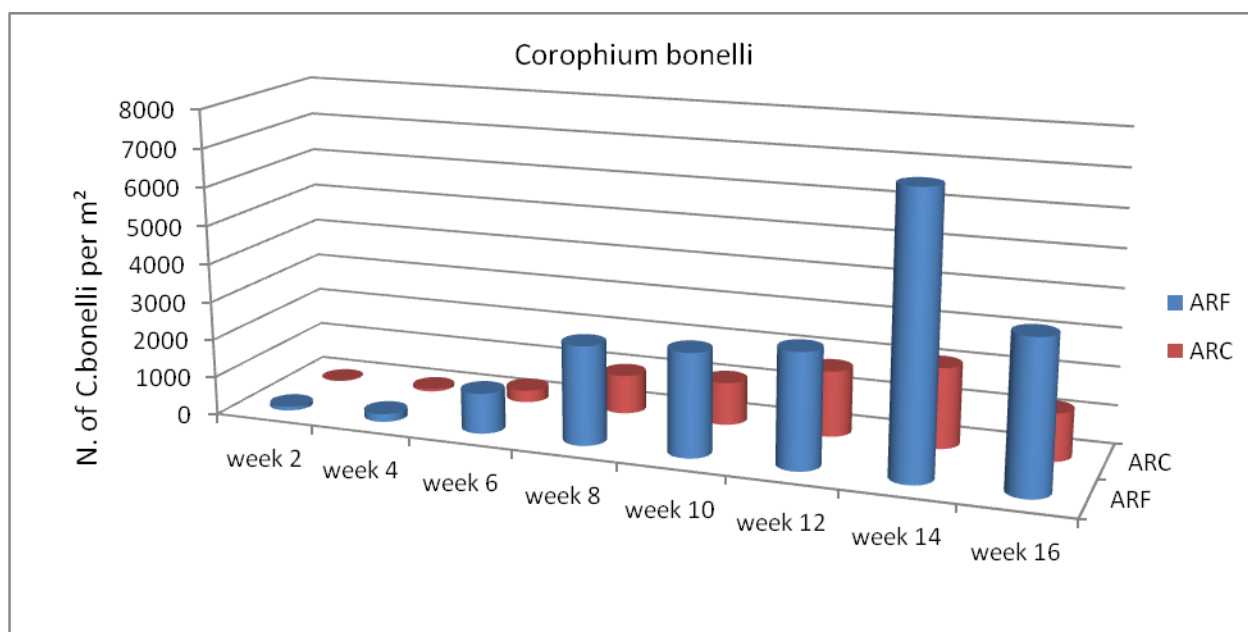


Figure 29: Abundances of *Corophium bonelli* individuals per m² on the reefs.

Table 23: Mean abundances, standard deviation, CV (STDEV/AVERAGE) of *Corophium bonelli* per m² on the reefs.

ARF	week 2	week 4	week 6	week 8	week 10	week 12	week 14	week 16
AVERAGE	98.64	208.24	1052.16	2575.6	3233.2	2986.6	7162.36	3901.76
STDEV	55.1641	148.129	181.641	384.486	1602.66	1045.35	3769.45	4255.64
CV	0.55925	0.71134	0.17264	0.14928	0.49569	0.35001	0.52629	1.0907
ARC	week 2	week 4	week 6	week 8	week 10	week 12	week 14	week 16
AVERAGE	5.48	65.76	317.84	1013.8	1112.44	1715.24	2087.88	1233
STDEV	10.96	30.9996	315.374	920.009	517.601	945.762	304.982	1681.55
CV	2	0.4714	0.99224	0.90749	0.46528	0.55139	0.14607	1.36379

Repeated Measures ANOVA indicate that there was no interaction between site and time for *Corophium bonelli* ($P = .977$, Table 24). However, there was a significant difference ($P < 0.05$) in amphipod growth rates between the reefs with higher recruitment at ARF than at ARC.

Table 24: repeated measures ANOVA of *Corophium bonelli*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Time	1	98253064	98253064	15.7533	0.007375
Site*time	1	23956607	23956607	3.8411	0.097714
Error	6	37421845	6236974		

Source	DF	Type III SS	Mean Square	F Value	Pr > F
site	1	46697542	46697542	19.871	0.02102
Error	3	7050027	2350009		

Among the motile species, four different types of polychaetes appeared on the reefs: *Spirorbis* sp., *Phyllodoce maculata*, *Harmothoe imbricata*, and *Ophryotrocha* sp. *Spirorbis* sp. was mentioned before with the analysis of the sessile species. Two of the polychaetes that were most noticeable, in addition to *Spirorbis* sp., were *Phyllodoce maculata* and *Harmothoe imbricata*. Initially these polychaetes were juveniles and therefore identified at the genus level, but by week ten it was possible to identify them to the species level. There was not much difference in growth or appearance of *H. imbricata* between the two sites. *P. maculata*, on the other hand, appeared from the first sampling dive until the last dive on the ARF (Fig. 30, table 25 & 36 Appx). It had more consistency and quantity on the ARF than ARC. The appearance of *Ophryotrocha* sp. was not consistent throughout the research.

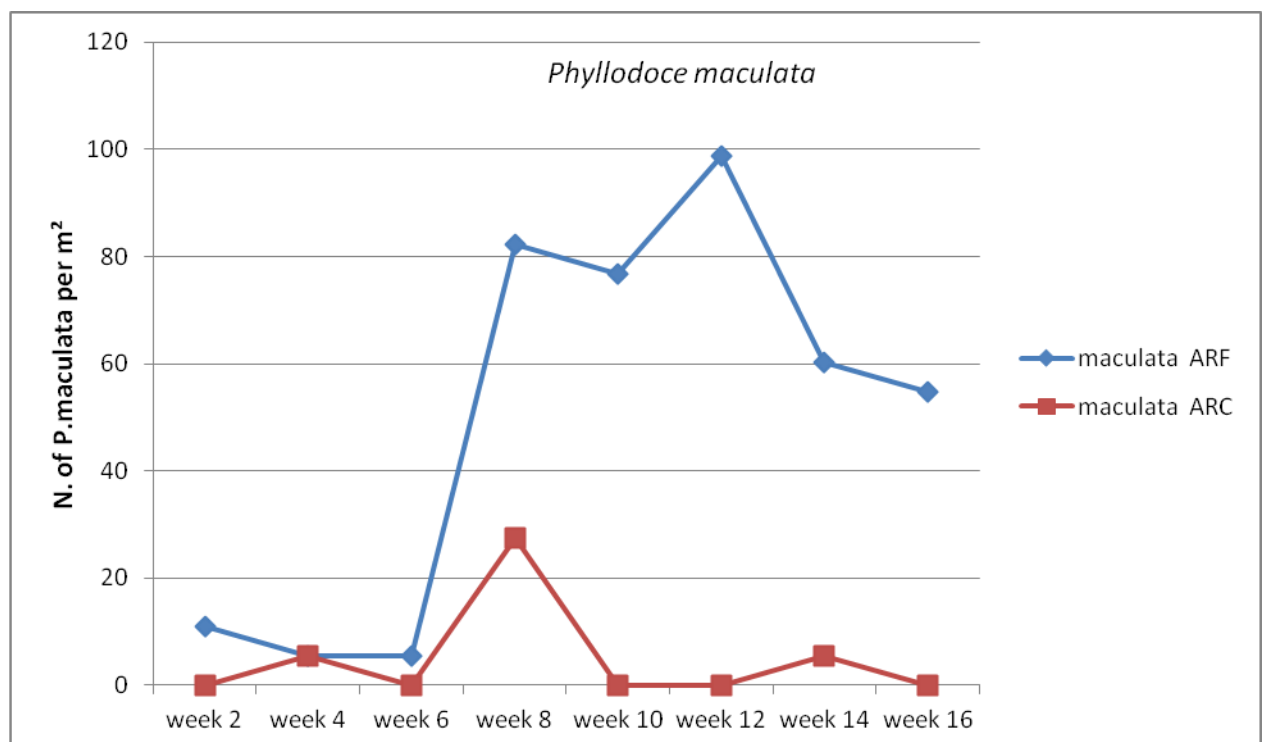


Figure 30: Number of *Phyllodoce maculata* per m² on reefs.

Table 25: Mean abundances, standard deviation, CV (STDEV/AVERAGE) and of *Phyllodoce maculata* per m² on reefs.

ARF	week 2	week 4	week 6	week 8	week 10	week 12	week 14	week 16
AVERAGE	10.96	0	5.48	82.2	82.2	98.64	65.76	54.8
STDEV	21.92	0	10.96	74.6032	60.363	113.9	40.0203	45.6301
CV	2		2	0.90758	0.73434	1.1547	0.60858	0.83267
ARC								
AVERAGE	0	5.48	0	0	0	0	5.48	0
STDEV	0	10.96	0	0	0	0	10.96	0
CV		2					2	

Patellgastropoda was the latest motile invertebrate species to appear on the reef, appearing only on the last sampling dive. The Patellgastropoda was found only on the ARC at the juvenile stage and was identified only to its order.

7.6 Additional species found on the reefs

Table 26: A summary of additional species that occurred, generally in lower abundances, on the 2 reefs. Values are abundances per m²; F stands for ARF and C stands for ARC.

Phylum	Genus	species	F 25/5	C 25/05	F 8/6	C 8/6	F 24/6	C 24/6	F 13/7	C 13/7	F 26/7	C 26/7	F 7/8	C 7/8	F 21/8	C 21/8	F 5/9	C 5/9
Annelida			5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Annelida	Ophryotrocha	sp.	0.0	0.0	11.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	43.8	0.0	0.0
Arthropoda	Jassa	sp.	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arthropoda	Caprella	septentrionalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	11.0	11.0	0.0	11.0	0.0
Arthropoda			575.4	350.7	350.7	213.7	454.8	597.3	158.9	443.9	241.1	515.1	169.9	613.8	1304.2	2285.2	509.6	2208.4
Arthropoda	Protomedea	fasciata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	438.4	0.0	93.2	0.0	164.4	0.0	0.0	0.0
Arthropoda	Gammarus	spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	142.5	0.0
Arthropoda			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	279.5	0.0	0.0
Bryozoa			0.0	0.0	0.0	0.0	0.0	0.0	482.2	76.7	734.3	285.0	1052.2	580.9	1578.2	876.8	1923.5	931.6
Mollusca	Dendronotus	frondosus	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	27.4	0.0	0.0	0.0	0.0
Mollusca	Margarites	helicinus	5.5	0.0	0.0	0.0	11.0	0.0	5.5	0.0	38.4	0.0	11.0	0.0	5.5	5.5	0.0	21.9
Mollusca	Margarites	groenlandicus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	5.5	0.0
Mollusca	Flabellina	sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0
Mollusca			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	778.2
Nematoda			0.0	0.0	5.5	0.0	0.0	0.0	27.4	0.0	0.0	0.0	131.5	0.0	21.9	186.3	21.9	27.4

Nemertina			0.0	0.0	16.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nemertea			0.0	0.0	0.0	0.0	5.5	93.2	5.5	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0
Platyhelminthes	Planarium		0.0	0.0	0.0	0.0	32.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.4	0.0	16.4	0.0
Foraminifera			0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.4	0.0	0.0

7.7 Dry Biomass

At week eight, dry biomass of both motile and sessile species was higher at ARF (Fig. 31). Yet in the following six weeks, dry biomass was higher at ARC even though there was a greater amount of species and number of individuals found on ARF. Only by the last sampling dive did ARF's dry biomass increase and exceed that of ARC.

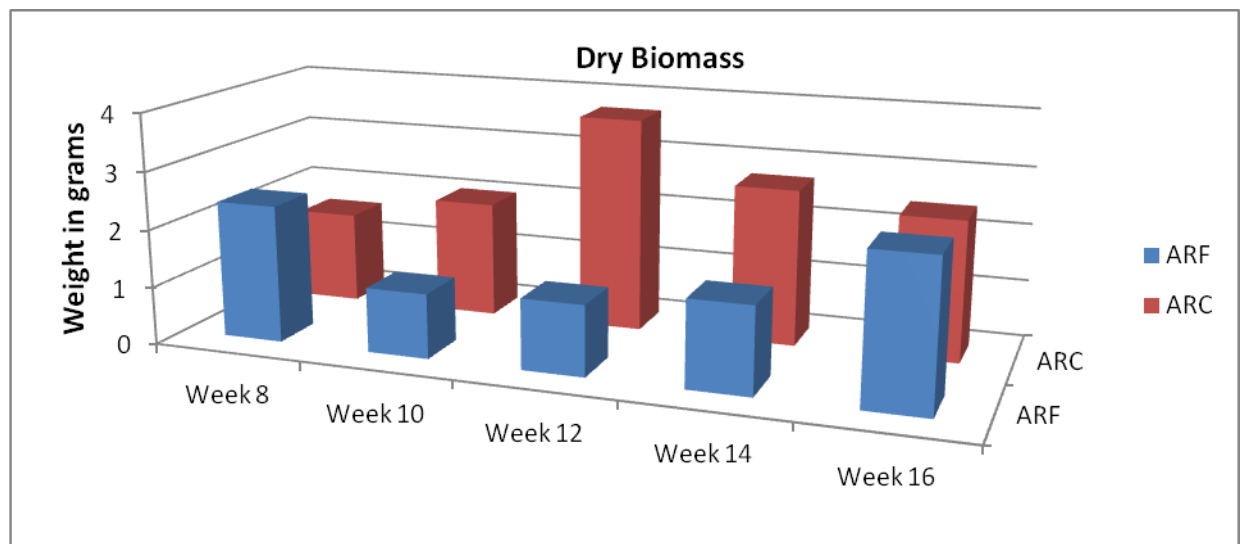


Figure 31: Dry biomass in grams of all species from the four plates.

The following section attempts to answer the main and supplementary research questions while addressing the statistical data presented in the results. The discussion section offers assumptions about the appearance and colonization of species found on the reefs. It also compares the results to similar research conducted elsewhere.

8. Discussion

Growth in demand for fish supply, inevitably lead to the extensive growth of mariculture. As a result of industrial growth, there has been an increase in negative impacts on the environment near mariculture netpens. Such negative impacts include organic effluents, which are the feeding remains and feces that are released from the netpens. One possible solution for this problem is the use of artificial reefs below or around the netpens. Artificial reefs placed near aquaculture sites have demonstrated their ability to attract invertebrates and bigger fauna, such as fish, that may consume organic discharges from mariculture netpens (Angel et al, 2002; Cook et al, 2006; Gao et al., 2008).

In this research project two experimental-scale artificial reefs were deployed near a cod farm for the first time in Icelandic water. To our surprise, algal growth was not observed on these reefs, but the reefs did demonstrate their ability to attract a variety of motile and sessile species. The reefs' pyramid-like structure was used prior to this research in a number of other projects involving aquaculture pens in the Red Sea, the western Mediterranean and near the island of Chiloe, Chile where it successfully accommodated various benthic species (Angel et al., 2002). Similar to past research, the pyramidal artificial reefs used in this project in Iceland also attracted various species. The reef below the fish farm, ARF exhibited higher recruitment in terms of both species richness and abundance of most of the groups observed and identified, aside from Hydrozoa, in comparison to the control reef, ARC.

8.1 Reefs and Species Richness

Species richness was found to be higher in the ARF site throughout the whole research project. The greater number of species is assumed to be associated with excess nutrients at this site. In a similar project (*BIOFAQs*) that was conducted in four different localities: Oban, Scotland; Sitia, Crete; Piran, Slovenia; and Eilat, Israel, similar results were documented only in Eilat (Cook et al., 2006). The study site near Eilat, Israel had a temperature range of 23-27 C° and 40.6-40.7 psu during the research period (Cook et al., 2006) while in Skutulsfjörður, Iceland water temperature increased from 2 to 10 C° during the study and salinity was 35 psu on average (Ingólfsson, 2008). Despite the large

differences in salinity and temperature, both the Israeli and Icelandic sites had fairly mild currents and it is possible that this factor may have contributed to the somewhat similar invertebrate settlement patterns observed. When water current is weak, most fish food remains and other discharges fall directly below the netpens and may serve as food for secondary feeders (Angel et al., 2002; Dempster & Sanchez-Jerez, 2008).

8.2 Reefs and Wild Fish

The higher number of species in the ARF in Skutulsfjörður was mostly due to the sessile and motile invertebrates that occupied the reef as only one wild fish, cod (*Gadus morhua*), was present at the site. The presence of wild cod at the ARF site is attributed to the available food as well as the enhanced benthic community associated with the artificial reefs. As an omnivore, wild cod have the capacity to feed off the remains that fall from the netpens and to consume invertebrates present at the site (Marinebio, n.d).

Unlike Skutulsfjörður, the artificial reefs in Eilat attracted many different wild fish, which account for the greater number of species at the farm site (Angel, 2002; Cook et al., 2006). The presence of an underwater surface can be viewed as a Fish Attracting Device (FAD). In research that was conducted with FADs, it was shown that greater numbers of fish were found in the FADs located near natural reefs (Workman et al., 1985). As a result, it can be assumed that in a coral reef environment, FADs such as artificial reefs will attract more wild fish. Since Skutulsfjörður is a reef-free environment, the observations of cod only at ARF (as opposed to ARC) was possibly related to the presence of food at the site.

The presence of a few lumpfish, *Cyclopterus lumpus* in the ARC reef was only detected after this reef was brought to the surface, suggesting there might have been other cryptic fish present in the reefs throughout the research. When the ARC was pulled out, *Cyclopterus lumpus* were found between the Hydrozoa branches and seemed to use these as a hiding place from predators.

8.3 Reefs and Sessile Species

Sessile species appeared on the ARF from week six while motile species appeared on the reef from week two. The likely reason for the motile species' early appearance on

the reefs is due to their ability to move around and therefore easily colonise new habitat (Gallo, personal communication, September 22, 2011). Many sessile species have motile planktonic larvae that float in the water column until they settle on a substrate and become sedentary. Thus, the later appearance of sessile species on the reefs compared to motile species might be related to the sessile species' life stage at the moment of the reefs' deployment; apart of Hydrozoa, which appeared in earlier life stages on the ARF, and there were also greater numbers of individuals. The earlier colonization and greater quantity of individuals on the ARF is assumed to be associated with the nutrient rich environment that can support larger communities. In addition, the fish farm, with its associated fouling communities probably served as a large source of propagules for settling on the ARF. By the last dive of this study, the total cover of sessile species on the ARF was about five and a half times higher than the ARC with a cover of 0.0106 sessile species per m² in the ARF and 0.00199 sessile species per m² in the ARC. A similar observation was made on the reef near the Eilat fish farm; total biomass of epibiota species at the farm site was six times higher than the control site by the end of the research period (Cook et al., 2006).

Sessile species growth was consistent throughout the ARF, and the settlement pattern was similar in all plates (apart of Hydrozoa) as the sessile species mostly settled on the inner part of the plates. Such patterns of settlement toward the inner parts of the plates is believed to take place because it is more sheltered in the interior and hence more protected from predators. In Eilat, Angel et al. (2002) also indicated that sessile species such as bivalves and sponges were settling in the inner part of the reefs' structure. The growth of sessile species such as Bryozoa Lichenoporidae, Crustacea *Semibalanus balanoides*, Polychaeta *Spirorbis spp.*, and Bivalvia *Mytilus edulis* was consistent throughout the research. Such data suggests that sessile species can potentially provide lasting filtration for the discharges as they remain immobile after they settle on the artificial reefs.

8.4 Reefs and Hydrozoa, *Obelia longissima*

The reason for the widespread growth of the Hydrozoa, *Obelia longissima* ONLY on the ARC was not clear. However, several explanations are possible: the use of copper-based antifouling paint on the netpens, presence of different species on ARF that might have disturbed the growth of Hydrozoa, as well as the water currents that carry the

Hydrozoan planulae. In order to reduce or prevent the formation of biofouling communities on farm structures and net pens, aquaculturists use antifouling substances on netpens (Willemsen, 2005; Braithwaite, Cadavid & McEvoy, 2007). One such substance is copper, used by *Álfsfell*, which has been shown to successfully reduce the accumulation of biofouling communities (Braithwaite et al., 2007); with enhanced antifouling activity against algae and Hydrozoa. Copper may have inhibited the settling of Hydrozoa planulae either directly or by means of algal inhibition. Another possibility for the absence of Hydrozoa from the ARF is the presence of more species at this site that may have fed on the Hydrozoa polyps and planulae.

8.5 Reefs and Motile Species

The number and abundance of motile invertebrates also increased on the reefs throughout the project, yet there was more fluctuation in numbers of individuals compared to the steady growth of sessile species. Such fluctuations are assumed to be related to the fact that these species are not attached to the plates. Water movement could also have been a factor as even movement generated by divers might have scared some of them off. The presence of bigger invertebrates and cod might have also had an effect on the motile species abundance as the cod and some bigger invertebrates such as *Hyas araneus*, *Pandalus borealis* and *Pagurus bernhardus* feed on smaller invertebrates. The most dominant motile species was *Corophium bonelli* which seemed to have successfully reproduced on the reefs. The first settlers of *Corophium bonelli* were adults, and within ten weeks, there was a considerable increase in the juveniles. This implies that the first generation that migrated and settled bred on the reefs, making the reefs the preliminary habitation for their newborns. It is assumed that the great decline in numbers of individuals between week fourteen and sixteen is because some juveniles were preyed or flushed away from the reef.

The presence of polychaetes such as *Phyllodoce maculata* and *Harmothoe imbricata*, as well as the Crustaceae *Hyas araneus*, *Pandalus borealis* and *Pagurus bernhardus* increased the complexity of the reef's food webs. These species are omnivorous and scavengers. As soon as they get bigger in size they begin to prey on smaller invertebrates.

8.6 Reefs and Dry Biomass

From week ten to week fourteen, dry biomass was higher in weight on ARC. The reason for the increased biomass can be related to two factors: the greater growth of Hydrozoa, *Obelia longissima*, and the lack of top predators (e.g. wild cod) on the ARC. At the ARF, there was a greater presence of potential predators like wild cod, Polychetas and Crustacea. Those species might have fed on other invertebrates, reducing the total biomass weight. By the last sampling dive in week sixteen, it was possible to see the increase in biomass on the ARF, and by that time it had exceeded the biomass of the ARC. Such an increase is most probably related to the widespread growth of sessile species on the plates. Even though the biomass of sessile species was not calculated separately from the motile species, the sessile species biomass in the ARF was higher than the ARC due to the greater amount of sessile species during the entire research period. Similarly Cook et al. (2006) found that sessile species biomass was higher on the farm site in Eilat and Oban throughout the whole project (Cook et al., 2006).

9. Recommendations

Mariculture is growing worldwide and such growth in the industry can also be viewed in Iceland, in particular the Westfjords. Therefore, it is essential to continue to investigate the various negative ecological impacts that the industry generates in order to provide solutions. This research was conducted during a period of sixteen weeks. A longer period of time would have allowed better observation and recording of species' succession, dynamic change, growth and reduction of species occupying the reefs.

The reefs were deployed in May, 2011 and were removed in September, 2011. From May to September hours of sunlight per day were: eighteen, twenty-four, twenty, eighteen, and fourteen hours for each month respectively. Greater amounts of sunlight increase the natural productivity of organisms that undergo photosynthesis such as Algae. Algae growth and algae bloom have an effect on primary consumers, the herbivorous species and indirectly affect secondary consumers, the carnivorous species. Therefore a greater number of sunlight hours per day can have an effect on the presence and distribution of both herbivorous and carnivorous species associated with the reefs. Consequently, it is essential to examine the attraction of organisms to the reef during winter in order to examine if there is a great change in the species occupying the reefs due to lack of sunlight, and/or other environmental factors, e.g. water temperature.

Reef size also had an impact on species found. Each of the reefs had a total surface of 19 m², but bigger structures might have provided a better representation of species growth. Reefs that cover a greater surface below the netpens may reduce bias results of species succession. For example, water currents can easily carry farm effluents further from the reefs and affect species distributions. Bigger structures can resolve such problem by covering a greater surface. Hence, constructing bigger reefs that cover larger amounts of the sea bottom surface (e.g. fish farm circumference) might yield different results.

Our results showed the reefs' capability to attract invertebrates and bigger fauna. However, the extent of the filtration process that took place due to the presence of these

species is still to be determined. Further research should be conducted to better assess the amount of organic material taken up by the species occupying the artificial reefs.

10. Conclusion

The initial purpose of this research was to look at a specific problem in coastal and marine management as well as excess nutrient loading and attempt to provide a solution to this negative impact on the mariculture industry by deploying artificial reefs. Whereas this study did not quantify the accumulation of organic discharge below the netpens in Skutulsfjörður, it was assumed that such accumulation occurs as a result of intensive farming of cod and low residual current speeds. However, such research also looks at the larger aspect of promoting the sustainable development of mariculture. In order to promote a sustainable agenda for mariculture in Skutulsfjörður and the Westfjords in general, it is essential that mariculturists understand the concept of “cleaning up” after themselves. The idea is to use the environment for production while attempting to have no impact, or as minimal impact as possible (CBD, 2004). However, sustainability encompasses more aspects than just the environmental impact, such as economic, social, and educational issues (Wurts, 2000).

Another important aspect of sustainability is that mariculture provides jobs, including indirect jobs, such as marketing, feed production, delivering, etc. Such considerations support the need for long lasting production of mariculture, and provide an economic and secure high protein food. In addition, this type of research promotes construction, implementation and maintenance of mitigation systems for mariculture.

Artificial reefs may also be used as educational instruments for the broader public, such as schools, and stake-holders. These structures can be used as explanatory tools while providing people with the opportunity to be on familiar terms with mariculture operation and its impact on the environment. They can also be used as an attraction for divers and to promote eco-tourism. Furthermore, artificial reefs can be cost-effective as they can be constructed from various materials and are fairly simple to build.

Consequently, from a management point of view, constructing and implementing artificial reefs in a coastal area where mariculture activities are operating, can benefit not

only the ecosystem, but a broader spectrum of human endeavors. To conclude, in order to increase production it is necessary to address the potential impact of mariculture on its surrounding area. Knowing the potential environmental hazards allows us to have a better understanding of the ecosystem and promote possible mitigations systems.

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12. Appendix

Complete tables of species found on plates

Table 27: Total numbers of species by weeks.

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate 1	3	5	8	10	7	9	10	15
plate 2	4	4	7	7	7	8	13	8
plate 3	4	6	6	7	9	12	11	10
plate 4	3	4	7	8	11	10	8	11
AVERAGE	3.500	4.750	7.000	8.000	8.500	9.750	10.500	11.000
STDEV	0.577	0.957	0.816	1.414	1.915	1.708	2.082	2.944
CV	0.165	0.202	0.117	0.177	0.225	0.175	0.198	0.268
ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate 1	2	4	3	5	3	6	9	13
plate 2	3	2	5	5	5	4	12	11
plate 3	4	4	8	9	6	10	10	10
plate 4	1	4	5	5	6	4	7	9
AVERAGE	2.500	3.500	5.250	6.000	5.000	6.000	9.500	10.750
STDEV	1.291	1.000	2.062	2.000	1.414	2.828	2.082	1.708
CV	0.516	0.286	0.393	0.333	0.283	0.471	0.219	0.159

Table 28: Total amount of organisms per m² on settling plates.

ARF								
Weeks	2	4	6	8	10	12	14	16
plate A	898.7	920.6	1556.3	4844.3	8592.6	986.4	17996.3	25076.5
plate B	482.2	241.1	1841.3	3309.9	5195.0	6795.2	25361.4	21700.8
plate C	942.6	1249.4	2148.2	4603.2	11091.5	18960.8	30951.0	30315.4
plate D	504.2	241.1	2520.8	4340.2	9907.8	13371.2	11442.2	25909.4
AVERAGE	706.9	663.1	2016.6	4274.4	8696.8	10028.4	21437.8	25750.5
STDEV	247.6	505.4	414.0	675.1	2547.8	7813.9	8517.7	3545.8
CV	0.4	0.8	0.2	0.2	0.3	0.8	0.4	0.1
ARC								
weeks	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
plate A	350.7	328.8	109.6	4384.0	1622.1	986.4	14423.4	13634.2
plate B	372.6	241.1	942.6	854.9	1315.2	2893.4	7518.6	5896.5
plate C	811.0	350.7	2060.5	854.9	964.5	3901.8	6181.4	4405.9
plate D	0.0	526.1	1359.0	986.4	2192.0	3025.0	6378.7	14138.4
AVERAGE	383.6	361.7	1117.9	1770.0	1523.4	2701.6	8625.5	9518.8
STDEV	332.2	119.4	815.3	1743.7	520.4	1228.0	3909.9	5084.0
CV	0.9	0.3	0.7	1.0	0.3	0.5	0.5	0.5

Table 31: Total of Bryozoa per plate in m²

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate A	0	0	0	482.24	942.56	1359.04	1161.76	1950.88
plate B	0	0	0	526.08	723.36	723.36	1644	2038.56
plate C	0	0	0	569.92	657.6	1380.96	2301.6	1819.36
plate D	0	0	0	350.72	613.76	1402.88	1205.6	1885.12
AVERAGE	0	0	0	482.24	734.32	1216.56	1578.24	1923.48
STDEV	0	0	0	94.7052	145.951	329.287	529.116	93.6423
CV				0.19639	0.19876	0.27067	0.33526	0.04868
ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate A	0	0	0	43.84	153.44	350.72	679.52	657.6
plate B	0	0	0	131.52	153.44	219.2	635.68	460.32
plate C	0	0	0	131.52	394.56	504.16	811.04	745.28
plate D	0	0	0	0	438.4	1249.44	1380.96	1863.2
AVERAGE	0	0	0	76.72	284.96	580.88	876.8	931.6
STDEV	0	0	0	65.76	152.917	460.668	344.267	632.396
CV				0.85714	0.53663	0.79305	0.39264	0.67883

Table 32: Total of Spirorbis per plate in m²

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate 1	0	0	0	482.24	1008.32	1096	2937.28	1994.72
plate 2	0	0	328.8	569.92	635.68	1117.92	3901.76	3616.8
plate 3	0	0	460.32	832.96	2761.92	3901.76	4493.6	4493.6
plate 4	0	0	832.96	1008.32	876.8	3551.04	2038.56	3441.44
AVERAGE	0	0	405.52	723.36	1320.68	2416.68	3342.8	3386.64
STDEV	0	0	344.5	241.452	973.139	1519.12	1080.47	1035.82
CV			0.84953	0.33379	0.73685	0.6286	0.32322	0.30586
ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate 1	0	0	87.68	0	0	21.92	328.8	679.52
plate 2	0	0	21.92	0	0	0	284.96	219.2
plate 3	0	0	109.6	0	87.68	876.8	811.04	1117.92
plate 4	0	0	21.92	0	197.28	153.44	2038.56	0
AVERAGE	0	0	60.28	0	71.24	263.04	865.84	504.16
STDEV	0	0	45.1892	0	93.6423	414.746	817.335	497.605
CV			0.74966		1.31446	1.57674	0.94398	0.987

Table 33: Total amount of Mytilus edulis per plate in m²

ARF	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate 1	21.92	0	21.92	21.92	21.92	43.84	284.96	1468.64
plate 2	0	65.76	65.76	43.84	21.92	43.84	328.8	591.84
plate 3	0	65.76	0	21.92	131.52	153.44	153.44	526.08

plate 4	0	0	21.92	109.6	109.6	43.84	0	350.72
AVERAGE	5.48	32.88	27.4	49.32	71.24	71.24	191.8	734.32
STDEV	10.96	37.96655	27.58206	41.49389	57.64863	54.8	147.99382	500.01309
CV	2	1.154701	1.006645	0.841320	0.809217	0.769231	0.771605	0.680920
ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate 1	0	0	0	0	0	0	5480	1337.12
plate 2	0	0	0	0	0	0	767.2	1819.36
plate 3	0	0	43.84	21.92	0	0	438.4	0
plate 4	0	0	0	21.92	21.92	0	21.92	0
AVERAGE	0	0	10.96	10.96	5.48	0	1676.88	789.12
STDEV	0	0	21.92	12.65551	10.96	0	2553.688	932.223
CV			2	1.154700	2		1.522880	1.181345

Table 34: Total cover of Hydrozoa, Obelia longissima per plate in m²

ARC	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
plate A	0	0	0	0.00115	0.0215	0.01015	0.01635	0.01275
plate B	0	0	0	0.0076	0.013	0.0089	0.01165	0.01275
plate C	0	0	0	0.00615	0.00775	0.0145	0.0122	0.00205
plate D	0	0	0	0.00875	0.0135	0.01125	0.0096	0.0072
AVERAGE	0	0	0	0.00591	0.01394	0.0112	0.01245	0.00869
STDEV	0	0	0	0.00335	0.00567	0.0024	0.00283	0.00514
CV				0.56634	0.40703	0.21432	0.22735	0.59172

Table 35: Total amount of Corophium bonelli per plate in m²

ARF	week 2	week 4	week 6	week 8	week 10	week 12	week 14	week 16
plate A	87.68	394.56	832.96	3003.04	4164.8	3266.08	9337.92	7781.6
plate B	43.84	43.84	986.4	2082.4	3485.28	3748.32	7781.6	7387.04
plate C	87.68	241.12	1249.44	2520.8	898.72	3485.28	9864	153.44
plate D	175.36	153.44	1139.84	2696.16	4384	1446.72	1665.92	284.96
AVERAGE	98.64	208.24	1052.16	2575.6	3233.2	2986.6	7162.36	3901.76
STDEV	55.1641	148.129	181.641	384.486	1602.66	1045.35	3769.45	4255.64
CV	0.55925	0.71134	0.17264	0.14928	0.49569	0.35001	0.52629	1.0907
ARC	week 2	week 4	week 6	week 8	week 10	week 12	week 14	week 16
plate A	0	43.84	0	2367.36	1468.64	438.4	2082.4	3748.32
plate B	21.92	43.84	394.56	482.24	1074.08	2630.4	2520.8	504.16
plate C	0	65.76	723.36	394.56	394.56	2170.08	1863.2	219.2
plate D	0	109.6	153.44	811.04	1512.48	1622.08	1885.12	460.32
AVERAGE	5.48	65.76	317.84	1013.8	1112.44	1715.24	2087.88	1233
STDEV	10.96	30.9996	315.374	920.009	517.601	945.762	304.982	1681.55
CV	2	0.4714	0.99224	0.90749	0.46528	0.55139	0.14607	1.36379

