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Blue Mussel (*Mytilus edulis*) in Faroese Fjords: Biology and Farming Potential

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Blue Mussel (*Mytilus edulis*) in Faroese Fjords: Biology and Farming Potential

Kræklingur (*Mytilus edulis*) í Føroyskum firðum: lívfrøði og møguleikar at ala krækling

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Abstract

Spawning, larval abundance, settlement and growth of mussels were measured at four different sites in the Faroe Islands during spring to autumn 2010. Different environmental conditions, such as temperature, current and chlorophyll *a* concentrations were also measured. These measurements showed that temperature and chlorophyll *a* concentrations have an influence on the spawning, and that current speed, phytoplankton availability and predators influence the growth of the mussels. DNA studies were made of mussels in the Faroes, and these showed that only one species of *Mytilus*, *Mytilus edulis*, was present. The result of the whole experiment is that mussel farming opportunities in the Faroes are good.

Samandráttur

Kanningar vórðu gjørdar av gýting, larvumongd í sjónum, áseting av larvum og vøkstri av kræklingum á fýra ymiskum støðum í Føroyum frá vár til heyst 2010. Eisini vóru ymisk umhvørvis viðurskifti, so sum hiti, streymur og klorofyl *a* nøgd kannað. Hesar kanningar vístu, at hiti og klorofyl *a* hava ávirkan á gýtingina og at streymurferð, tøkt plantuæti og rovdjór ávirka vøksturin hjá kræklingunum. Ílegu kanningar vórðu gjørdar av kræklingi í Føroyum, og hesar vístu, at bert tað eina slagið av kræklingi, *Mytilus edulis*, var at finna. Úrslitini av øllum kanningunum vísa, at møguleikarnir fyri kræklingaaling í Føroyum eru góðir.

1. Introduction

1.1 Mussel farming

Shellfish farming is a world-wide industry, which represents approximately one quarter of the world aquaculture production, with an annual yield of about 11 million tonnes (FAO, 2003). Shellfish farming is highly efficient aquaculture both in terms of energy and cost, since

a) Bivalves feed directly on phytoplankton and are therefore located at the second lowest trophic level in marine ecosystems,
b) They take up their food themselves, and are not dependent on active feeding by farmers

Furthermore shellfish farming can be considered as environmental friendly or “green” industry, since organic materials are not put into the environment (as it is in fish farming). On contrary, it takes organic particles out of the environment. China is now the largest producer of blue mussels and other important producers of blue mussels are Spain, the Netherlands, France, and the UK followed by Ireland and Germany (FAO, 2004). There is no industry for shellfish aquaculture in the Faroe Islands at present.

The main principle in mussel farming is that by lifting up the mussels in the ocean they get a better food environment and faster growth. In the first growing season of mussel farming, spat collectors must be hung out in a longline. Rigs using a combined spat collector and growth bands are preferred. There are many different kinds of growth bands with different shapes and surface structures that can be used to provide good attachment for the mussels. The collectors must be placed in the water at the same time as the spawning takes place for the larva to fasten on the rope when the pelagic stadium is finished. The location of the collectors should be in the inner part of the fjord, so as to have the highest settlement (fig. 1.1). The rigs stay in the ocean for two to three years, depending on what the growth rate and market size are, and are then ready to be harvested. A potential farm must be placed in an area where the current forces and the phytoplankton availability are sufficient, because mussels pump large amounts of seawater. There are a lot of ecological factors that must be known, to achieve the best result.

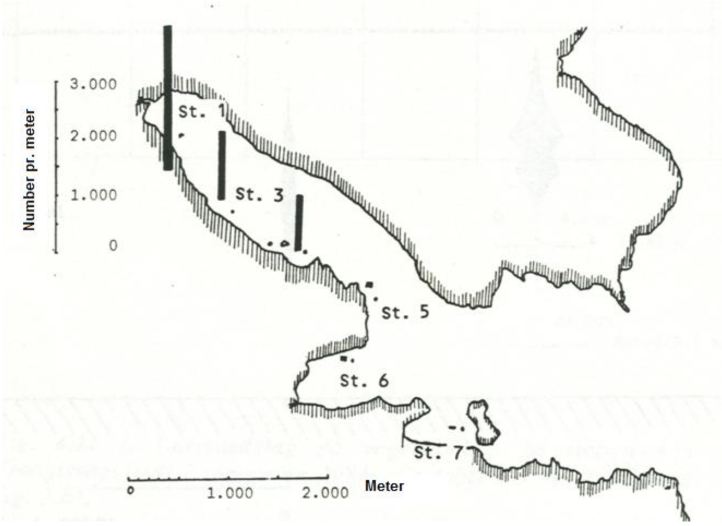

Fig. 1.1 Number of mussel larvae per meter on spat collectors in Trongisvágsfjørður, Faroe Islands (Gaard, 1986)

1.2 The ocean surrounding the Faroe Islands

The waters around the Faroe Islands are dominated by relative warm and saline North Atlantic Current Water which hits the Faroe shelf on the western side, and is rotated by the Coriolis force around the islands in a clockwise direction. On the shelf itself the temperature ranges from approximately 6 ˚C in February to approximately 10 ˚C in August and September. The salinity on the shelf usually is slightly lower than offshelf due to the precipitation and a shallower water column, and usually does not exceed 35.30 ‰ (Gaard and Hansen 2000; Hansen and Østerhus 2000).

1.3 The Fjords

The main feature that characterizes fjord current systems is the so-called estuarine circulation: Freshwater, which flows into the fjord is lighter than saltwater, and therefore makes the current known as the estuarine current. Freshwater from river runoff, mixes with the sea water and creates low saline upper layer, which flows out of the fjords, and is replaced by saltwater that is entering the fjords in deeper layers, creating a persistent upwelling in fjords (Fig. 1.2).

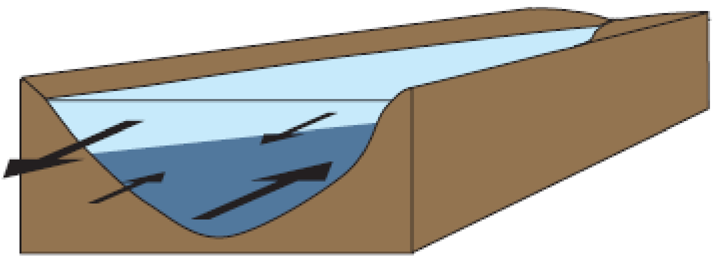

Fig. 1.2 Schematic estaurine circulation (Hansen, 2000)

Both the water flowing out of the fjord and in to the fjord are pushed by the Coriolis force to the right (Gaard et al., 2011).

Due to an amphidromic point located on the shelf, several of our fjords have little difference in the tides and the tidal induced amplitudes and currents within Faroese fjords are weak. However due to the unstable weather conditions on the Faroe Islands, wind forces highly influence the conditions in the fjords and create highly dynamic systems.

Some of the fjords have a shallow sill at the entrance and larger depths farther in. In these fjords the current is restricted during summer. In the summer the sea outside the fjord gets warmer and lighter than the sea in the bottom layer inside the fjord, and the bottom layer therefore is stagnant (fig. 1.3). These sill fjords have a high risk of oxygen depletion in the bottom layer during summer, as detritus and dead animals sink to the bottom, and during mineralization oxygen is used. If no oxygen is in the bottom layer, toxic hydrogensulfide that is produced in the sediment may accumulate in the bottom layer.

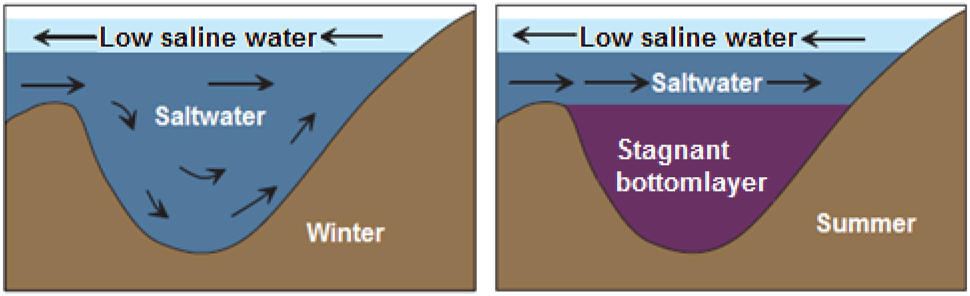

Figure 1.3 Circulation in a sill fjord during winter (left), and during summer (right) (Hansen, 2000)

1.4 Primary production

The seasonal fluctuations in primary production in Faroese fjords are high, changing from very low levels in winter, to a highly productive system in spring and summer. Due to the estuarine circulation there is a continuous influx of nutrients followed by upwelling to the euphotic zone. As mentioned it is particularly the wind forces that influence the currents in the fjords, and therefore the wind forces have a great influence on the primary production of the fjords. Results of productivity measurements by Gaard et al. (2011) in Kaldbaksfjørður (a typical Faroese fjord) in 2006 and 2007 reveal values of about 335 gC/m/y of which about 98% occurred between April and October. These values are 2-3 times higher than reported from neighboring regions, such as Icelandic, west Norwegian and west Scottish fjords. The causal mechanism is the high flushing rate of the freshwater zone and high influx of nutrients, relatively to the surface area. On average, the majority of the production is mainly based on new production. The productive season is from late March - early April until

October. Large size diatoms are generally dominating the growth in the Faroese fjords (Gaard et al., 2011) and these are suitable food for mussels (Penney et al., 2001).

1.5 Biology

1.5.1 About *Mytilus edulis*

The blue mussel *Mytilus edulis* is a bivalve mollusk that belongs to the phylum Mollusca, which is the largest marine phylum in Kingdom Animalia. There are other *Mytilus* species such as *Mytilus galloprovincialis* and *Mytilus trossulus* that can be found around the world. The meaning of the word "edulis" is the one you can eat.

Kingdom:	Animalia
Phylum:	Mollusca
Class:	Bivalvia
Order:	Mytiloida
Family:	Mytilidae
Genus:	*Mytilus*
Species:	*M.edulis*

1.5.2 Anatomy

The mussels have two asymmetrical shells, purple, blue or brown, with no radiating ribs. The shells can be opened by a system of muscles and can be tightly closed by a large posterior adductor muscle when the mussel is exposed to air (Beaumont et al., 2006).

The soft part and the interior organs are capsuled by a cape. When the shells are open, the cape is coming out through the hindmost part, which has the form of a half circle and it is in this part, that the mussel pumps the water in. After the water has passed through the interior it is pumped out again through the exhaling opening, which is placed in front of the inhaling opening.

The water passes through the gills, but mussels are suspension feeders, so the gills also function as a filter. The plankton, which the mussel catches by filtration of the water, gets transported from the mouth and throughout the stomach by cilia on the gills surface. It is the number and size of the particles in the water that decides how much the mussel can pump. If there are a lot of particles in the water then the speed of the pumping will decline and the mussels will try to keep a constant filtration rate.

The mussels also have at foot which they can stick out between the two shells, and this makes them able to move around on the bottom or any other substrate. Furthermore the mussels have a cardio-vascular system with "blood" and a primitive nervous system.

Moreover the mussels produce byssalthreads from the byssal glands in the foot/muscle which they use to attach to any substrate. The more exposed they are to current or waves, the more threads they produce. The threads can be cut off and new threads can be produced if the mussel wants to move to a new substrate.

1.5.3 Reproduction

The mussels are of separate sexes. The males spawn the sperm into the water, the female mussels recognize this, and immediately react by spawning the eggs into the water. The reproductive system is very simple. The gonads located in the mantle, consist of five main channels on either side of the body, and a larger number of smaller channels, each ending in a follicle. Eggs and sperm are formed in the follicles and continue through the channels to an opening just in front of to the posterior closing muscle (Giese and Pearce, 1979).

Spawning in *M. edulis* in northwestern Europe generally occurs during spring and early summer. Studies made in Hvalfjørður in Iceland over a period of two years showed that the spawning period started in the middle of June at 8˚C, but the main spawning took place in mid July to mid August, when the temperature was 10 to 12˚C (Thorarinsdottir, 1996). Around Great Britain and Ireland spawning begins in March and April. It is often partial, and a second spawning period occurs in July–August (Bayne, 1964; Seed, 1969a; Wilson and Seed, 1974; McKenzie, 1986). Generally it can be said, that not only do mussels from southern regions spawn earlier than those from colder, northern waters (Seed 1969a), but also do mussels under oceanic influence spawn earlier than mussels in shallow coastal seas, at about the same latitude (de Vooys, 1999). The spawning of the mussels is said to occur when the temperature reaches 10°C (Chipperfield, 1953; Wilson and Seed, 1974; Podniesinski and McAlice, 1986; Thorarinsdóttir, 1996). Others point to phytoplankton to be the main trigger in spawning of *M. edulis* (Himmelman, 1975; Newell, 1982; Kautsky, 1982). Some investigation, although without making any statistical tests, claim that spawning is related to spring tide, and that it could possibly be the dominating factor in synchronized spawning of *M. edulis* in the sea (de Vooys, 1999).

1.5.4 Larvae

When the eggs are fertilized they drift in the water, where they develop into a top-shaped trochophore larva with its characteristic ciliary bands. By moving them rapidly, they can control their way of movement and additionally bring food (planktonic algae) closer. Mussels have a lecithotrophic trochophore, which means that they have a short planktonic existence (Ruppert & Barnes, 1991). After a few days, the trochofore starts developing a velum from the ciliary ring. It grows and is now called a veliconcha. After four till six weeks it has got a size of about 0.3 – 0.4 mm and the velum is lost. The mollusk metamorphoses into the adult stage, and hence develops a shell and a foot, which it uses to examine and find a substratum to settle upon. The larva (pediveliger) now appears as a grown mussel and has the same functions (fig. 1.4). It is only a small fraction of the larva, about 1%, that survives the time until settling (Rosenberg, 1984).

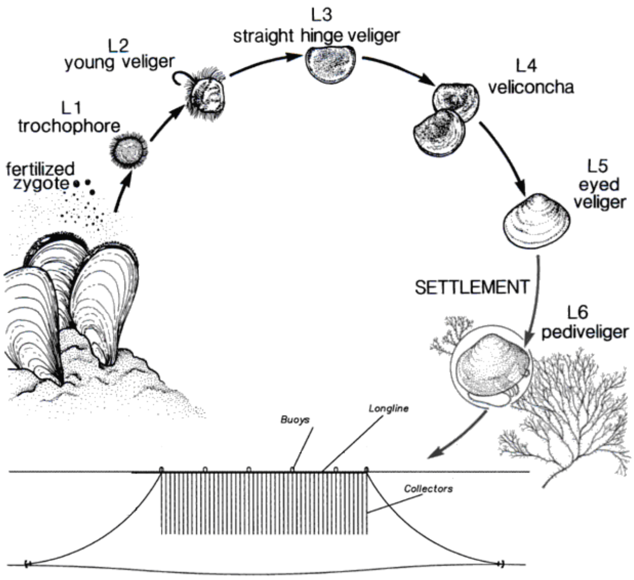

Fig. 1.4 Spawning of mussels, and the different stages of the larvae (Wildish and Kristmanson, 1997).

1.5.5 Habitat

Mussels can live almost everywhere. It is an opportunistic species, characterised by relatively fast growth, large reproductive output with abundant free-swimming larvae that can readily colonise all free suitable surfaces (Seed, 1976; Seed and Suchanek, 1992), but the habitat where mussels are mostly seen is the intertidal area (sometimes referred to as the littoral zone). This is an environment with harsh extremes with temperature sometimes being very high, and sometimes close to the freezing point. In the littoral zone, mussels may also experience large variability in salinity. Furthermore the mussels may experience to be in air at low tide and during these periods it closes the shells in order to prevent dehydration. As *M. edulis,* especially small individuals*,* have relatively weak defenses and are vulnerable to predation, invasions of predators may occasionally eliminate entire populations (Seed, 1969b; Dare, 1982). The mussels can avoid predators, such as seastars, in this extreme habitat. The mussels use the byssal threads to attach to the substrate, which often is a hard substrate. This substrate can also be ropes as in a mussel farm, and if the ropes are lifted from the sea floor the mussels avoid predators and thrive.

1.6 Predation and competition

Mussels serve as an important food source for a wide range of organisms e.g. starfish, eider ducks and oystercatchers.

1.6.1 Seastar

Seastars (*Asterias rubens*) are generally reported to be effective predators on mussels, but mussels may co-occur with considerable number of predators by growing out of the size range preferentially taken by predators (Reusch and Chapman, 1997; Sommer et al., 1999). The feeding behaviour of asteroids is usually analyzed with optimal foraging models (Dolmer, 1998). Field observations, done by Dolmer, showed among others that *Asterias* at subtidal beds feeds on mussels whose size were the same or larger than the mean size for the population. Experiments done by Saier (2001) show that a high abundance of large *A. rubens* in a seastar invasion can clear subtidal patches of mussels.

1.6.2 Eider ducks and oystercatchers

The most important predators consuming mussels are eider ducks (*Somateria mollissima*) and oystercatchers (*Ostralegus haematopus*). Swennen (1976), Swennen et al. (1989) and Smit (1980) calculated that eider ducks in the Wadden Sea consumed about 3 million kg dry weight per year, whereof 1.2 million of the weight was mussels. 90 % of the mussels were taken from subtidal beds and cultures. Oystercatchers consumed about 2 million kg of food yearly, consisting of 25 % mussels (Lasiewski and Dawson 1976; Hulscher 1980; Smit 1980). Eiders specialize in feeding on mussels although they take a range of other foods to supplement their diet. They swallow the mussels whole, shell and all, and crush up the shell in their very muscular gizzard. They can ingest between 1.5 to 2.7 kg of mussels per day, the variation is due to difference in lipid and meat content of mussels of different size and at different times of the year. Eider ducks prefer shorter mussels (<20 mm), which have the lowest shell content (Bustnes, 1998). Eider ducks stripping mussels off culture ropes on mussel farms in Scotland has become a serious economic problem. In pulling the mussels off culture ropes they dislodge other clumps of mussel that fall in to the seabed and so represent further losses to mussel farmers. Eiders prefer rope-cultivated mussels to wild ones, as the cultivated ones grow faster and achieve higher meat content with thinner shells. The most effective means of protection is use of netting around farms (Furness, 2000).

1.6.3 Jellyfish

Jellyfish *(Aurélia aurita)* are considered to be planktonic and not capable of extensive movements against currents (Graham et al., 2001). Jellyfish therefore primarily drift with the current, even when swimming. Jellyfish polyps readily eat mussel, gastropod and fish larvae (Grondahl, 1988).

1.6.4 Barnacles and Tunicates

Barnacles (*Semibalanus balanoides*) and mussels are great compeditors about the space on any hard substrate. As a fouling organism tunicates as well as barnacles compete for space and food with mussels, potentially decreasing mussel productivity (Thompson and MacNair, 2004). Barnacles are small cructaceans living in a calcite shell in especially the intertidal zone, where mussels also live, in fjords and straits. Barnacles are hermaphrodites, but have to mate with another barnacle and therefore barnacle larvae often fasten to a substrate in groups. Barnacles have two nektonic larval stages, the nauplius- and the cypris stage, the latter being the shorter. The main spawning of barnacles is in spring (fig. 1.5), and the numbers of larvae can be huge, both in the fjords and on the Faroe shelf, where barnacles also are common (Gaard et al., 2006). Barnacles use two ways to win the competition for space. They have evolved to grow very fast, so they can resist displacement, and they also use a strategy in the settling, where large numbers of larvae settle at the same place at once, allowing at least some to survive. Therefore it is important that the mussels are the first to settle on a rope, and the ropes must not be in the sea for too long before the mussel larvae appear in the water otherwise they may lose in the competition for the space on the rope.

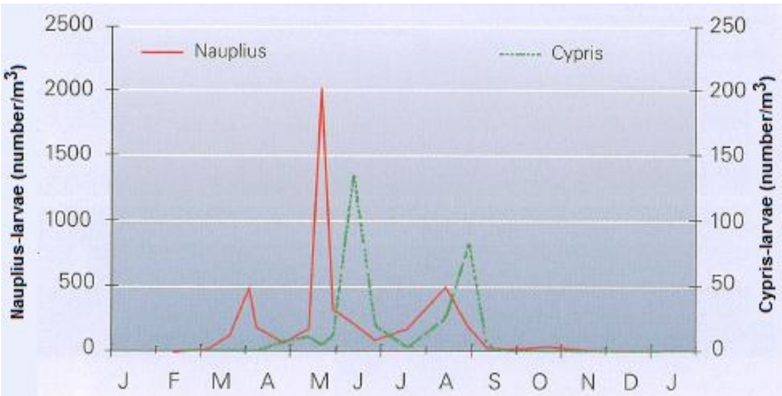

Fig. 1.5 Seasonal variability in abundance of naplius- and cypris stage of the barnacle larvae on the Faroe shelf (Gaard et al., 2006)

1.6.5 Detection of predators by mussels

As mussels use a ciliary filter-feeding system to extract particulate and dissolve matter from the water column, the angle of shell gape is dependent on the water flow, and a greater flow gives a higher rate of matter extraction. Experiments with a simulated predation risk showed that the mechanorecpetors and olfactory receptors in the nervous system of a blue mussel can presumably detect the movement and chemical cues of both predator and food, resulting in a lower gape angle. The experiment showed that the mean gape angle generally decreased as the degree of simulated predation risk increased (Robson et al., 2010). The behavior of the mussels becomes a trade-off between effective feeding and the likelihood of predation.

1.7 Flow impact on filtration rate

Page and Hubbard (1987) detected a close correlation between chlorophyll *a* and growth in *M. edulis*. In later studies by Camacho et al. (1995) chlorophyll *a* content of the water is a secondary factor explaining growth variation compared to the major effect of the actual phytoplankton availability, as determined by the current speed.

Fig. 1.6 illustrates the flow impact on filtration rate of *Mytilus edulis* compared to another bivalvia, the clam *Ruditapes decussatus*. *R. decussatus* has an exhalant siphon that reaches speed of up to 1 cm/s and the jetting can be as high as 7 cm. The inhalant siphon is at a different level than the exhalant. *R. decussatus* uses this ability to expel depleted water from the mussel bed, and therefore is well adapted to living in sheltered environments with low currents. This situation is a contrast to *M. edulis* where the depleted water is not exhaled far, and the water depletion thus is just above the mussel bed in low current conditions (Sobral and Widdows, 2000). The filtration rate of *M. edulis*, and *R. decussates* is measured in term of algal cell depletion (clearance rate mg/h) at a constant suspended particular matter in the water column at different current speeds. The impact of seston depletion by *M. edulis* on their filtration rate at the lower current velocities (<8 cm/s) is observed. Mussels, 4 cm length, maintain a constant clearance and filtration rate over a wide range of higher current velocities up to >40 cm/s.

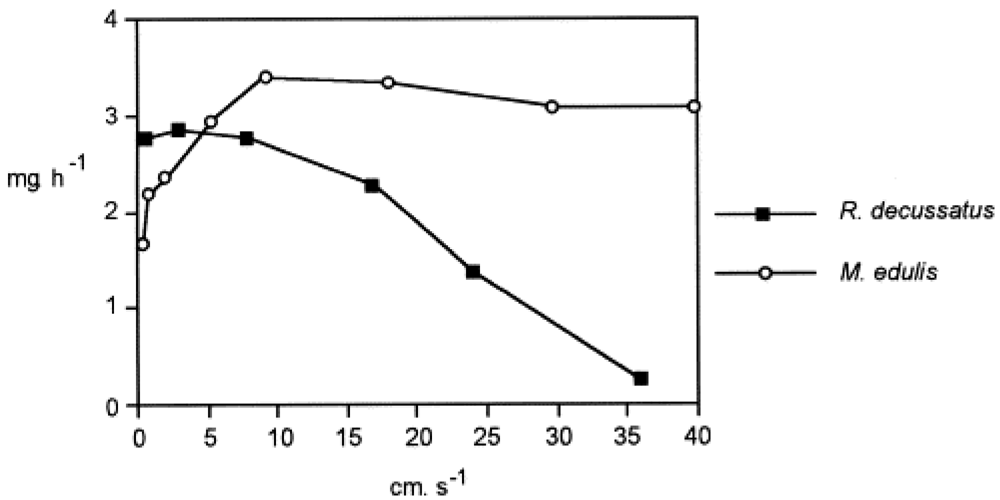

Fig. 1.6 Flow impact on filtration rate for *M. edulis* and *R. decussatus*, current speed (cm/s) on the x-axis and ingestion rate (algal cell depletion in mg/h) on the y-axis (Sobral and Widdows, 2000)

1.8 Multi-trophic farming

There has been increased interest in developing multi-trophic farming, where fed aquaculture species, such as salmon, are combined with inorganic extractive species, such as seaweed and organic extractive species, such as mussels. Such systems should benefit a recycling of waste nutrients from higher trophic level species into the production of lower trophic level species.

M. edulis has been confirmed to ingest and absorb organics from particulate fish food in laboratory experiments (MacDonald et al., 2011), which shows the capability of mussels to capture and absorb excess fish food, and thereby potentially reducing the nitrification process. Studies made in Lochs in the west coast of Scotland, where 1-2 year old *M. edulis* were suspended from salmon sea cages, mussel rafts and mussel long-lines, showed a significant higher shell length growth of the mussels suspended at the salmon sea cages. Food availability was also measured at the sites, and showed higher food availability in the salmon sea cages, due to utilization of organic matter. This difference was thought to participate in the higher growth of the mussel in the salmon sea cages, especially during winter, when the food availability decreased in the lochs (Stirling and Okumus, 1995). The results indicate, that in a multi trophic farm, where mussels are combined with salmon, there is a recycling of waste nutrients.

Large sea lice density at farms has become a problem because of the infectious pressure. Studies by Davenport et al. (2000) showed that *M. edulis* ingests most mesozooplankton present in inhaled sea water. Animals 100 to 1000 µm are routinely ingested and animals as large as 3 to 6 mm in length are occasionally ingested. The size of the copepodid stage of the lice (780-830µm) falls within the size range of crustaceans that Davenport et al. (2000) used in the mussel filter feeding experiment. A new study carried out by Molloy et al. (2011) clearly demonstrates that mussels are capable of removing sea lice copepodids from the water column. Large mussel individuals (50 to 70 mm shell length) each pump up to 70 l seawater/day (Davenport and Wolmington, 1982), and might reduce the lice in the mussel farm area to a great extent. Integrated multi-trophic aquaculture (IMTA) therefore gives an exciting alternative to reduce environmental impacts of commercial aquaculture system and a good alternative for lice management.

1.9 *M. galloprovincialis*: an invasive species

In Europe there are three species of mussels in the genus *Mytilus*: *M. edulis* (blue mussel), *M. galloprovincialis* (Mediterranean mussel) and *M. trossulus* (Baltic mussel). *M. trossulus* is thought to be around the Baltic Sea, while *M. galloprovincialis* is mostly in southern Europe, but has spread northwards all the way to the Shetland Islands, maybe as a result of global warming (Beaumont et al., 2006). *M. galloprovincialis* is one of 100 most invasive species, on the global invasive species database's list of worst invasive species. In the northern part of Europe *M. galloprovincialis* has hybridized, and their hybrids are fertile with *M. edulis*, the dominant species in the northern part of Europe. The knowledge of the distribution of mussel species around Europe, as it was assessed in 1992, is shown in fig. 1.7. Hybrids occur in regions where the species meet or overlap (Beaumont et al., 2006).

Fig. 1.7 Approximate distributions of *M. edulis*, *M. galloprovincialis* and *M. trossulus* in Europe (Beaumont et al., 2006). Faroe Islands is not present on the map.

1.10 The present study

In the present study, settling ropes and ropes with one year old mussels were placed on four different sites in the Faroe Islands. Trough the spring and summer samples of larval abundance, temperature, salinity and chlorophyll *a* measurements were taken and gonads of mussels in one fjord were collected. Samples of mussels were also collected for DNA studies. With these data the growth, the settling of mussels and the spawning of mussels were investigated as well the larval abundance and the environmental factors which influence these. These studies should give an idea of the farming potential in Faroese fjords. The DNA studies are to check if *M. galloprovincialis* is present in the Faroes.

2 Materials and methods

2.1 The study sites

The farming experiments and most measurements were done at the sites Kaldbaksfjørður, Skálafjørður, Sundalagið Str. and Sundalagið Ey. Both Kaldbaksfjørður and Skálafjørður are sheltered areas, where the influence by the tidal currents is not as prominent. Sundalagið is different in this aspect. At Nesvík temperature measurements were made, and in Saksun and Nesvík mussels were collected for DNA research.

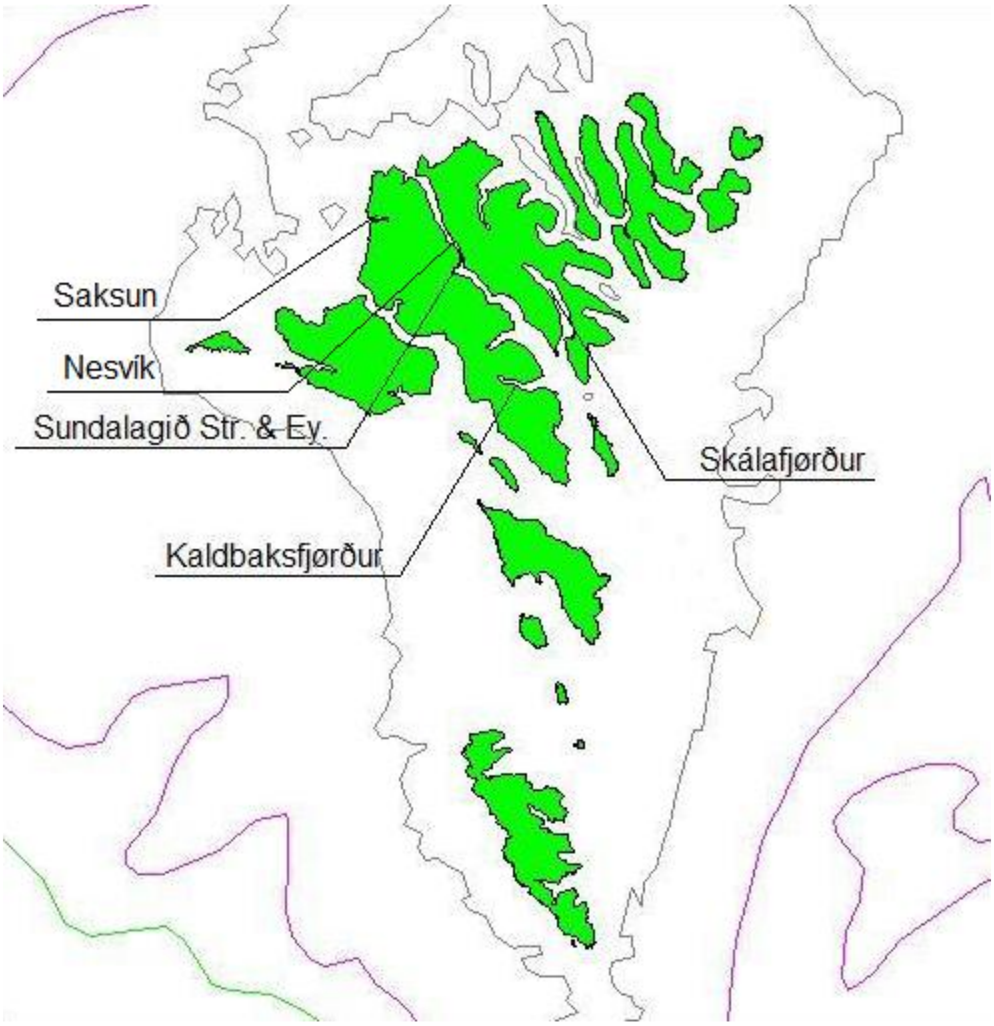

Fig. 2.1 The different study sites in the Faroes

2.1.1 Skálafjørður

Skálafjørður is a ~15 km long fjord, lying in a northwest – southeast direction. At the fjord entrance there is a 30 m deep sill, whereas the deepest part inside the sill is 70 m. The bottom layer is usually isolated during summer. The studies were made at position 62˚10.4 N and 6˚48.6 W, at 25 m depth. The site is marked by a star in fig. 2.2. Here we deployed a longline system, where we attached the mussel lines.

Fig. 2.2 The study site in Skálafjørður

2.1.2 Kaldbaksfjørður

Kaldbaksfjørður is a ~7 km long fjord, lying in an east-west direction. At the fjord entrance there is a 40 m deep sill, whereas the largest depth inside the fjord reaches 60 m. The bottom layer is usually isolated during summer. The study point is at position 62˚03.4 N and 6˚53.5 W at 9 meters depth. The study point is marked by the star to the left in fig. 2.3. The mussel lines were hung from a floating pier. The star to the right marks the point where CTD measurements are made by the Faroe Marine Research Institute (FAMRI).

Fig. 2.3 The study site (star to the left), and the site where CTD measurments are made by FAMRI (star to the right) in Kaldbaksfjørður.

2.1.3 Sundalagið

Sundalagið is a narrow sound and the influence of the tidal current is great. Our study points are marked by stars in fig. 2.4: the western point (Sundalagið Str.) is at position 62˚11.6 N and 7˚00.1 W and 5 meters depth and the eastern point (Sundalagið Ey.) at position 62˚12.0 N and 6˚59.6 W at 2.5 meters depth. The western point, which is completely exposed, has strong current, whereas the currents at the eastern point, which is pretty much sheltered, are much weaker. These locations were picked to investigate the impact of current speed on the mussel. Due to high mix of the waters, no difference is expected in the water conditions at the two sites, only in the current speed.

Fig. 2.4 The study sites in Sundalagið. Sundalagið Str. is marked by the star to the left and Sundalagið Ey. is marked by the star to the right.

2.2 Environmental variables

2.2.1 Salinity and temperature

Salinity and temperature profiles were obtained with a Seabird SBE-25 CTD. The data were averaged to 1-meter depth intervals by linear interpolation between measuring points.

2.2.2 Fluorescence

The fluorescence was measured with a fluorometer that was attached to the CTD. For calibration, selected samples were collected and measured spectrophotometrically, according to Parsons et al. (1984). 2 L of seawater were filtrated on Whatman GF/F filters and the extraction was carried out with 90% acetone. The chl. *a* content was calculated using the equation by Jeffrey and Humphrey (1975).

2.2.3 Current measurements

Current measurements were made with a SEAGUARD® RCM. The SEAGUARD was deployed at each station for approximately 2 weeks, and this should give us a good indication of the current forces.

The measurements made by the SEAGUARD were, the current direction (degrees) and the speed of the current (cm/s). For calculating the correct direction, we had to subtract 7˚. Then we could calculate the North and East vector using formula:

$$N = speed * cos(direction)$$

$$E = speed * sin(direction)$$

2.3 Genetics

To examine which species of mussels are in the Faroe Islands, DNA samples were taken from 50 mussels from 4 different sites. The examination was done on The Aquaculture Research Station of the Faroes with help from the personal. The mussels were collected at Kaldbaksfjørður, Skálafjørður, Nesvík and Saksun. Nesvík is just north of the bridge by our sites in Sundalagið. The last sample was taken from Saksun, which is in the north of Streymoy. Saksun was chosen to include a site with water directly influenced by the ocean.

The markers chosen for the species determination were Glu-5’ and Glu-3’ (Rawson et al. 1996).

Glu-5’ can differentiate between the species *M. edulis, M. galloprovincialis* and *M. trossulus*, while Glu-3’ can identify *M. edulis* and *M. galloprovincialis.*

PCR assays with these markers produces species specific banding patterns. Rawson et al. (1996) identified two bands for Glu-5’ in *M. edulis*, 350bp and 380bp. The genotypic frequencies were 0.85 for 350/350, 0.12 for 350/380 and 0.03 for 380/380. When applied to *M. galloprovincialis* the PCR assay showed two primary bands of size 300bp and 500bp, occasionally only the 300bp band was present.

Borsa et al. (1999) characterised the same Glu-5’ alleles by approximate size, estimated from visual comparisons with a 100bp ladder, and by nucleotide count from sequences presented in Rawson et al. (1996). These two methods defined the 380bp allele as 410bp and 427bp for visual and nucleotide count respectively. Likewise, the 350bp allele was defined as 390bp and 397bp for visual and nucleotide count respectively. The differences in precise definition of size, is due to differences in sample treatment and analysis.

2.3.1 Sample treatment and analysis

DNA was extracted using a combination of HotSHOT genomic DNA preparation (Truett et al. 2000) and Qiagen Blood & tissue DNeasy kit. The PCR amplification procedures were based on the method described in Rawson et al. (1996) but using a Qiagen Multiplex PCR kit. The PCR products were analysed in a 3130xl genetic analyser (Applied Biosystems)

2.4 Gonad index

Gonads were taken from 15 mussels from Kaldbaksfjørður on the same dates as the other samples were taken. Pieces of the mantle (1cm x 1cm) were preserved in 4% formalin, and later histological preparations (thickness: 10 µm) were made. The gonads were colored in Harris hematoxylin according to Seed (1975) and Seed and Brown (1977).

The sex of the mussels was then identified using a microscope and the gonad from each mussel was classified into different developmental stages, according to the following classification:

Resting stage: Immature or already spawned, resting gonads. No germinal follicles and the sexes cannot be distinguished.

Development:

- Developmental stage I: Early stage of gametogenesis. It is difficult to distinguish between sexes in the beginning of this stadium and it’s difficult to tell egg from sperm cell.
- Developmental stage II: Ripe eggs and sperm cells appear in the middle of the follicles and less developed at the border.
- Developmental stage III: The follicles are about half-filled with mature gametes.

- Developmental stage IV: Follicles have invaded almost the entire mantle. Cells undergoing gametogenesis can still be found in the margins of the duct, but ripe gamete dominate.
- Developmental V: resembles developmental stage IV. The release of the gametes from the mussel has begun. Follicles are full of ripe gametes. Tightly compacted eggs have an angular configuration because of the pressure.

Spawning:

- Spawning stage IV: Follicles are almost full of ripe eggs and sperm and the animals have just started to spawn. The eggs appear more rounded because of less pressure.
- Spawning stage III: This stage looks a lot like developmental stage III because of the follicles that are half-filled with gametes, but can be distinguished because of the scarcity of developing cells and the egg are more round.
- Spawning stage II: Gametes fill less than half of the follicles. The ducts still continue to shrink, whereas the connective tissue is expanding
- Spawning stage I: The follicles have disappeared almost completely, but some sperm and eggs remain in the follicles although some may be empty. It is difficult to determine the sexes at this stage

Gonad development was monitored by microscopic observation of thin sections of the gonad. This method is not completely precise as it can sometimes be difficult to distinguish one stage from another, but it gives a reasonable estimate, that can be used to calculate the gonad index.

Mussels were analyzed 9 times during the spring-summer (approximately 2-3 weeks intervals). A gonad index for each sample was attained by multiplying the number of mussels in each stage by the numerical ranking of that stage and dividing the resulting value by the total number of mussels in the sample (Seed, 1969a).

$$Gonad\ index = \frac{number\ of\ animals\ at\ each\ stage\ \times stage\ number}{total\ number\ of\ mussels\ measured}$$

2.5 Larval abundance and sizes

Mussel larvae were collected in the upper ~6 m (depending on the various stations) with a plankton net. The diameter of the net opening was 26 cm and the mesh size was 20 µm. The net was towed approximately 8 meters through the water column. The actual volume of seawater that was filtered could not be measured, and therefore the actual information on larval concentrations is not available. However, since the same sampling procedure was used every time, the information on relative abundance, can be compared between dates and sites. The larval collection started on April 18th 2010 and sample collection continued throughout the summer, until September 13th 2010. All the samples were collected at the same time as the CTD casts. The samples were preserved in 4% formalin. At the laboratory the larvae were counted and measured to nearest 0.01 mm, using microscope.

2.6 Settlement and spat growth

2.6.1 Settlement

10 mm thick ropes were used for the larval settlement. In both sites at Sundalagið the horizontal longlines were attached to land and the spat collectors + the growth ropes were hung on the longlines, with ~0.5 kg weights on the ends (fig. 2.5). In Kaldbaksfjørður the collectors + the growth lines were hung from a floating pier. In Skálafjørður the longline was anchored in a system and suspended under the surface (fig. 2.6.).

Spat collectors were deployed at three different dates (in May and June), starting from one week prior to when the larvae were expected to settle. The reason for this is that the larvae do not settle on clean ropes. It is necessary that there is established a thin film of microorganisms on the surface of the ropes, that is attractive for the larvae.

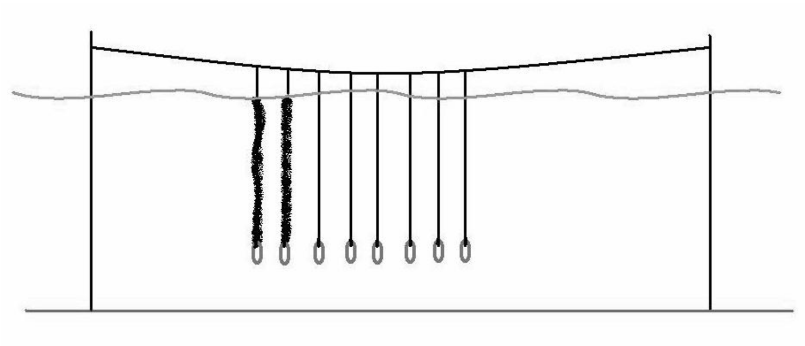

Fig. 2.5 The setting of the mussel ropes in the two sites in Sundalagið and Kaldbaksfjørður. The first two ropes are the one year old mussels, and the other 6 are settling ropes from 3 different deployment dates.

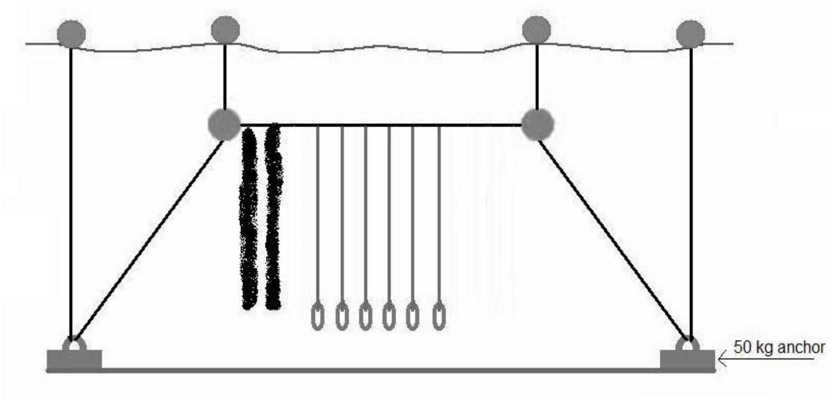

Fig. 2.6 The setting of the mussel ropes in Skálafjørður. The first two ropes are the one year old mussels, and the other 6 are settling ropes from 3 different deployment dates.

2.6.2 Spat number and sizes

For examining the abundance of juvenile mussels on the ropes, all individuals were collected from 18 cm of the rope, at ~1 m depth (~2m dept in Skálafjørður) as seen on fig. 2.7. Samples were collected on September 25th 2010 in Skálafjørður and on October 28th 2010 at the other locations.

Fig. 2.7 Farming site in Kaldbaksfjørður. Settling measurements were made by collecting all mussels on 18 cm of the rope and measuring the abundace, length and dryweight of the mussels.

2.7 Growth tests of one year old mussels

The one year old mussel lines had been growing in Kaldbaksfjørður the first year (fig. 2.8). These mussels were deployed from May 3rd to September 25th 2010 on Skálafjørður and from May 17th to October 28th 2010 on Sundalagið Ey., Sundalagið Str. and Kaldbaksfjørður. 18 cm of the lines were cleaned for mussels and the bulk sizes were weighed. Lengths and tissue weights were measured on 20 mussels from each site. The mussels were dried at 70°C for two to three days, and then the length of the shell was measured to the nearest 0.1 mm and the tissue was removed and weighed.

Fig. 2.8 The one year old mussels from Kaldbaksfjørður used for the growth research, prior to deployment at the different sites.

2.8 Data analysis

Statistical analyses and statistical models were made using the statistical program R from http://cran.r-project.org

3 Results

3.1 Temperature, salinity and fluorescence

The temperature, salinity and fluorescence measurements were made with the use of a Seabird SBE-25 CTD, with an attached fluorometer. The measurements were made throughout the spring-summer 2010, but as can be seen in the plot of the measurements, no data is collected in the July period, as the CTD was not available for our use. The data from the CTD is plotted in fig. 3.1-3.3 as the average chlorophyll *a* concentration, temperature and salinity through the water column at the different sites.

3.1.1 Temperature

The temperature increased gradually from ~7,5˚C in early May to ~11˚C in mid-late August, whereafter it decreased slightly in September (fig. 3.1). The temperature was almost identical at the different sites.

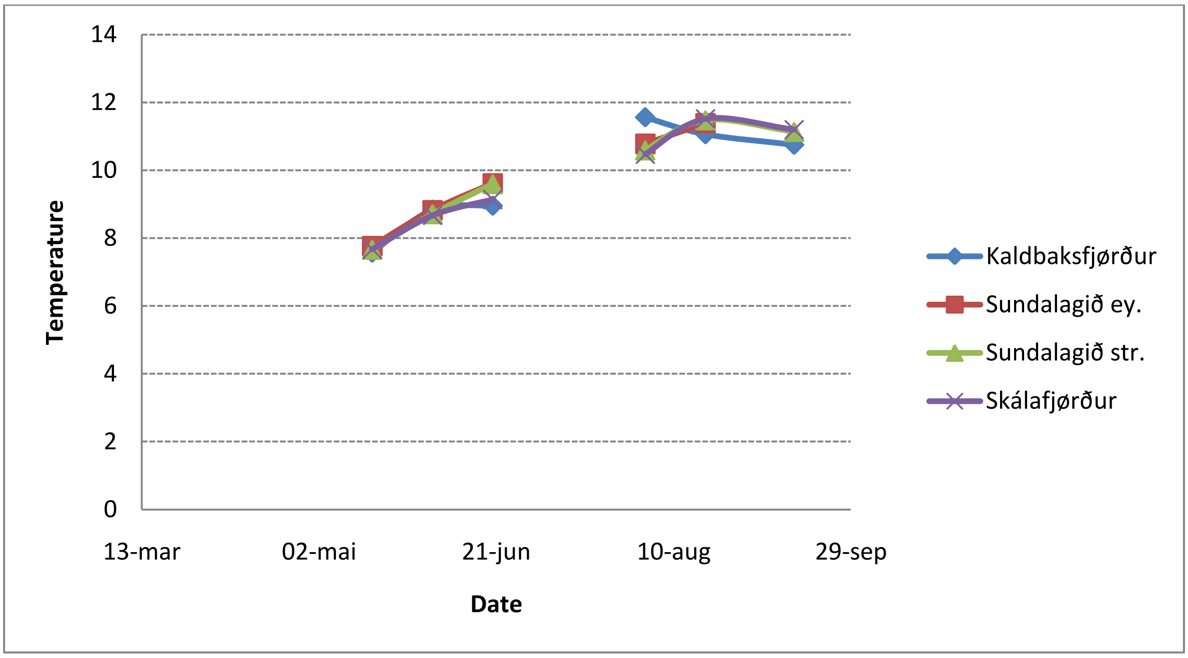

Fig. 3.1 The temperature data (˚C) from the four study sites.

Because the measurments at the study sites are deficient, we got CTD measurments from FAMRI farther to the west in Kaldbaksfjørður, at the position marked by the star to the right in fig. 2.3. Only the top 8 meters of the data were used, because we wanted to compare these to the data from the study site, which also were taken at the top 8 meters further inside the fjord. The temperature data is almost identical to the temperature data from the study site (fig. 3.2) and these temperature data from FAMRI can therefore be used as the temperature at the study site in Kaldbaksfjørður.

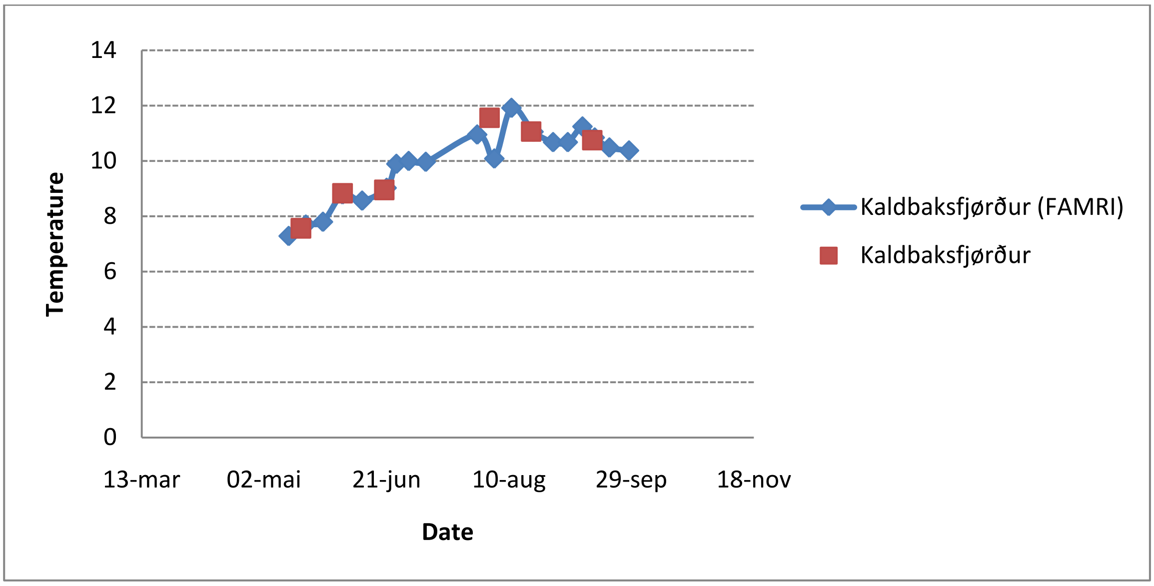

Fig. 3.2 Temperature data (˚C) from FAMRI, measured in Kaldbaksfjørður and the temperature (˚C) at the study site in Kaldbaksfjørður.

The CTD measurments from Nesvík, north of the study sites in Sundalagið were made in water pumped from 18 meters depth, and therefore the chlorophyl *a* and salinity data were not similar to our data which were taken at much lower depths. The temperature data however are almost identical to our data from both sites at Sundalagið, and the data from Nesvík can therefore be used as the temperature fro the two sites in Sundalagið (fig. 3.3).

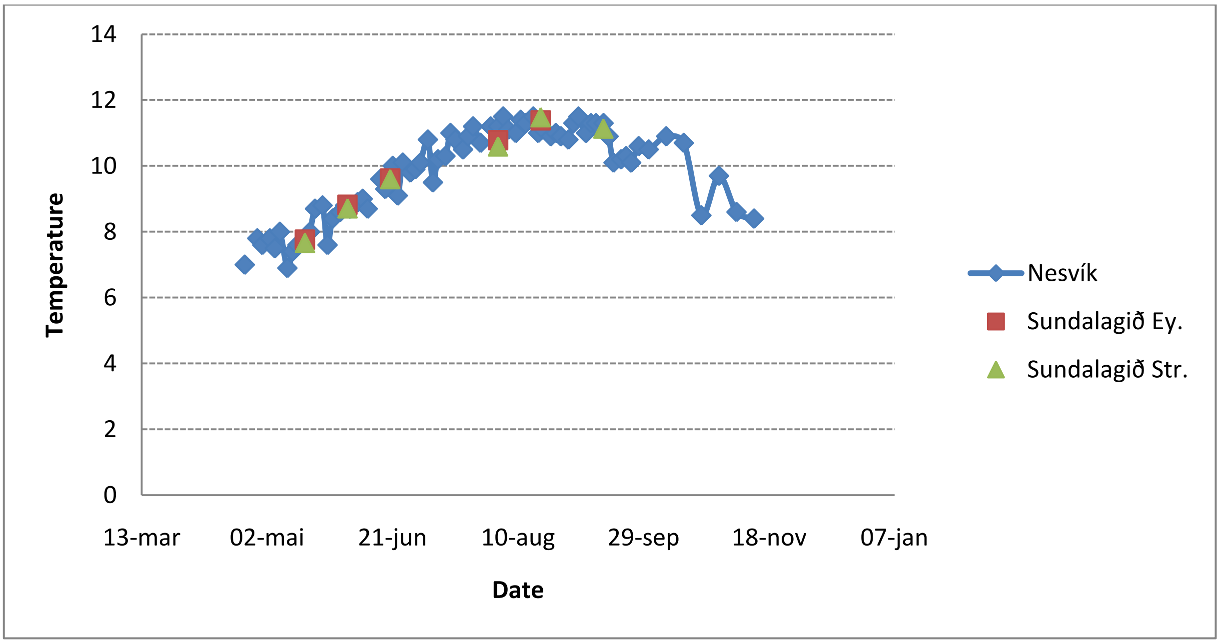

Fig. 3.3 Temperature data (˚C) in Nesvík from the Aquaculture Research Station of the Faroes and temperature (˚C) from both study sites in Sundalagið.

3.1.2 Salinity

The salinity measurements show that both sites in Sundalagið had quite similar salinity. The salinity increased slightly from the beginning of May to early August and than decreased in late August (fig. 3.4). The salinity values in Kaldbaksfjørður and Skálafjørður seem to be a bit higher, especially in late August and September.

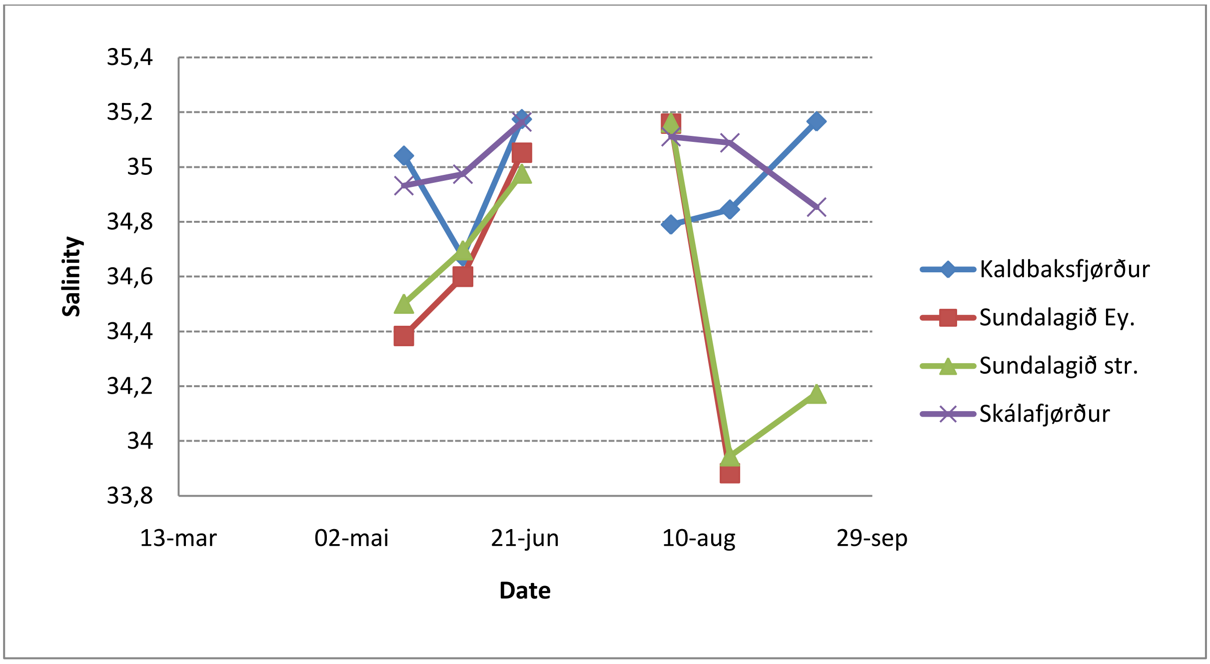

Fig. 3.4 The salinity data (‰) from the four study sites.

The salinity data in Kaldbaksfjørður from FAMRI are quite similar to the measurments at the study site (fig. 3.5).

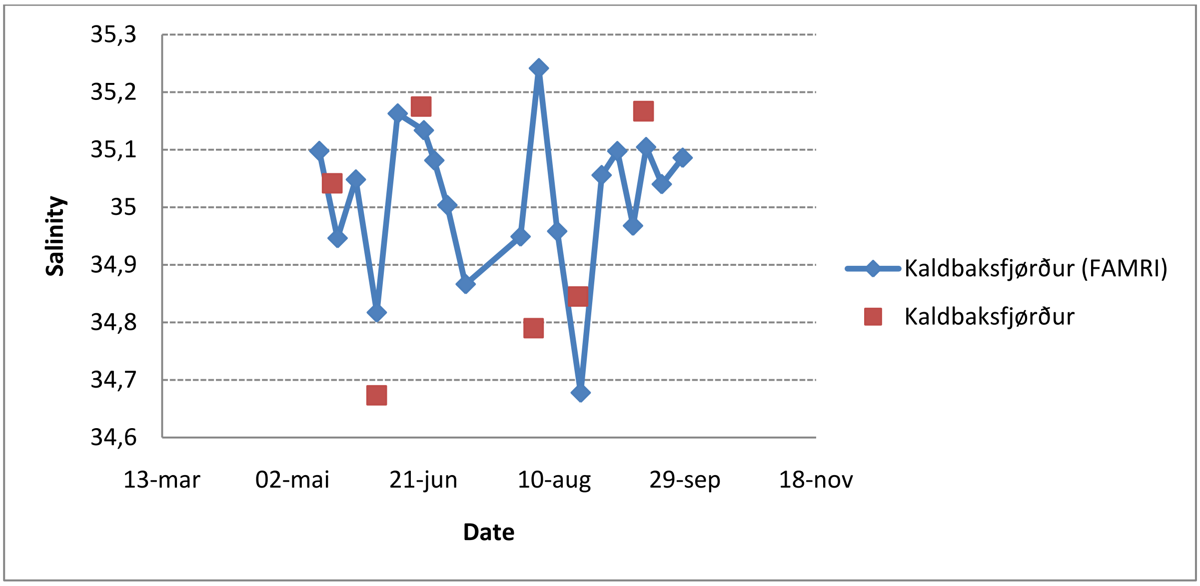

Fig. 3.5 Salinity data (‰) from FAMRI, measured in Kaldbaksfjørður and the salinity data (‰) from the study site in Kaldbaksfjørður.

3.1.3 Chlorophyll *a*

For converting the fluorescence data into chlorophyl *a* concentrations, we plot the fluorescence in the water column from Kaldbaksfjørður against spectrophotometrically measured chlorophyl *a* concentrations from samples at different depths (fig. 3.6). A trendline showed the formula: Chl *a* = 1.199 x fluorescence (R^2 = 0,71). This factor is used to convert fluorescence into chlorophyll *a* concentrations.

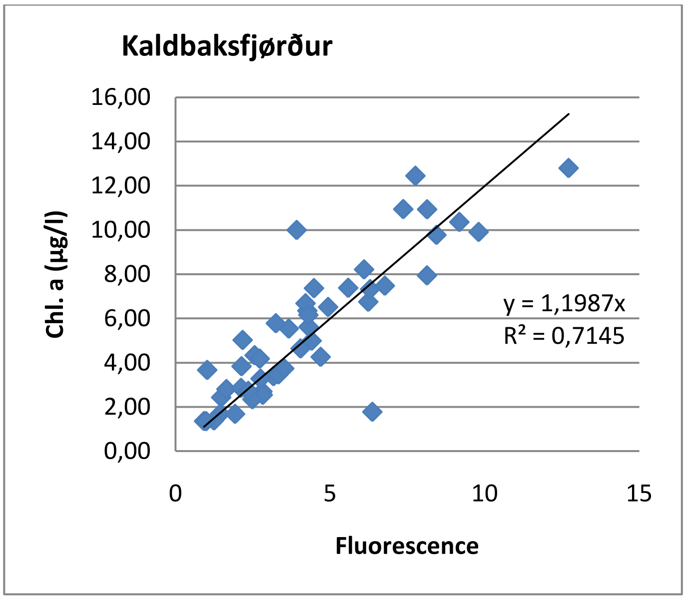

Fig. 3.6 Fluorescence plotted against chlorophyll *a* concentrations (µg/L) in Kaldbaksfjørður

The calibrated fluorescence measurements (Chl. a/L) (fig. 3.7) show a high increase in the chlorophyll *a* in mid August for all sites, and a drop in mid September. The results showed no clear difference in Chl. *a* concentrations between sites.

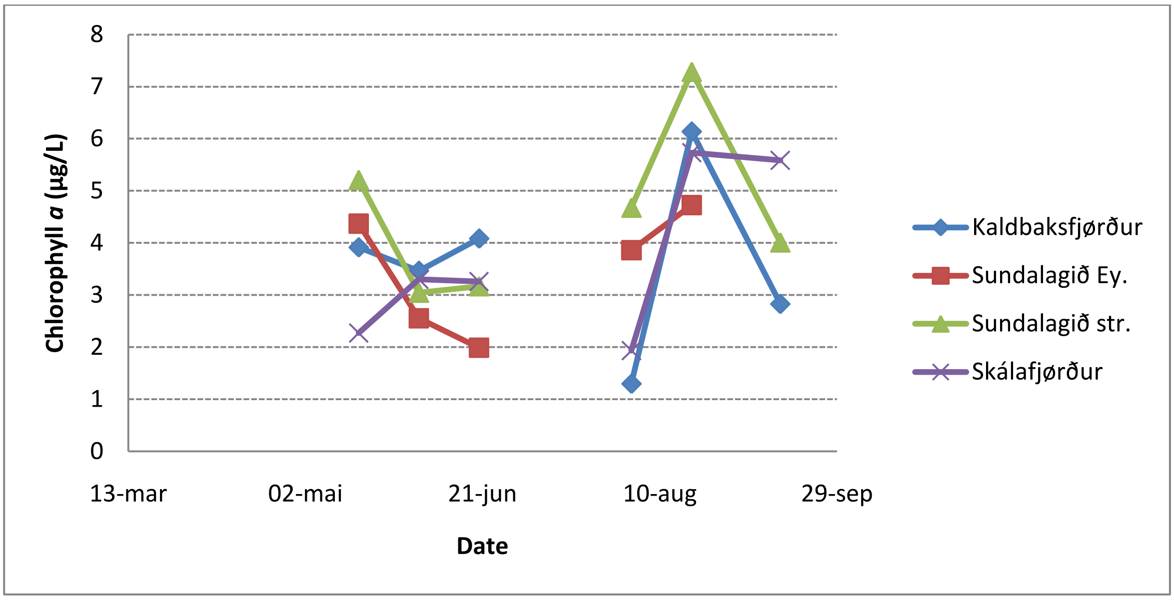

Fig. 3.7 The chlorophyll *a* data (µg/L) from the four study sites

The chlorophyll *a* data from the study site in Kaldbaksfjørður is plotted together with chlorophyll *a* from FAMRI (fig. 3.8). In fig 3.8 it is seen that the chlorophyll *a* data from the study site in Kaldbaksfjørður is almost identical to those from FAMRI.

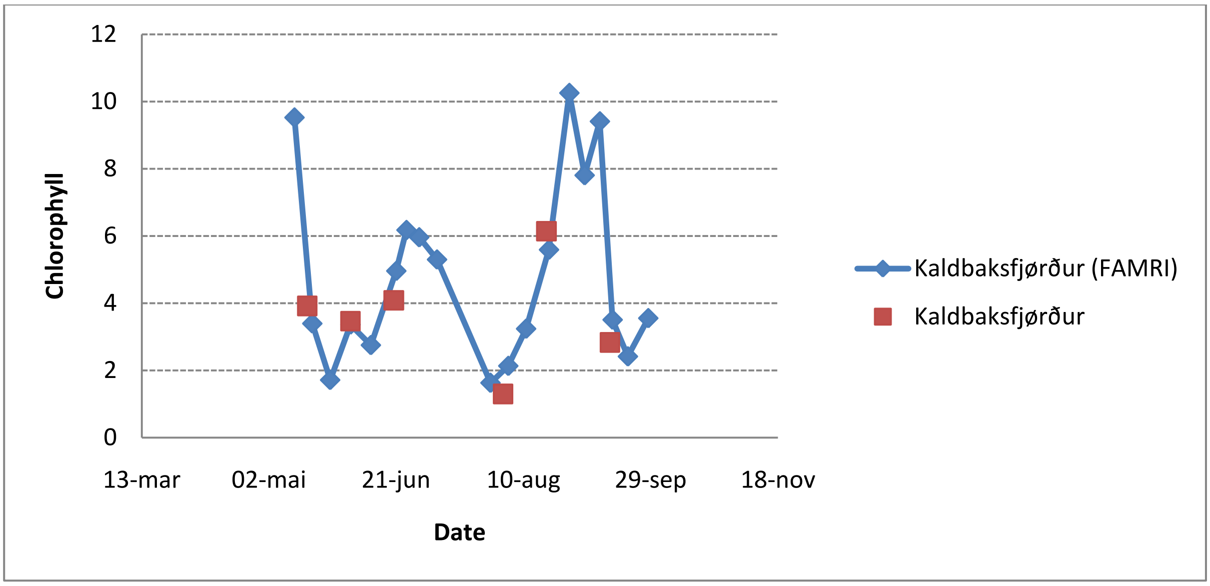

Fig. 3.8 Chlorophyll *a* data (µg/L) from FAMRI, measured in Kaldbaksfjørður and the chlorophyll *a* data (µg/L) from the study site in Kaldbaksfjørður.

3.2 Current measurements

The current measurements were made in all four sites for ~3-4 weeks from March 11th to May 16th. The current measurements were made at depths ranging from ~1-4 meters. The average current speed was highest in Sundalagið Str. (26.74 cm/s), 5.91 cm/s in Skálafjørður, 3.67 cm/s in Kaldbaksfjørður and the lowest measured average current speed was in Sundalagið Ey. (2.39 cm/s) (table 3.1).

Table 3.1. Date, depth and average speed of the current measurment at the four sites

Site	Date	Depth (m)	Average speed (cm/s)
Skálafjørður	January 26th to March 4th in 2011	~4	5.91
Sundalagið Ey.	March 11th to April 6th in 2011	~1	2.39
Sundalagið Str.	April 4th to April 27th in 2011	~2	26.74
Kaldbaksfjørður	April 27th to May 16th in 2011	~4	3.67

The North and East directions were calculated and the velocity vectors every 10 min. were plotted in fig. 3.9. In Sundalagið Ey. (a) the direction of the current is mostly in an East and West direction, but with low speeds. In Skálafjørður (c) the direction of the current is in a Northwest and Southeast direction. In Sundalagið Str. (d) the direction of the current is in a North and South direction, and in Kaldbaksfjørður (b) the direction of the current is in a Northwest and Southeast direction.

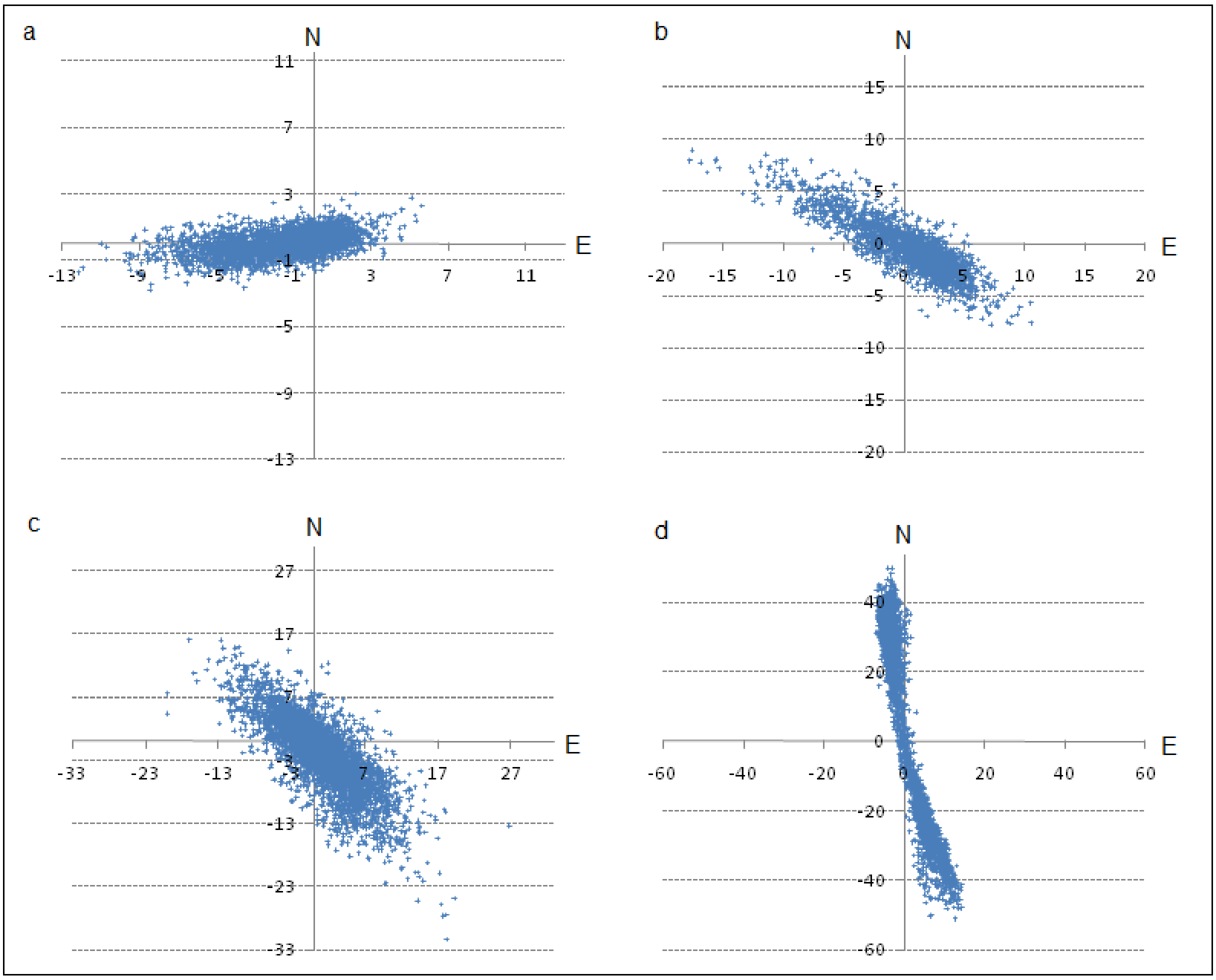

Fig. 3.9 Scatterplots of the current velocities at Sundalagið Ey. (a), Kaldbaksfjørður (b), Skálafjørður (c) and Sundalagið Str. (d). Note the different scale of the axes. The units of the plot are in cm/s.

The range of the speed measurements is shown in table 3.2 where the quantiles of the current speed are calculated. In Sundalagið Ey. the range of the speed measurements was from 0.02 cm/s to 12.27 cm/s, and 90 % of the measurements were 5.12 cm/s and below. In Skálafjørður the range of the speed measurements was from 0.12 cm/s to 36.28 cm/s, and 90 % of the measurements were 11.83 cm/s and below. In Sundalagið Str. the range of the speed measurements was from 0.25 cm/s to 52.62 cm/s, and 90 % of the measurements were 39.44 cm/s and below. In Kaldbaksfjørður the range of the speed measurements was from 0.04 cm/s to 19.72 cm/s, and 90% of the measurements were 6.78 cm/s and below.

Table 3.2 The quantiles of the current speed in the four sites

Quantile(Speed) in Sundalagið Ey.											
Percentage	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Speed(cm/s)	0.02	0.55	0.83	1.1	1.41	1.79	2.32	2.97	3.86	5.12	12.27
Quantile(Speed) in Skálafjørður											
Percentage	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Speed(cm/s)	0.12	1.52	2.31	3.1	3.94	4.87	5.89	7.11	8.86	11.83	36.28
Quantile(Speed) in Sundalagið Str.											
Percentage	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Speed(cm/s)	0.25	10.95	17.56	22.15	25.47	28.17	30.92	33.34	35.75	39.44	52.62
Quantile(Speed) in Kaldbaksfjørður											
Percentage	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Speed(cm/s)	0.04	1.08	1.67	2.16	2.64	3.17	3.72	4.38	5.2	6.78	19.72

3.3 Gonad maturity and spawning

Below are figures from the different stages of the gonad development, spawning and resting stage from both male and females. Fig. 3.10 illustrates the different stages of the male mussels, fig. 3.11 of the female mussel, and fig. 3.12 shows the spent stage of the gonads (same for both sexes). Note that not all stages were observed.

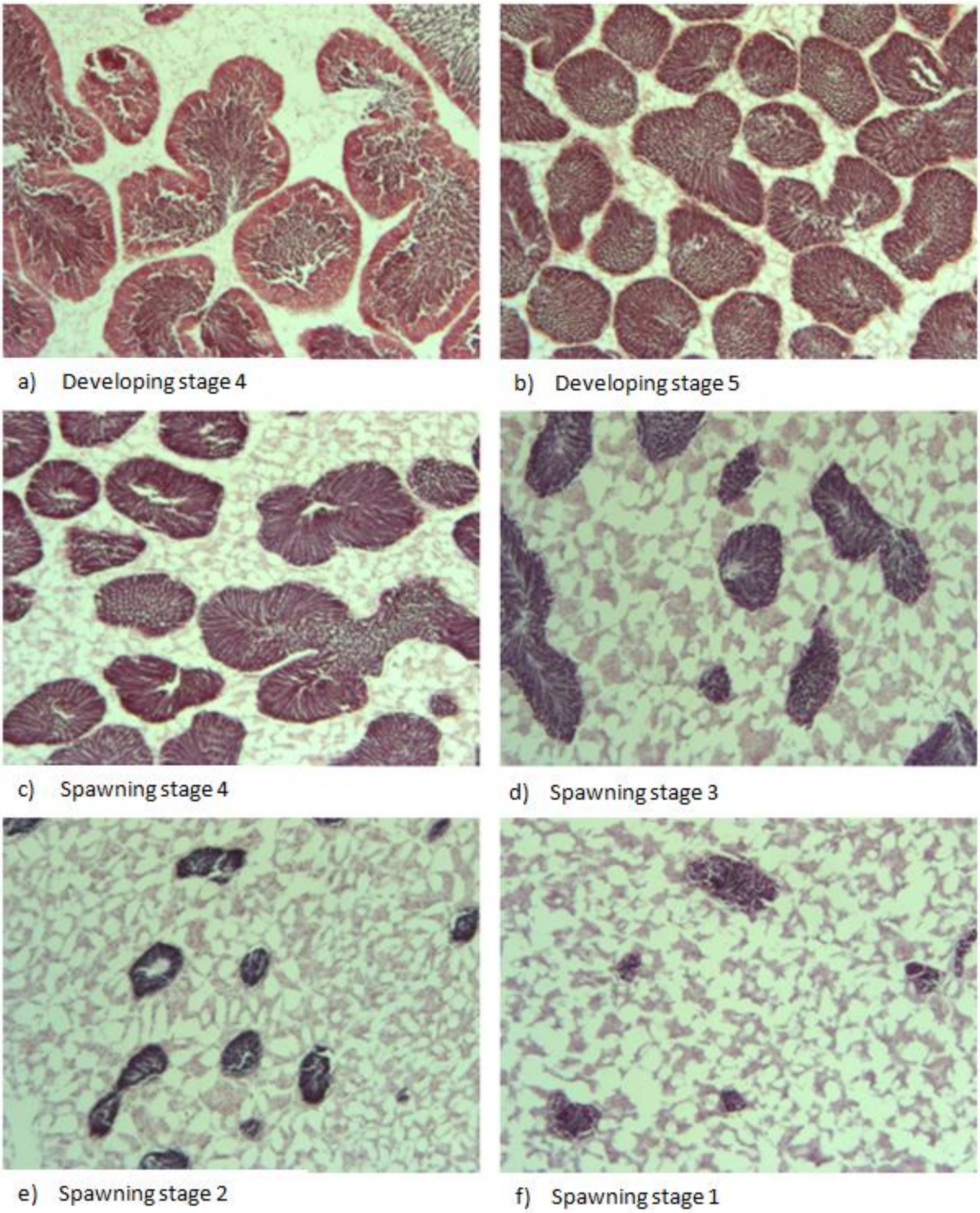

Fig. 3.10 Developing and spawning stages observed in male mussels.

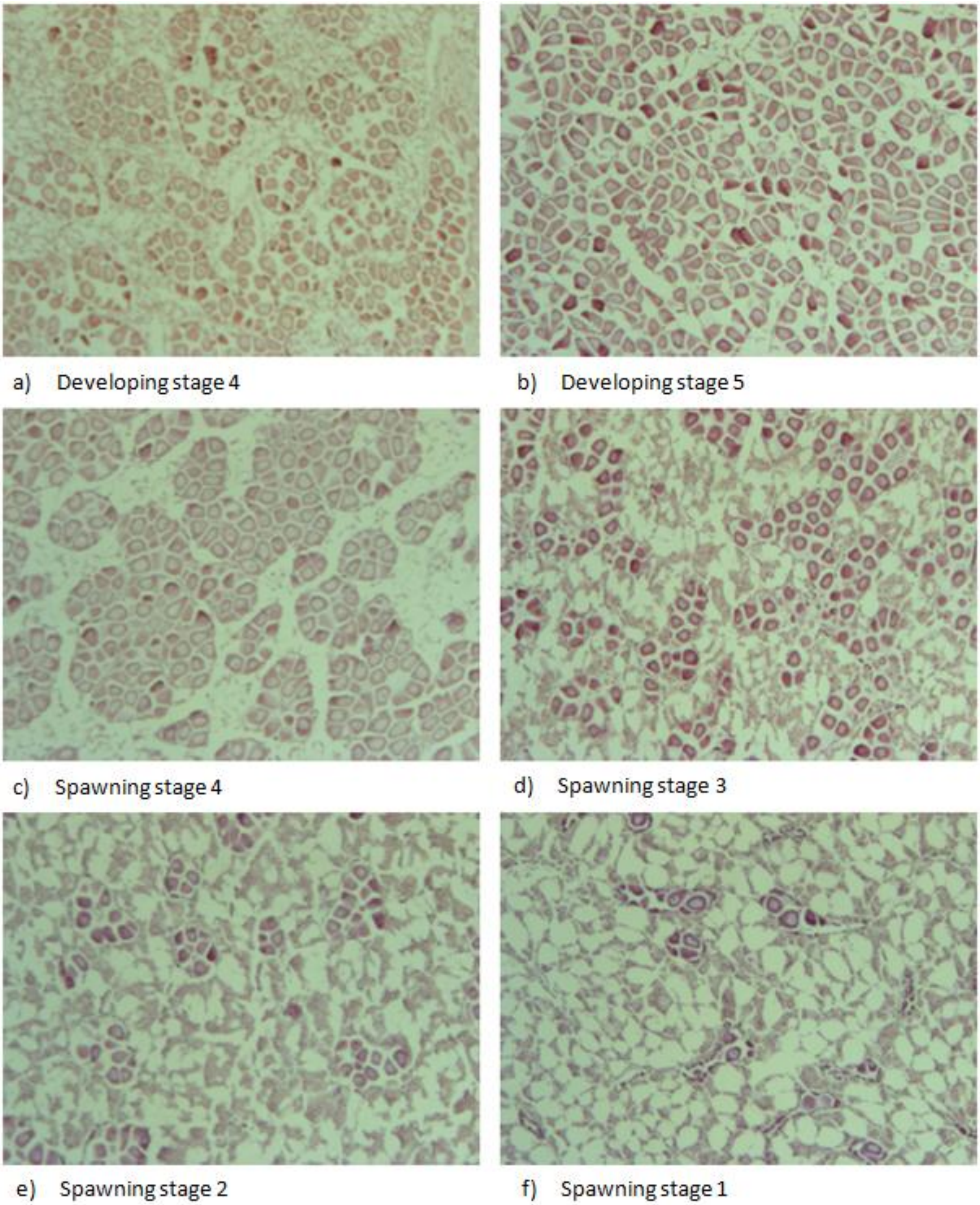

Fig. 3.11 Developing and spawning stages observed in female mussels

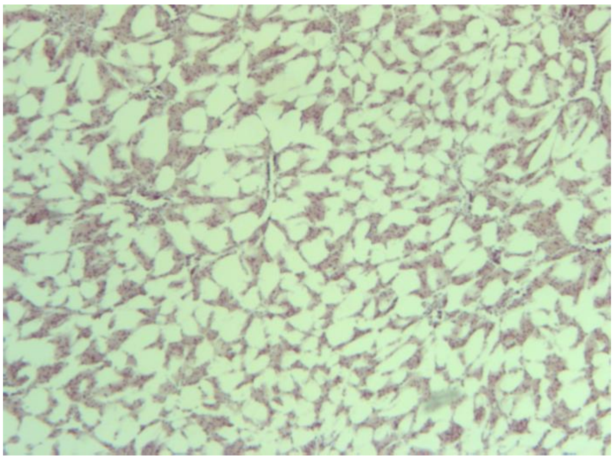

Fig. 3.12 The spent stage of mussels

The gonad index in fig. 3.13 shows that when our measurments started in mid April the mussels were fully mature and that the spawning was about to begin. A short spawning period was observed in the beginning of May, afterwards the curve flattened. In mid June, there was a distinct spawning period and the gonad index approached 0.

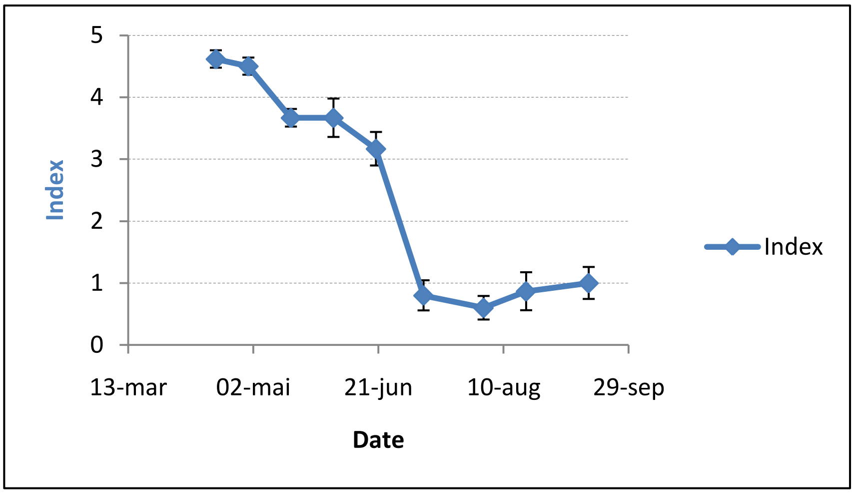

Fig. 3.13 The gonad index in Kaldbaksfjørður with standard error bars (SE = $\frac{s}{\sqrt{n}}$)

3.4 Larval abundance and sizes

In fig. 3.14 the relative larval abundance is plotted for the four sites. The abundance was highest in late June at Kaldbaksfjørður, Sundalagið Ey. and Str. At Skálafjørður the abundance is highest in the beginning of July, but the total number was highly variable between sites with Sundalagið Str. having the highest total number at the peak. Another small peak is observed for the same three sites in mid May, where Skálafjørður had a small peak in the beginning of May. In mid August the amount of larvae decreased to almost zero.

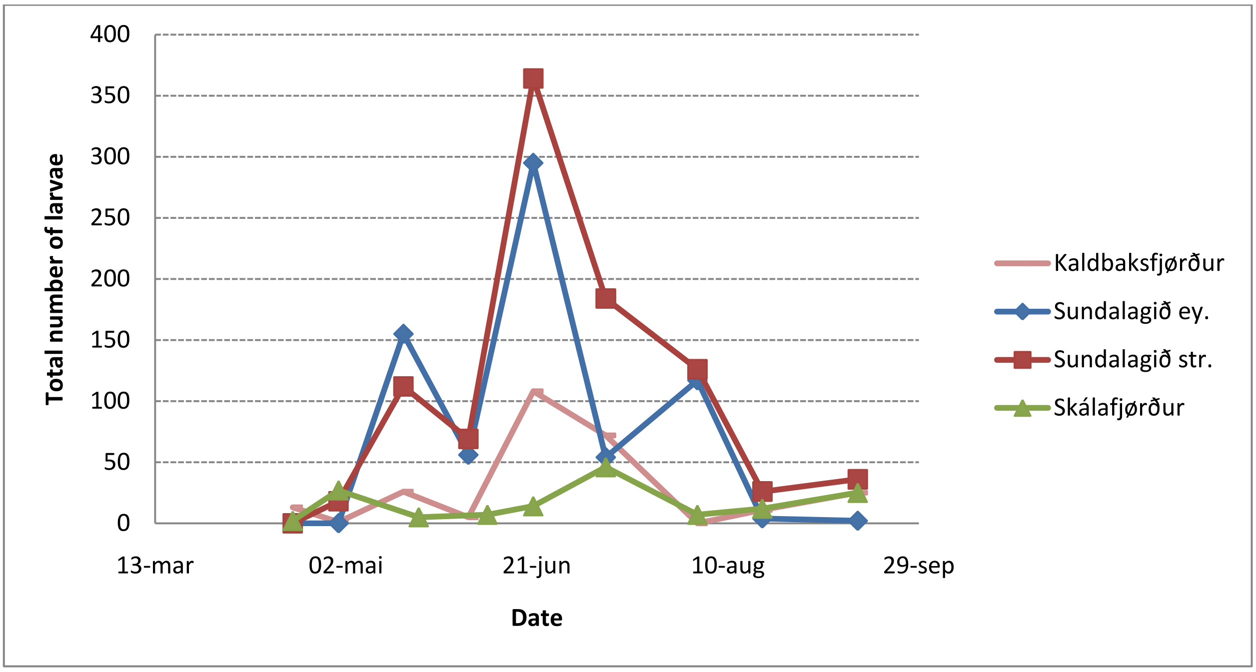

Fig. 3.14 Relative abundance of veliger larvae in Kaldbaksfjørður, Sundalagið Ey., Sundalagið Str. and Skálafjørður

In the box plot of the relative abundance of larvae (fig. 3.15) we see that the abundance seems higher on Sundalagið Ey. and Str. By setting up a contrast ANOVA, we get the result that both Sundalagið Ey. and Str. are significantly higher in abundance than Kaldbaksfjørður and Skálafjørður (P-value of < 0.01). No significant difference is between Kaldbaksfjørður and Skálafjørður, and no significant difference is between Sundalagið Ey. and Sundalagið Str.

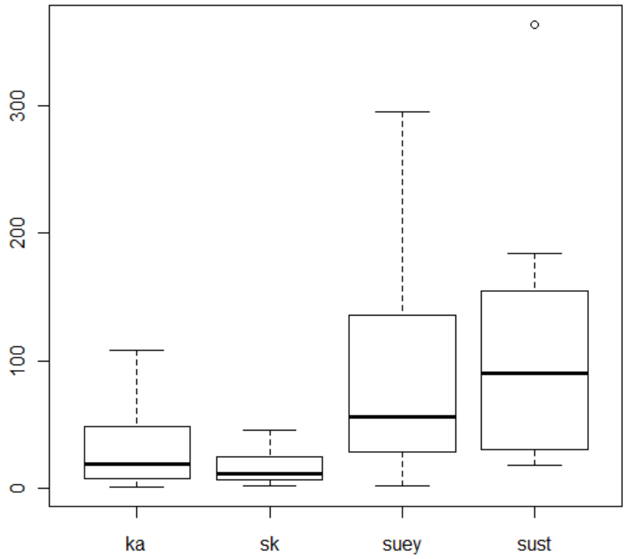

Fig. 3.15 The quartiles of the relative larval abundances as measured by the sampling nets at each site through the spring. Number of larvae (y-axis) and the sites (x-axis), ka = Kaldbaksfjørður, sk = Skálafjørður, suey = Sundalagið Ey., sust

Fig. 3.16 illustrates the sizes of the larvae. There was a steady increase in the total average sizes troughout the spring and summer. The stacked bars show an increase of the big larvae > 0,29 mm from mid June, whereas from April to the beginning of June almost all the larvae were below 0,29 mm. Note that on May 17th and on June 20th most small larvae (0.12-0.2 mm) were observed.

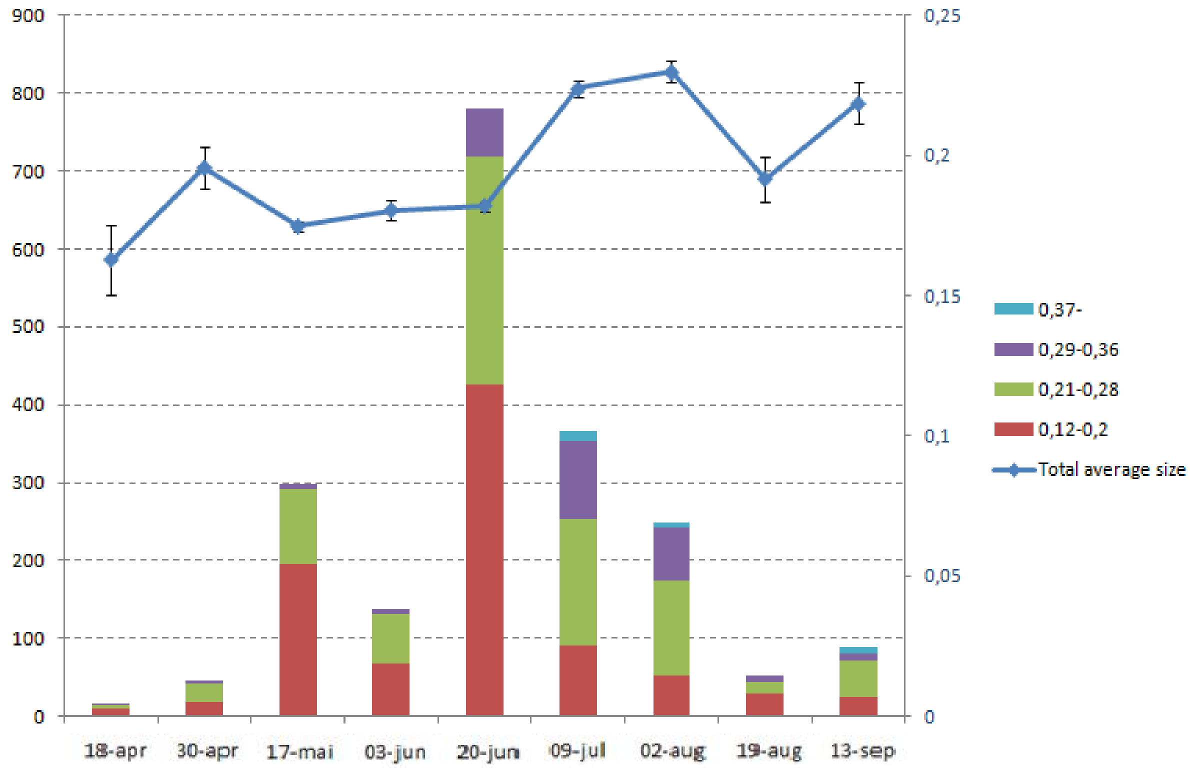

Fig. 3.16 The sizes of the larvae (mm) at all the sites (stacked bars), with number of larvae on the left y-axis, and the total average size of the larvae (mm), on the right y-axis, in all sites (line) with standard error bars (SE = $\frac{s}{\sqrt{n}}$).

If all the different sites are looked upon one by one (fig. 3.17), the same tendensies as in fig. 3.16 appears for Kaldbaksfjørður, Sundalagið Ey. and Sundalagið Str., and the higest number of small larvae were on May 17th and June 20th. In Skálafjørðurin, however, the first peak of small larvae was at April 30th and the second peak of small larvae at July 9th, although the realtive number of small larvae compared to larger ones on July 9th were low.

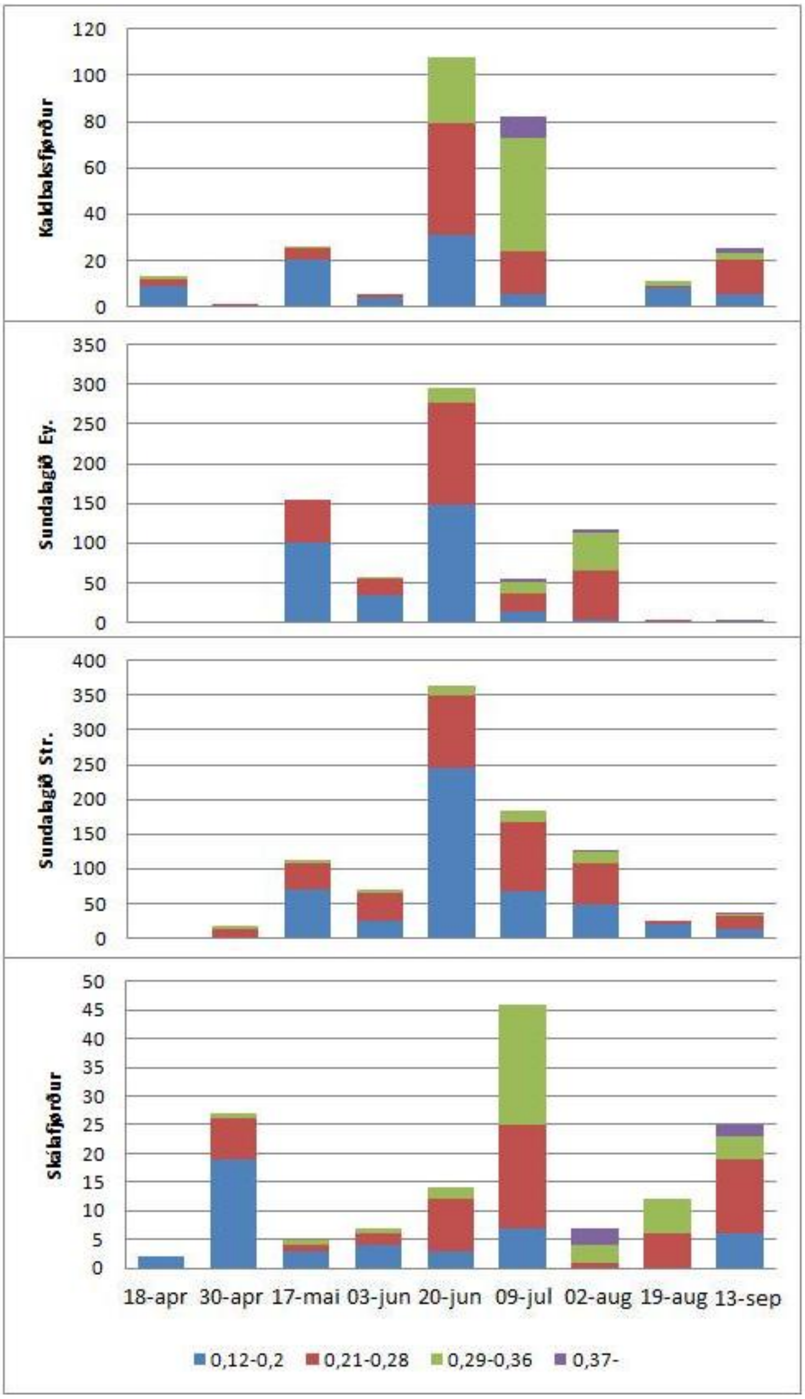

Fig. 3.17 Larval sizes (mm) at the different sites. The number of larvae is on th y-axis. Note the different scales of the y-axes.

3.5 Settlement: sizes and growth on ropes

In fig. 3.18 the number of settled mussels on the ropes at October 28th 2010 (Skálafjørður September 25th 2010) is shown. All three deployment dates show that Kaldbaksfjørður and Skálafjørður had the highest number of larval settlement, and Sundalagið Ey. has striking low numbers at all three deployments. The settling reached a top in Skálafjørður on the second deployment where the number was 816 per 18 cm, which corresponds to approximately 4533 settled mussel per meter.

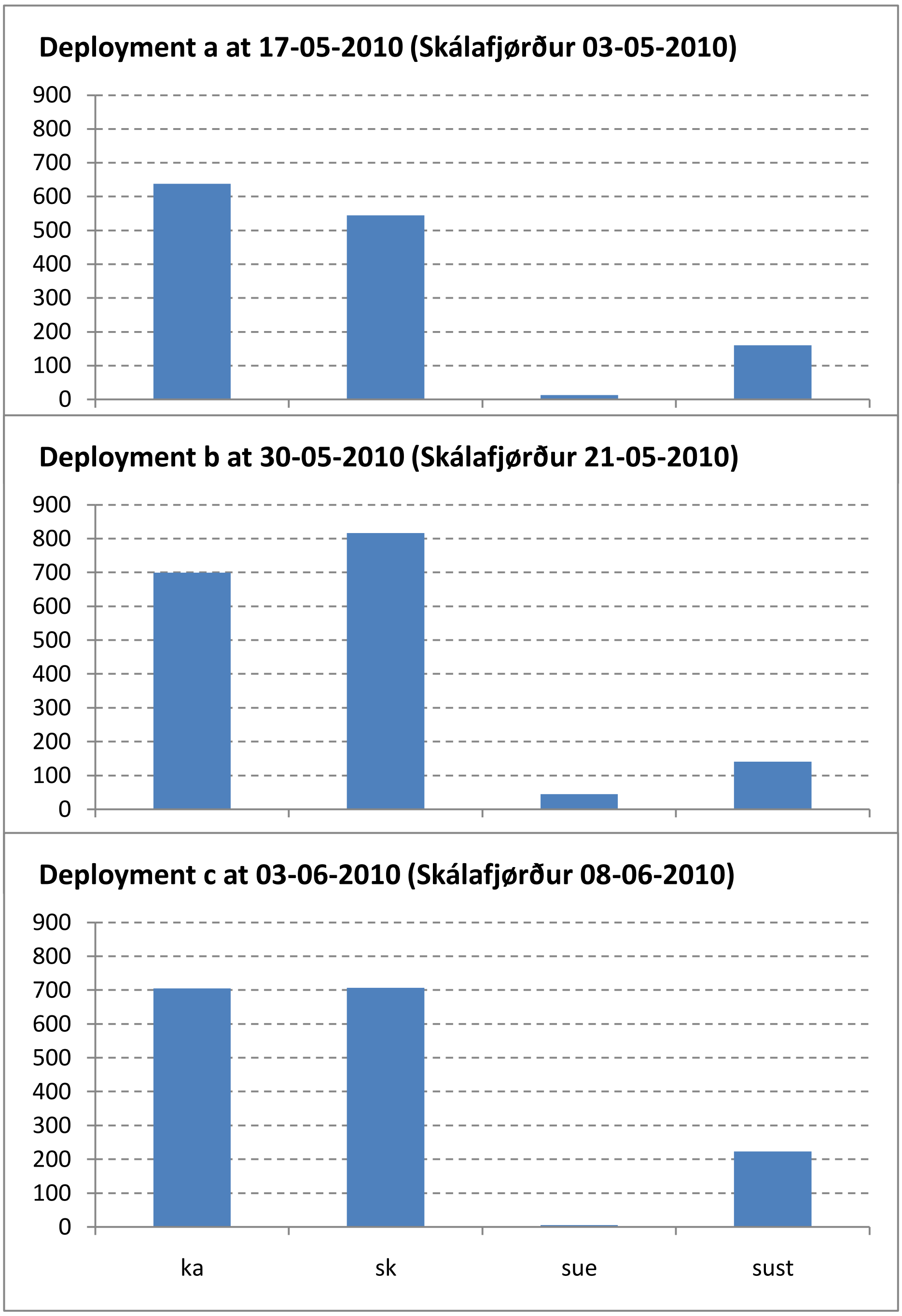

Fig. 3.18 The total number of settled mussel (y-axis) on September-October 2010 per 18 cm rope at the different sites and at the different deployment dates. ka = Kaldbaksfjørður, sk = Skálafjørður, sue = Sundalagið Ey., sust = Sundalagið Str.

The shell length of the settled mussels was significantly higher in Skálafjørður than in the other sites (P-value < 0.001) at all three deployments, and the shell length in Skálafjørður appears to decrease with deployment date. The lengths of the mussels in Kaldbaksfjørður were significantly longer than Sundalagið Ey. and Str. at all three deploment dates (P-value < 0.001). As seen in fig. 3.19 the number of mussels in Sundalagið Ey. and Str. were very low, and therefore there cannot be seen any trend in the declining sizes to date of the settlement. There was no significant difference between the lengths of the mussel in Sundalagið Ey. and Str. at deployment a and b, but at deployment c, the lenghts in Sundalagið Ey. were significantly higher than Sundalagið Str. (P-value < 0.001).

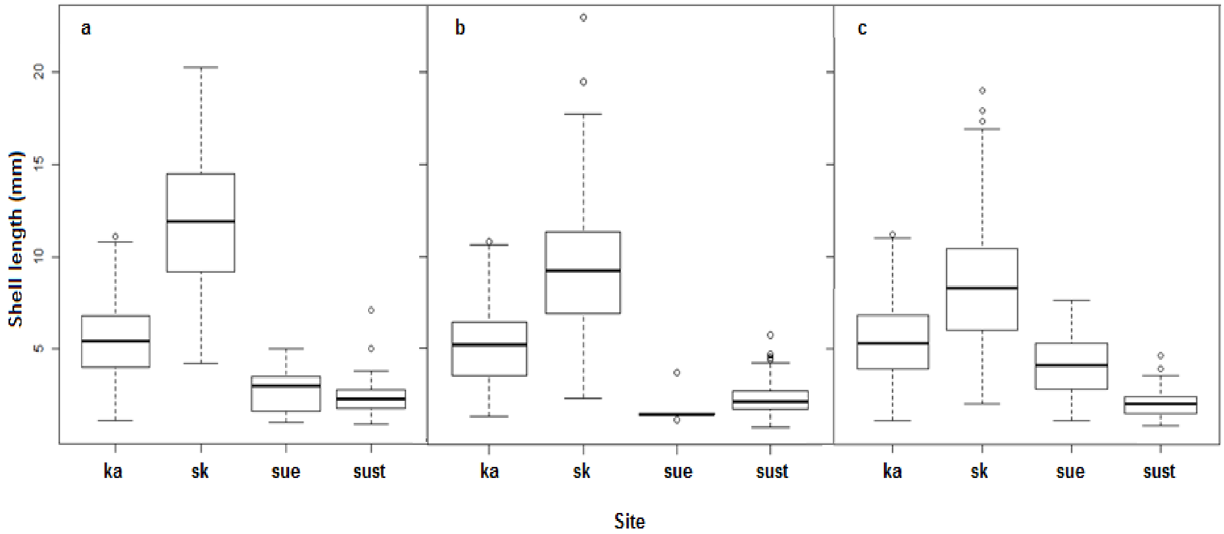

Fig. 3.19 The quartiles of the shell length (mm) on September-October 2010 of the settled mussel at the different sites and at the different deployment dates a, b and c. (ka = Kaldbaksfjørður, sk = Skálafjørður, sue = Sundalagið Ey. and sust = Sundalagið Str.)

Table 3.3 shows that the mean length in Skálafjørður was higher at all three deployments, with the first deployment having the highest mean length. It also shows that both sites at Sundalagið had the lowest mean lengths, and in Sundalagið Ey. the mean length was greatest at deployment c, whereas in Sundalagið Str. and Kaldbaksfjørður the mean lengths were very similar at all three deployments.

Table 3.3 The average lengths of the mussels at the different sites at the different deployment dates a,b and c

Site	Deployment a	Deployment b	Deployment c
Kalbaksfjørður	5,47 mm	5,09 mm	5,40 mm
Skálafjørður	11,92 mm	9,28 mm	8,41 mm
Sundalagið Ey.	2,78 mm	1,82 mm	4,27 mm
Sundalagið Str.	2,37 mm	2,26 mm	2,00 mm

3.6 Growth of the one year old mussels

These mussels were deployed from May 3rd to September 25th 2010 on Skálafjørður and from May 17th to October 28th 2010 on Sundalagið Ey., Sundalagið Str. and Kaldbaksfjørður, and they had been growing in Kaldbaksfjørður until the deployment dates. The average starting length of the one year old mussels before deployment at the different sites was 8.30 mm. Deployment at Skálafjørður was on May 3rd and on May 30th 2010 on the other three sites. The measurements made of the growth were made at Skálafjørðurin on September 25th and on October 28th 2010 on the three other sites. The growing period was therefore 4 months and 22 days in Skálafjørðurin, and 4 month and 28 days in the other three sites.

The meat percent in the one year old mussels grown on Skálafjørður shown in fig. 3.20 was significantly higher than on the other places (P-value < 0.001). The three other sites had almost similar dry meat percentage with no significant difference.

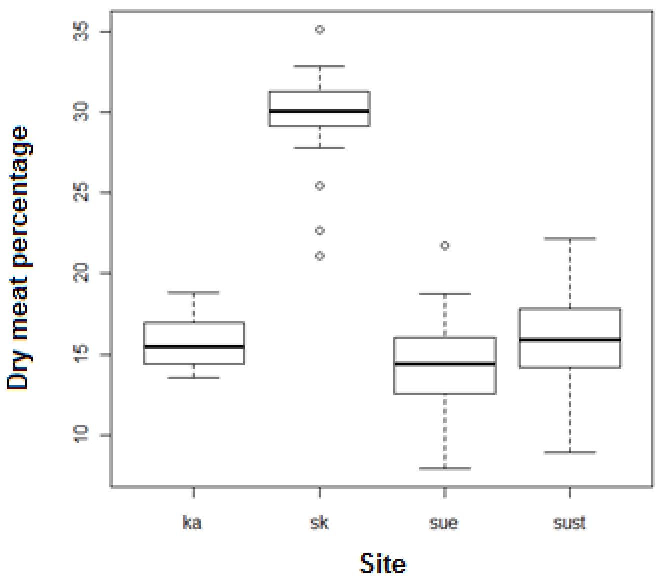

Fig. 3.20 The quartiles of the dry meat percentage (%) of the different sites

Length-weight relationship was fitted to the formula $W = a \times L^b$, where W is the dryweight of meat in grams, L is the shell length in millimeters, and a and b are constants. As shown in fig. 3.21 the mussels in Skálafjørður had the highest dryweigth per cm shell length, where Sundalagið Ey. had least dryweight per mm shell length. Kaldbaksfjørður and Sundalagið Str. had very similar numbers, small mussels, but a higher meat weigth than Sundalagið Ey. R^2 for Sundalagið Str. was only 0.75. The 5 mussels at approximately 40 mm length from Sundalagið Ey. had high differences in meat weight.

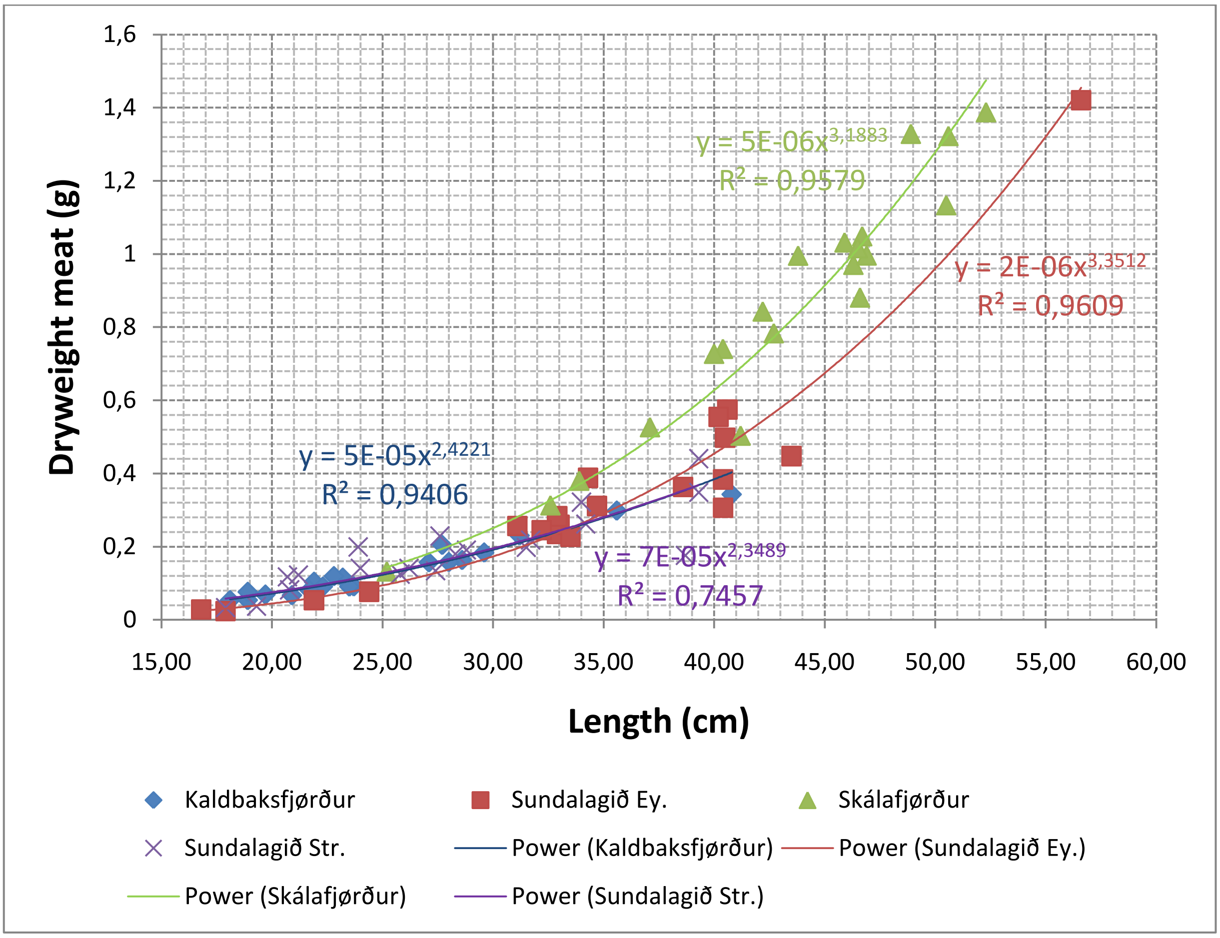

Fig. 3.21 The dryweight of the meat in grams (y-axis) and the length in mm (x-axis) of the grown mussels at each site

3.6.1 Bulk size

The bulk size was measured by cleaning mussel of 18 cm of the rope, and weighing the mussels wet. As seen in table 3.4 the weight of the bulk was highest in Skálafjørður and somewhat lower in Sundalagið Ey. At the site in Kaldbaksfjørður the mussels were very small and almost only found in a small bulk at the end of the rope. This is a site easily accessed by people, and others also had mussels growing there for own use. The most likely explanation for the missing mussels is that people have been collecting them. In Sundalagið Str. there were also only a small number of mussels in the end of the rope, this is most likely due to the high current which carried seaweed etc. which got entangled in the ropes and made the mussels lose their grip. Because of these circumstances it is of no interest to measure the bulk weight at these two particular sites.

Table 3.4 Bulk sizes of the one year old mussels (Kg/18 cm)

Site	Bulk weight	Observations
Kaldbaksfjørður		A lot of barnacles, people collecting mussels from the ropes and few eider ducks
Skálafjørður	1.66 kg/18 cm	
Sundalagið Ey.	1.13 kg/18 cm	A lot of eider ducks
Sundalagið Str.		High current, a lot of eider ducks. Barnacles and large drifting seaweed.

The average shell length of the one year old mussels was significantly highest in Skálafjørður (p-value <0.001, by contrast ANOVA) compared to all three other sites, as is indicated in fig. 3.22.

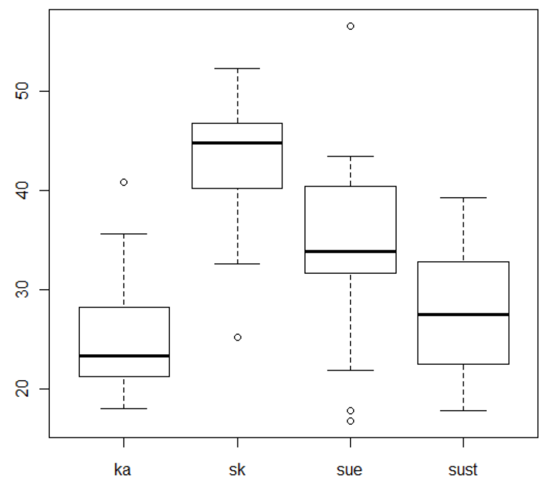

Fig. 3.22 The quartiles of the shell length (mm) of the different sites

Skálafjørður also had most kg per meters (kg per meters only measured at two sites) as seen in table 3.5. Sundalagið Ey. significantly had the second highest average shell length (p-value <0.001) and then Sundalagið Str. and Kaldbaksfjørður, with no significant difference between them.

Table 3.5 Growth of the one year old mussel

Site	Weight of mussels	Average shell length
Kaldbaksfjørður	-	25.21 mm
Skálafjørður	9.21 kg/m	43.02 mm
Sundalagið Ey.	6.26 kg/m	34.32 mm
Sundalagið Str.	-	28.03 mm

Growing time:

Skálafjørður: deployment a, and one year old mussels: 145 days

Kaldbaksfjørður and Sundalagið: one year old mussels: 151 days

Kaldbaksfjørður and Sundalagið: deployment a: 164 days

The one year old mussels had been growing for as many days as the settled mussels, on Skálafjørður, while on the other three places the settled mussels had been growing for 13 more days than the one year old mussels (this is for deployment a only). The growing time for the settled mussels was 145 and 151 days respectively. Growth of settled mussels (deployment a) is shown in table 3.6. The settled mussels in Skálafjørður had grown 11.92mm in 145 days. The settled mussels in Kaldbaksfjørður had grown 5.47 mm in 164 days.

Table 3.6 Growth of the settled mussels from Skálafjørður and Kaldbaksfjørður (deployment a)

Site	Length	Growing time	Growth/ day
Skálafjørður	11.92 mm	145 days	0.08 mm
Kaldbaksfjørður	5.47 mm	164 days	0.03 mm

The growth of the one year old mussels starts the measured growth period from 8.3 mm, which was the length they had grown the first year in Kaldbaksfjørður. When they had been growing for 145 days in Skálafjørður they had reached a length of 43.02 mm, which is a growth of 34 mm for 145 days. In Sundalagið Ey. the mussels had become 34.32 mm long, which is a growth of 26.02 mm in 151 days (table 3.7).

Table 3.7 Growth of the one year old mussels in Skálafjørður and Sundalagið Ey.

Site	Start length	End length	Growth	Growing time	Growth/ day
Skálafjørður	8.3 mm	43.02 mm	34.00 mm	145 days	0.23 mm
Sundalagið Ey.	8.3 mm	34.32 mm	26.02 mm	151 days	0.17 mm

3.7 Genetics

3.7.1 Glu-5’

Our samples identified two bands, the homozygotes 386bp (Fig. 3.25) and 416bp (Fig 3.24) and the heterozygote 386/416 (Fig. 3.23).

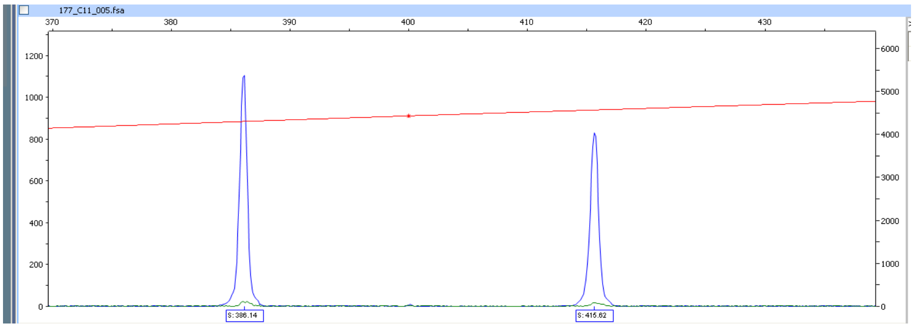

Fig. 3.23 Glu-5' heterozygote 386/416

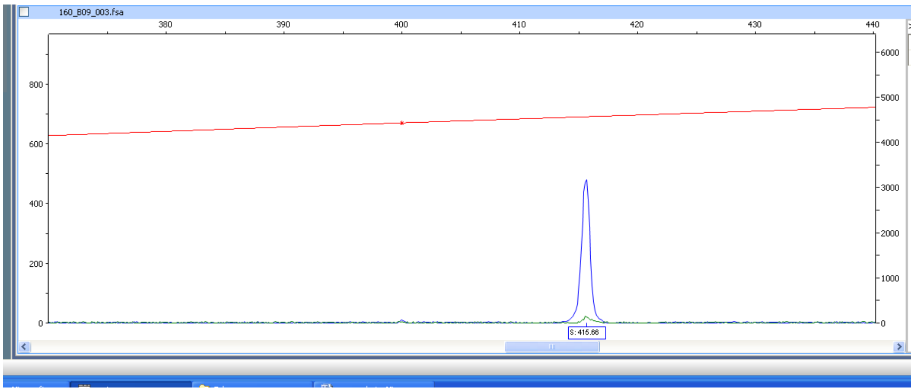

Fig. 3.24 Glu-5' homozygote 416/416

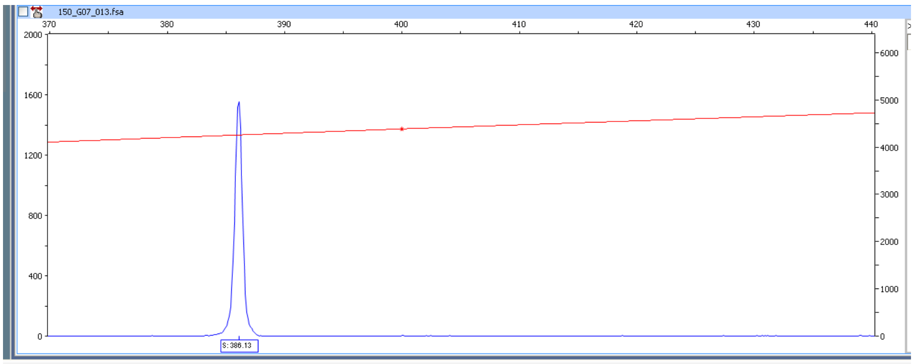

Fig. 3.25 Glu-5' homozygote 386/386

The genotypic frequencies showed that the 386 homozygote is most frequent, with a frequency of 0.73. The 386/416 heterozygote had a frequency of 0.19, and the 416 homozygote least frequent with a frequency of 0.09 (Table 3.8).

Table 3.8 Number of samples (n) and genotypic distribution of Glu-5' alleles for the four locations sampled

Glu-5'	**Kaldbaksfjørður**	**Nesvík**	**Saksun**	**Skálafjørður**	
n	48	48	47	48	**Average**
386/386	0.71	0.72	0.71	0.77	0.73
386/416	0.21	0.14	0.25	0.14	0.19
416/416	0.07	0.14	0.04	0.09	0.09

3.7.2 Glu-3'

Rawson et al. (1996) identified a PCR product of 220bp in *M. edulis* and 214bp in *M. galloprovincialis*. Our analysis gave consistently a PCR product of 230bp (fig. 3.26).

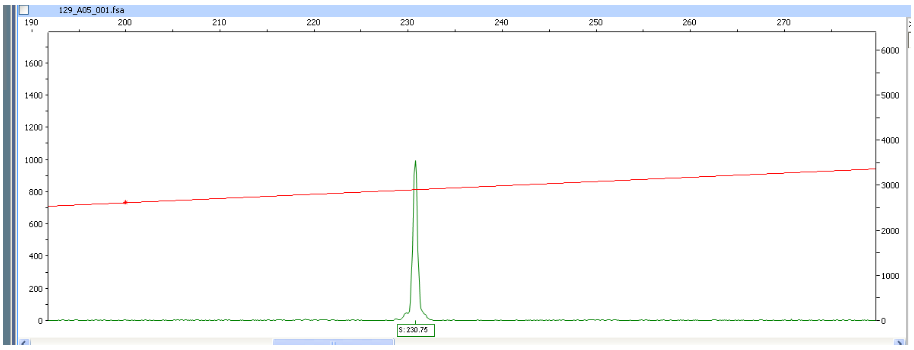

Fig. 3.26 Glu-3' homozygote 230/230

4 Discussion

4.1 Salinity, temperature and flourescence

In fig. 4.1 all temperature data are plotted together. It can be seen that the temperature at Sundalagið, Kaldbaksfjørður and Skálafjørður were almost identical at all sites, ranging from ~7˚C in the beginning of May to a maximum level of 11-12˚C in mid August, and then slightly decreasing again during autumn.

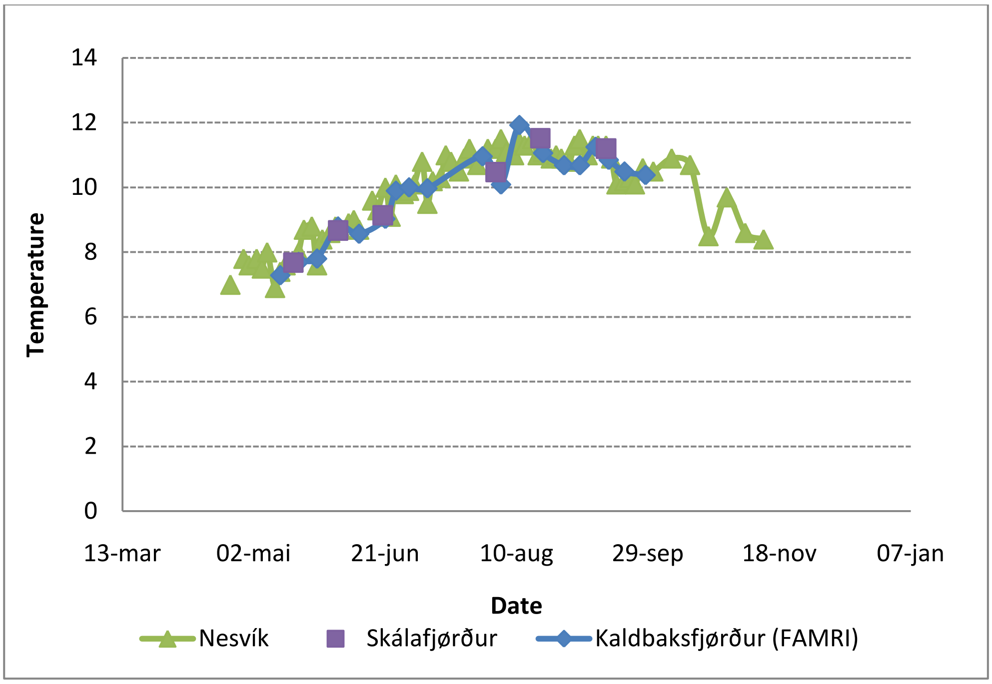

Fig. 4.1 Temperature (˚C) from Nesvík (representing both sites at Sundalagið), Kaldbaksfjørður (FAMRI) and from the study site in Skálafjørður.

The salinity measurements ranged from 33.9 to 35.2‰, with the sites in Sundalagið having the lowest concentrations, but this was expected because the maximum depth of the measurements were only ~2 m in Sundalagið Ey. and ~4 m in Sundalagið Str. In Kaldbaksførður maximum depth was ~8 m, and in Skálafjørður the maximum depth was ~6,5 m. There was only a slight difference in the salinity. The salinity measurements did not point out any single site with a deviant salinity.

The chlorophyll *a* concentrations were quite even for the different sites (fig. 4.2). The concentrations in Kaldbaksfjørður and Skálafjørður were quite similar, and the concentrations at both sites in Sundalagið were also almost identical, as was expected since these sites are very close to each other and share the same water mass. Since the chlorophyll *a* concentrations were so similar and there were only a few measurements, any single site cannot be pointed out with either the lowest or the highest chlorophyll *a* concentration during the whole period. Overall the data indicate that all sites had quite similar phytoplankton concentrations, which temporally were highly variable. Gaard et al. (2011) have shown that primary production and phytoplankton concentrations in Faroese fjords are highly dynamic, depending on weather conditions (mainly wind and precipitation).

Studies in Iceland (Thorarinsdóttir, 1996) have shown the highest mussel growth in late summer, and this growth was related more to phytoplankton availability rather than temperature. Our studies showed highest chlorophyll *a* concentrations in spring and late summer. Generally the phytoplankton concentrations were high. Clausen and Riisgård (1996) found that the maximum mussel growth rate was obtained at an algal concentration of 5 µg/L chlorophyll *a*. The measurements from Kaldbaksfjørður from May to September (fig. 4.2) had an average chlorophyll *a* of 4.9 µg/L and the chlorophyll *a* concentrations are above the concentrations for maximum mussel growth rate at periods in the summer.

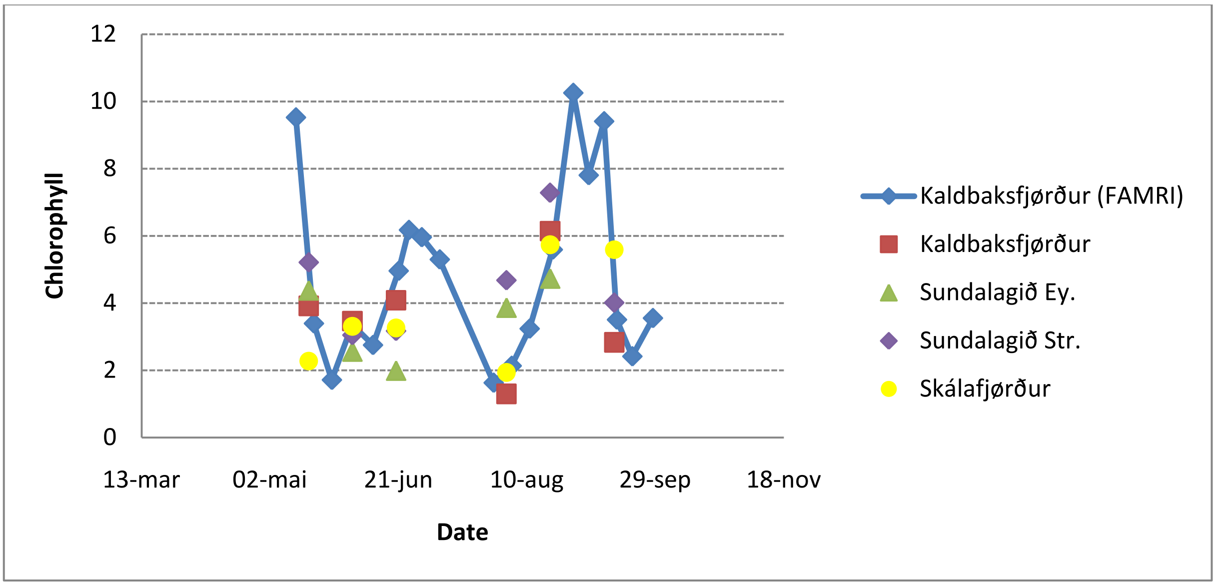

Fig. 4.2 Chlorophyll *a* concentrations (µg/L) from all study sites plotted together, the blue line is the data from FAMRI measured in Kaldbaksfjørður.

Examples of high average annual chl *a* concentrations are 16 µg/L in Ria de Arousa in Spain, where mussel production in this region is the highest in Europe and one of the most intensive in the world, giving employment to 9000 people directly (Figueiras, 2002). The average chl *a* in the growing season is 7.5 µg/L in Oosterschelde Nederlands (Figueiras, 2002). These farming sites are located on upwelling areas, and are shallow bays with high tidal amplitude leading to resuspension of organic material and an additional increase in food availability.

4.2 Current

The different sites showed very different current measurements, where Sundalagið Ey. with 2.4 cm/s had the lowest average current speed and rarely exceeded 5.1 cm/s, Kaldbaksfjørður had an average speed of 3.7 cm/s, and 90% of the measurements were 6.78 cm/s and below. Skálafjørðurin had an average current speed of 5.9 cm/s and 10% of the time it was above 11.8 cm/s, while Sundalagið Str. had the highest average current speed of 26.7 cm/s and rarely was below 10.9 cm/s. 10% of the time the current speed was above 39.4 cm/s in Sundalagið Str. and the highest measured speed was 52.6 cm/s.

It is not only the chlorophyll *a* concentration that is essential for growth of mussels, but the chlorophyll *a* that is available. Current strength is an important factor for the filtration rate of *M. edulis* (fig.1.6). The low current speeds in Sundalagið Ey. (5.1 cm/s and less), which are at a low filtration rate for the mussels at all times according to Sobral and Widdows (2000), might reduce the growth of the mussels. The same might be the case for Kaldbaksfjørður with a somewhat higher current speed, but rarely exceeding 6.8 cm/s. Although Skálafjørður also had relatively low current speeds (average speed = 5.9 m/s), they were approximately 15% of the time at optimal filtration rate (~10 cm/s), and thereby might have a higher growth.

The current speeds in Sundalagið Str. were very high (fig. 4.3), and were in fact of the chart (fig. 1.6) approximately 10% of the time (table 3.2). These high current speeds should give a high growth for the mussels, but with the high current other problems followed. The current carried a lot of large seaweeds such as *Laminaria saccharina*, *Laminaria hyperborea* and *Laminaria digitata* (fig. 4.4) that got entangled in the ropes. This made the ropes wrap together, and may have caused some of the mussels to lose their grip on the ropes and in other ways disturb the growth of the mussels.

Fig. 4.3 Farming site in Sundalagið Str. The high current forced the lines in an almost horizontal direction

Fig. 4.4 Farming site in Sundalagið Str. There was trouble of the high current forces, carrying seaweed etc. which got entangled on the lines

4.3 Gonad maturity and spawning

When gonad index and larval abundance from Kaldbaksfjørður are plotted together (fig. 4.5) it can be seen that the spawning occurred from spring to midsummer, but the peak of the larvae was in mid June to late June, following the peak spawning period that started in mid June. A small peak of larval abundance can also be seen in mid May after the first small spawning period in the beginning of May.

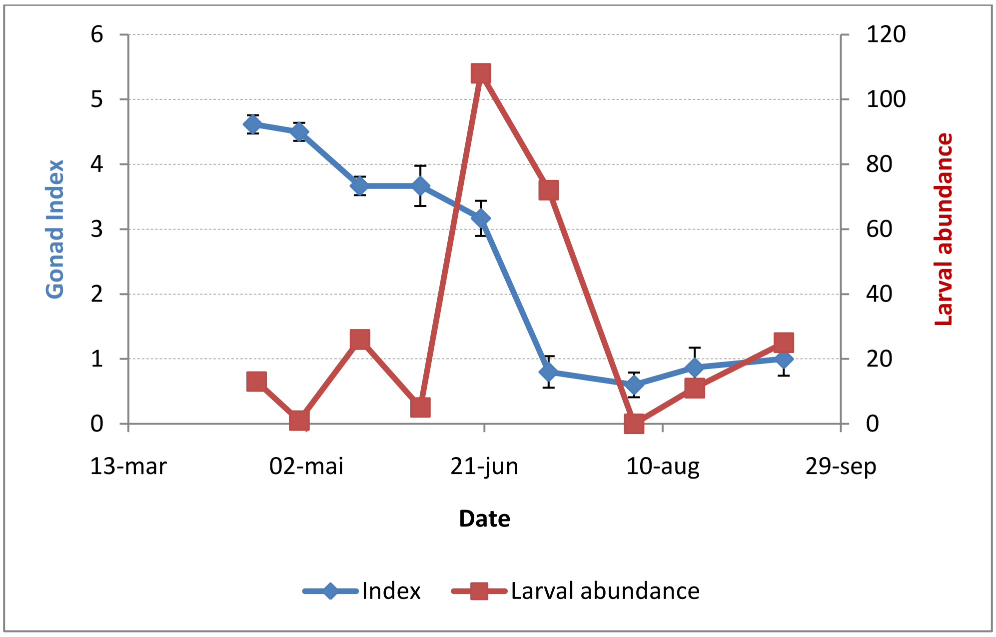

Fig. 4.5 The gonad index with standard error bars (SE = $\frac{s}{\sqrt{n}}$) and the larval abundance as measured by the sampling net in Kaldbaksfjørður. Number of larvae on the right y-axis.

In fig. 4.6 the gonad index is shown with the temperature measurements from Kaldbaksfjørður. The distinct spawning period started when the temperature reached ~10˚C in late June. Our temperature data only goes as far back as 12th of May, which unfortunately is after the first minor spawning period.

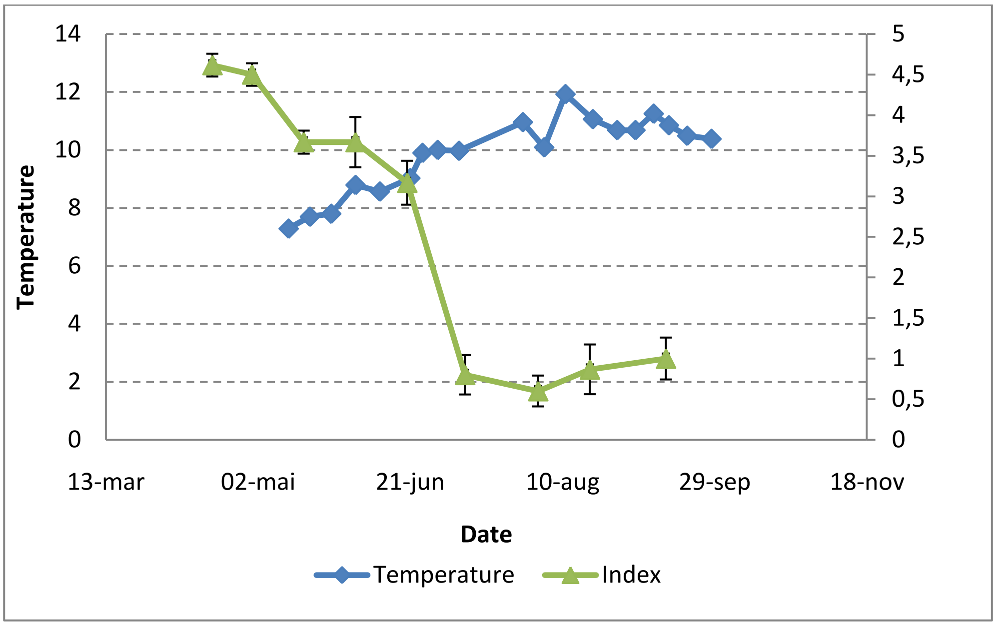

Fig. 4.6 The gonad index with standard error bars (SE = $\frac{s}{\sqrt{n}}$) and the temperature (°C) in Kaldbaksfjørður

The spawning periods, as obtained by the gonad index, fit very well with the relative larval abundance at these times (fig. 4.5). The gonad index fit well with the abundance of small larvae on all sites together on these dates (fig. 4.7) as well as for the dates with the highest abundance of small larvae in Kaldbaksfjørður (fig. 3.17).

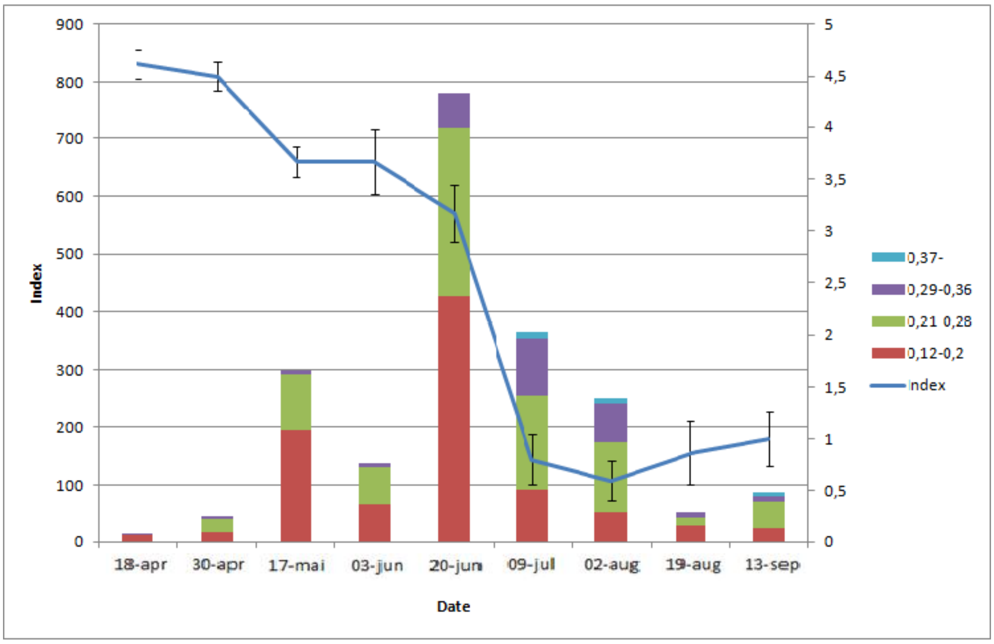

Fig. 4.7 The average larval sizes for all sites together (stacked columns) and the gonad index (blue line) with standard error bars (SE = $\frac{s}{\sqrt{n}}$)

One single factor triggering spawning of *M. edulis* is not known, and most likely it is triggered by a combination of several factors. Temperature is a widely acknowledged factor influencing mussel spawning (Chipperfield, 1953; Wilson and Seed, 1974; Podniesinski and McAlice, 1986; Thorarinsdóttir, 1996). However, since the distribution range of *M. edulis* is very wide, geographically as well as regarding temperatures, the actual temperature that may trigger spawning must assumed to be influenced by adaption to local temperatures. In fig. 4.6 we see that the start of the spawning was at the end of April-beginning of May, and the temperature was still rising. At our first temperature measurement on May 12th the temperature is around 7˚C, and unfortunately we did not have temperature data from Kaldbaksfjørður just when the spawning started or just prior to the spawning. It is likely that there has been a rise in the temperature at this time. Although no rise in temperature was seen in the sea temperature on the Faroese shelf during this period (FAMRI, unpublished data), there is a very distinct rise in the air temperature in Tórshavn at the end of April (fig. 4.8), and this might have increased the sea temperature in the upper layers of the fjords at this time.

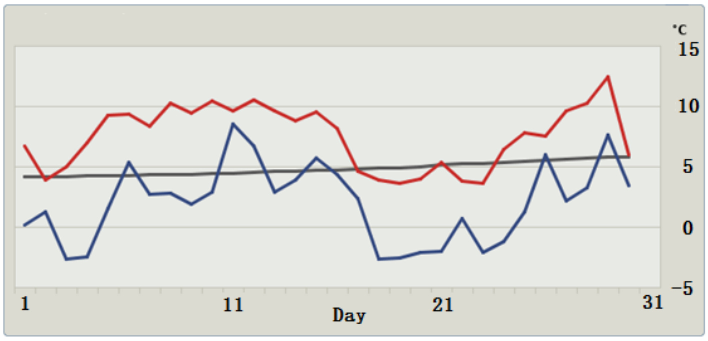

Fig. 4.8 The air temperature (˚C) in Tórshavn in April 2010. The red line shows the highest temperature, while the blue line shows the lowest temperature on each day. The gray line is the average temperature this month from 1961-1990.

In the temperature measurements from Nesvík, north of Sundalagið, there was a small rise in temperature, up to ~8˚C in the end of April, although these measurements were from 18 m depth (fig. 3.3). This temperature increase might have triggered the first spawning period. The major spawning period started when the temperature reached around 10˚C. This is very similar to the measurements made in Iceland by Thorarinsdottir (1996), but here the major spawning period is somewhat earlier, from the beginning of June to approximately July 10th, whereas in Iceland it took place in the middle of July to the middle of August. The temperatures measured at our study sites were low compared to the countries with the most mussel farming in southern Europe. In a farming site such as the Thau lagoon, France, the temperature is already at ~10˚C in March, and increases steadily to ~25˚C in August (De Casabianca et al. 1997). Although Faroese mussels obviously spawn at much lower temperatures than in southern Europe, the quite late spawning of mussels in the Faroese fjord compared to warmer regions in southern Europe, may be due to lower temperatures.

Studies by Himmelman (1975) showed that mussels spawned when exposed to phytoplankton in laboratory, indicating that some substance bound to or released by phytoplankton stimulates spawning. Others have also found strong relations between the spring bloom and the spawning of mussels (Newell et al., 1982; Kautsky, 1982). Our studies indicate some degree of relation between the phytoplankton and the gonad index. The chlorophyll *a* concentrations were not measured at the start of the spawning, but were high (~10 µg/L) in the middle of the first spawing peak. Afterwards there was a lowering of the phytoplankton to ~2 µg/L and the spawning stopped. It continued when the chlorophyll *a* concentrations began to rise again at the start of the second and major spawning peak (fig. 4.9)

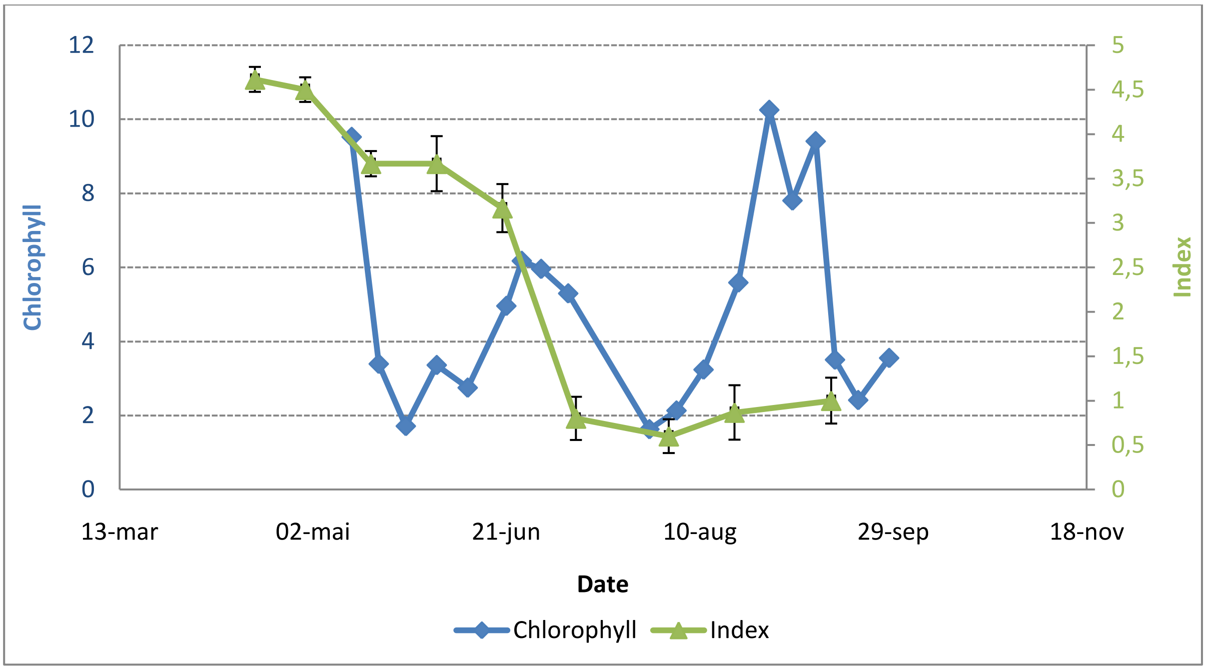

Fig. 4.9 The gonad index with standard error bars (SE = $\frac{s}{\sqrt{n}}$) and the chlorophyll *a* concentrations (µg/L) in Kaldbaksfjørður

Other results have indicated that the spawning started at dates of spring tides (Chipperfield, 1953; Podniesinski and McAlice, 1986). Since the time between sampling for identification of gonad index is too long, compared to the short intervals between spring tides, a such relationship cannot be verified in our study (Fig 4.10). However, as mentioned earlier, the current forces in the fjords are not driven by the tides, but primarily of wind and rainfall, and if the mussels spawn at high current speeds in Faroese fjords to ensure a good dispersion, it would not be seen in the tidal curve.

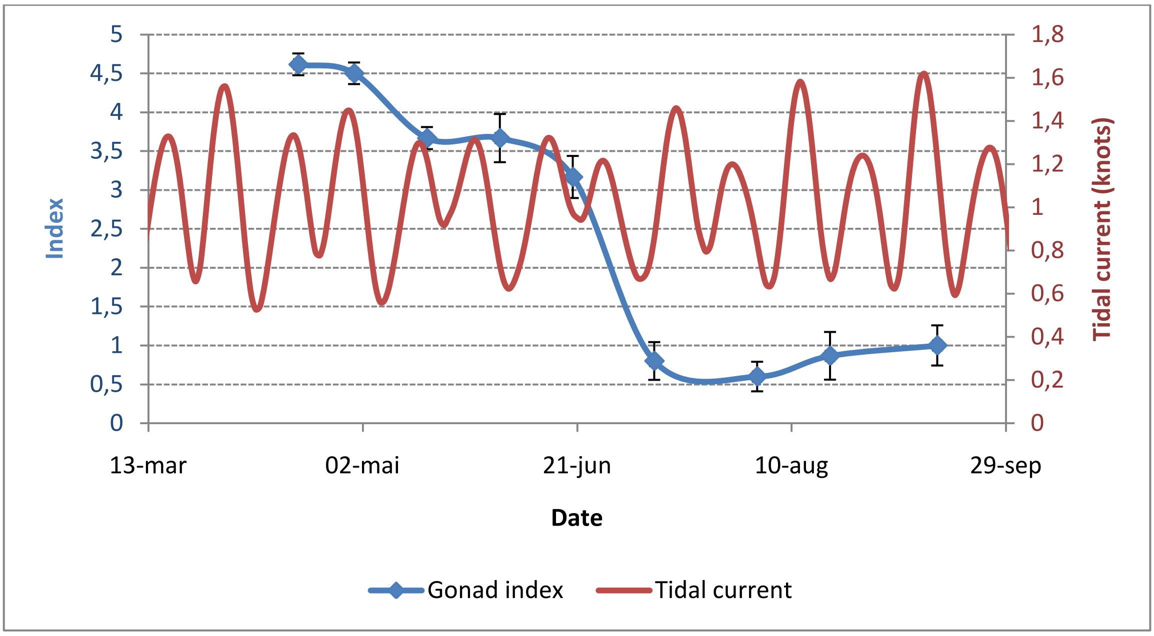

Fig. 4.10 Gonad index and tidal current (knots) on the Faroe Shelf (Munkagrunnurin) (Simonsen, 2009).

4.4 Larval abundance and sizes

On fig. 3.17 larval sizes through the spring/summer are illustrated, the dates with the highest number of small larvae for Kaldbaksfjørður and both sites at Sundalagið were on May 17th and June 20th. On these same two dates we had the two peaks of high abundance of larvae in Kaldbaksfjørður and both sites at Sundalagið (fig. 3.14). These dates fit in well with the gonad index (fig. 3.13) where these two dates were on the two spawning periods.

In Skálafjørður the two peaks of larval abundance were on April 30th and July 9th, and these two dates were also the dates with the highest number of small larvae in Skálafjørður (fig. 3.17). This indicates that the peak spawning in Skálafjørður occurred at a different time than in Sundalagið and Kaldbaksfjørður. In Skálafjørður the number of larvae was very small compared to the other sites, and therefore the numbers had a large margin of error. Nevertheless in the later of the peaks there were somewhat fewer small larvae compared to large ones than presumed in a major spawning period.

On May 21st a very high number of jellyfish (*Aurelia aurita)* was observed in Skálafjørður. By counting there were approximately 30 jellyfish per m^3 throughout the whole fjord. On June 8th the jellyfish still occurred in dense concentrations in the fjord, but on July 9th no jellyfish were observed. On May 3rd no jellyfish were observed, and since they were spotted at May 21st it is fair to presume that they were advected from outside the fjord somewhere between May 3rd and May 21st, and they have left the fjord somewhere between June 8th and July 9th probably due to a major flushing of the fjord, with winds and precipitation causing high currents out of the fjord. As jellyfish, as mentioned, prey on mussel larvae

(Grøndahl, 1988) it is likely that the dense jellyfish concentration in the fjord has lowered the larval abundance in Skálafjørður a great deal during the two spawning peaks observed in the other three sites. And thereby it is possible that the spawning has occurred at the same date in Skálafjørður as the other sites, although it is not made clear in the numbers of larval abundance.

3.5 Settlement on ropes.

The numbers of settled mussel were highest in Skálafjørður and Kaldbaksfjørður. There was almost no settlement in Sundalagið Ey., and only a few settled mussels in Sundalagið Str. (fig. 3.18). This is the complete opposite of what was observed in the larval abundance, where both sites in Sundalagið had the highest and Skálafjørður the lowest number.

A possible explanation for the low number of settled mussels in Sundalagið might be eider ducks. As mentioned earlier, eider ducks are great predators on mussels, and were observed in high numbers in Sundalagið. The depth of the sites in Sundalagið was only 2 m in Sundalagið Ey. and 4 m in Sundalagið Str. and therefore all of the settled mussels were easily accessible by eider ducks. The current speed was highest in Sundalagið Str. with an average speed of 26.7 cm/s, and as seen in fig. 4.4 there was a lot of drifting seaweed that got entangled in the ropes because of the high current. This may have disturbed the settlement and caused some of the settled mussels to lose their grip. However, in Sundalagið Ey., the currents were low, and the settlement was low as well.

Kaldbaksfjørður had a higher larval abundance than Skálafjørður, even though the settled mussels were close to equal in numbers at both sites. There were a lot of barnacles in Kaldbaksfjørður that were settled between the mussels (fig. 4.11a), which may have inhibited settlement of mussel larvae. As mentioned earlier barnacles and mussels are strong competitors for space, and the barnacles took up some of the space for the settling of mussels. Tunicates were seen in small numbers in Kaldbaksfjørður, as is indicated on fig. 4.11b, and these may also have competed for space with the mussels. Eider ducks were observed in small numbers at the site in Kaldbaksfjørður as well, and might have predated somewhat on the mussel settlement.

Fig. 4.11 Farming site in Kaldbaksfjørður. a: very high numbers of barnacles on the settling ropes. b: High number of tunicates on the one year old mussels prior to deployment at the different sites.

In Skálafjørður the long line and the settling ropes were lowered ~1 m under the sea surface. This made the ropes avoid some of the disturbance caused by waves ensuring a calmer environment than in the other sites, where the long line was placed above sea-level. Additionally, the larger depth of the mussel lines makes the mussels less assessable to eider ducks. The ropes in Skálafjørður were completely covered in mussels, and almost no competing species were observed.

The average size of the settled mussel was on October 28th in 2010: 5.4 mm in Kaldbaksfjørður, 3.7 mm in Sundalagið Ey. and 2.2 mm in Sundalagið Str. In Skálafjørður it was 9.6 mm on September 25th in 2010 (table 4.1.). Not only occurred settled mussels in Skálafjørður in denser concentrations than in both sites at Sundalagið (fig. 3.18), they were significantly larger than in both sites in Sundalagið. The very small sizes of mussels in both sites in Sundalagið were most likely due to the eider ducks, which predated on the mussels as soon as they had reached a "reasonable" size. The settled mussels in Kaldbaksfjørður, as well as in both sites in Sundalagið, had a much lower average size than in Skálafjørður, although the numbers of settled mussel in Kaldbaksfjørður and Skálafjørður were close to similar (fig. 3.18). A possible explanation for this might have been that the mussels were competing with the barnacles for food as well as space. The current speed was lower in Kaldbaksfjørður than in Skálafjørður and almost all of the time keeping the mussels at a low filtration rate (fig. 1.6), while on Skálafjørður the mussels regularly had a high filtration rate. Along with this, the mussel ropes were calmer in Skálafjørður and this might have influenced the lower growth in Kaldbaksfjørður compared to Skálafjørður.

Table 4.1. Average shell length of one year old mussels before deployment (May 30th 2010) and the settled mussels at the different sites in September and October 2010

Location	Average shell length
1 year old mussels before deployment	8.30 mm
Settled mussels from Skálafjørður	9.63 mm
Settled mussels from Kaldbaksfjørður	5.36 mm
Settled mussels from Sundalagið Ey.	3.73 mm
Settled mussels from Sundalagið Str.	2.22 mm

The growth rate of the settled mussel was 0.08 mm/day in Skálafjørður and 0.03 mm/day in Kaldbaksfjørður. Calculated forward for two years with same growth rate, they would have grown to a length of 60.01 mm in Skálafjørður. The settled mussels in Kaldbaksfjørður would be 24.35 mm after two years, keeping in mind, that this is if they grow the same in winter as during summer and the same the first year as in the second, which they don´t.

4.6 Growth of the one year old mussels

The one year old mussels that were taken on October 28th 2010 (September 9th 2010 in Skálafjørður) had a dry meat content that was significantly higher in Skálafjørður than at the other sites. On Skálafjørður the dry meat percentage of the total dry weight (incl. shell) was ~30% and on the other three sites it was ~15% (fig. 3.20). The growth of mussels is given by the formula: $W = a \times L^b$, and these percentages cannot be easily compared, as the average sizes varied, and were highest in Skálafjørður (table 3.5). Using the length-weight relationship obtained in fig. 3.21, the average dry meat weight of mussels with shell length of 40 mm from the different sites was calculated in table 4.2:

Table 4.2. Average meat dry weigth of 40 mm mussels at each site

Site	Formula ($W = a \times L^b$)	Meat dry weight (W)
Skálafjørður	$5 \times 10^{-6} \times 40\ mm^{3.1883}$	0.64 g
Sundalagið Ey.	$2 \times 10^{-6} \times 40\ mm^{3.3512}$	0.47 g
Sundalagið Str.	$7 \times 10^{-5} \times 40\ mm^{2.3489}$	0.41 g
Kaldbaksfjørður	$5 \times 10^{-5} \times 40\ mm^{2.4221}$	0.38 g

The chlorophyll *a* concentrations are not likely to explain the differences in mussel growth or food content between sites, since the chlorophyll *a* concentrations were quite similar (and high) at all sites. Here, as well as regarding the growth of the settling, the reason for the high growth in Skálafjørður might have been the high current speed, resulting in high filtration rates. Another reason could be the different rope design in Skálafjørður, causing calmer conditions for mussels and potentially lower predation by eider ducks. On the ropes in

Sundalagið Ey., and especially Skálafjørður, the mussels were virtually completely clean (fig. 4.12), and almost only mussels were observed on the ropes, whereas in Kaldbaksfjørður and in Sundalagið Str. there were a lot of barnacles and other growth which could have influenced the growth of the mussels.

Fig. 4.12 The mussels from Skálafjørður

In Sundalagið Ey. the mussels were large in size, but not in meat content. There may be several reasons for this: one might be the high number of eider ducks which were observed at this site. The average current speed in Sundalagið Ey. was very low and kept the mussels at low food uptake nearly all the time (fig. 1.6) maybe explaining some of the low meat content and the size difference from Skálafjørður which had higher current speeds. In Sundalagið Ey. there were 5 mussels of approximately 40 mm length with a high difference in meat weight (fig. 3.21). This indicates that mussels at same length have had a different enviroment. The bulk size was 6,26 kg/m and the mussels were somewhat stacked upon each other (fig. 4.13). As the current speed was very low in Sundalagið Ey. the mussels located innermost on the rope might have had an even lower phytoplankton availability, and therefore the difference in the meat content of the mussels.

Mussels have a well developed nervous system with which they can detect predators and in the attendance of one, they reduce their gape angle, therefore also their filtration rate (Robson et al., 2010). This reduction in the filtration rate at the presence of eider ducks may have reduced the growth of the mussels, especially in both sites in Sundalagið. Other predators such as sea stars and crabs on the sea bed may have had the same effect on the mussels in Sundalagið Ey. because of the low depth at the site and short distance from the mussel ropes to the sea bed. A sea star was observed on the ropes in Sundalagið Ey. which had cleaned ~40 cm of mussels from the rope (fig. 4.13).

Fig. 4.13 The mussels growing in Sundalagið Ey. Note the seastar (*Asterias rubens*) eating upwards the rope

The mussels in Kaldbaksfjørður and Sundalagið Str. were only found in small bulks at the deep end of the ropes. Possible explanations for the missing mussels in Kaldbaksfjørður may have been that people have collected some of the mussel as the site is easily accessed. Eider ducks might as well have eaten some of the mussels, but are probably not the main reason, since the numbers of grown mussels in Sundalagið Ey. were high, even though a lot of eider ducks were observed there. In Sundalagið Str. the high current forces may explain the missing mussels. The mussels were grown in Kaldbaksfjørður the first year where the average current speed and the highest measured speed were very low compared to Sundalagið Str. (table 3.1 and 3.2). The mussels, when growing in Kaldbaksfjørður, therefore did not have the need to develop byssal threads for the high currents, and when deployed to Sundalagið Str. they may have been swept of the ropes. As seen in fig. 4.4 a lot of seaweed got entwined in the ropes, forcing the ropes to cross. This could be another reason for the mussels to lose their grip on the rope, as well as predators such as sea stars might have been carried to the ropes on the drifting seaweed.

The average size of the mussels in September-October was 43.0 mm in Skálafjørður, 34.3 mm in Sundalagið Ey., 28.0 mm in Sundalagið Str. and 25.2 mm in Kaldbaksfjørður (table 3.5). But on the ropes in Sundalagið Str. and Kaldbaksfjørður there were a lot of mussels missing and therefore it is misleading to compare the sizes in these two sites. If the mussels would have continued with the same growth rate of 0.23 mm/day in Skálafjørður, they would have reached a length of 171.2 mm in two years. In Sundalagið Ey. the growth rate was 0.17 mm per day, and the mussels would have reached a length of 125.79 in two years. The mussels would of course be much smaller, because they, as explained earlier, do not grow as much during wintertime as during summertime. As the measured growth is only for the growth period in the summer, although not the whole period, and it is assumed that there is almost no growth in the winter, we can assume that the measured growth is for the whole year. The result will be 68.0 mm after two years in Skálafjørður and 52.4 mm after two years in Sundalagið Ey. Note that the growth rate of the one year old mussels is much higher than the growth rate of the settled mussels, and hence the mussels would grow a lot less the first year than the second year.

4.7 Genetics

The results showed two amplification products for Glu-5', 386 and 416. Although they are not of exact same size as any of those reported by Rawson et al. (1996) or Borsa et al. (1999), they have the same difference in size, 30bp, as the alleles characterising *M. edulis*, 350 and 380, and the same genotypic pattern. There is no relatedness to the 300/500 alleles of *M. galloprovincialis*. The genotypic frequencies reported by Rawson et al. (1996) were 0.85 for 350/350, 0.12 for 350/380 and 0.03 for 380/380.

As Rawson et al. (1996) reported for *M. edulis,* the 386 homozygote is most frequent, but not to the same degree, with a frequency of 0.73 compared to 0.85 (Table 3.8). The 416 allele is thus more frequent in our samples.

The analysis of the Glu-3' gave a consistent PCR product of 230bp. It is of course difficult to relate the product specifically to either the 220bp or 214bp product by Rawson et al. (1996), but since Glu-5' showed no evidence of *M. galloprovincialis* presence, it would be very unlikely that our single consistent PCR product of 230bp from Glu-3' would be that of *M. galloprovincialis*. It is therefore safe to assume that our product is that of *M. edulis*.

The conclusion is that the samples collected for this analysis belong solely to the species *M. edulis*, and from these results we can say that the only Mytilus species in the Faroe Islands so far is *Mytilus edulis*.

Although the Faroe Islands are close to the Shetland Islands, the two island communities are separated by the Faroe-Shetland Channel and two different currents. As shown in fig. 4.14 the slope current (SS) travels on the slope on the European shelf from southern Europe and northwards. This watermass is in the southern part of the Channel only, and flows into the North Sea or towards Norway. In the northern part of the Channel the North Atlantic current (NAS) occurs, entering from much further offshore. Thus organisms that are advected the slope current would not be expected to be transported to the Faroes. Furthermore, NAS is slightly colder and has a lower salinity than SS. Because of the difference in the temperature and salinity of these two currents, the mixing is restricted. This might very well be the explanation why the species *M. galloprovincialis* was not found in the Faroes, although its distribution has extended northwards along the European coast.

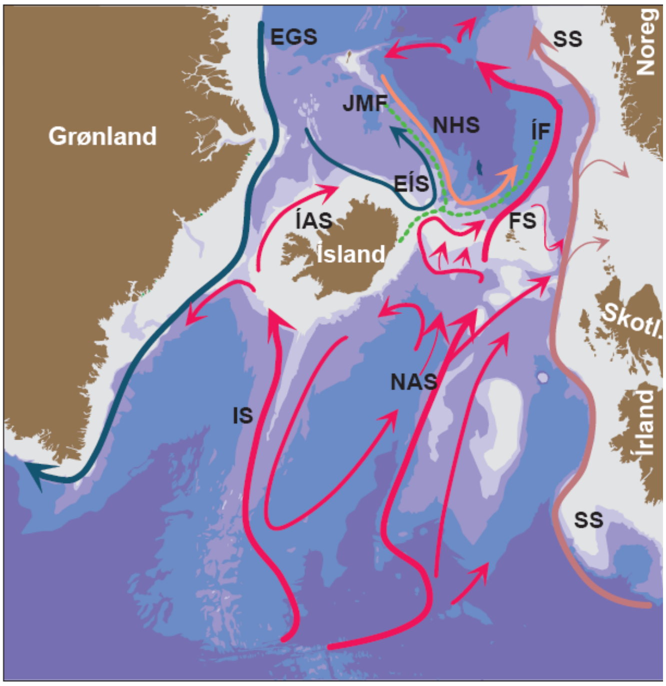

Fig. 4.14 The currents in the north atlantic (Hansen, 2000)

Introduced species, such as *M. galloprovincialis*, may flourish because they escape the effects of natural control agents such as predators or parasites. Alien invaders may gain an advantage over native species via three means. They may (1) leave their natural parasites behind; (2) introduce parasites that that are detrimental to native species, or (3) be naturally free of parasites relative to native species (Price et al., 1986). *M. edulis* is a species of mussel highly adapted to the cold regions surrounding the Faroe Islands, whereas in contrast *M. galloprovincialis* is a species adapted to warmer regions. Although it has been suggested by Skibinski and Beardmore (1979) that in some environments hybrids and individuals of mixed ancestry may have fitness superior to that of the edulis form, the consequences of an introduced species are not fully understood.

4.8 Farming potential

At the site in Skálafjørður the settled mussel grew to a size of 11.92 mm in just 145 days. If we assume that these mussel would have grown somewhat in the winter and spring, until the time when we deployed the one year old mussels in Skálafjørður (which grew from 8.3 mm to 43.02 mm in 145 days), the mussels probably would have reached a length of 50 mm wich is the normal market size for mussels in two years (two summers).

Our results show that phytoplankton concentrations are high and quite similar at all study sites during spring/summer. But the phytoplankton availability affected mainly by the current forces (Camacho et al. 1995; Sobral and Widdows, 2000) are different. Therefore a significant factor, to achieve the optimal growth of the mussels, when placing a mussel farm in a Faroese fjord would be the current forces. These current forces should have an average speed that is approximately 10 cm/s (Sobral and Widdows, 2000).

Experiments done at a 200m × 15m mussel farm (1.6 m between the long lines and 0.5 m between the mussel ropes) showed that the mean current speed decreased rapidly within the farm area. The current speed was reduced to less than 30 % compared with the current speed outside the farm, and more than 50% of the incoming phytoplankton biomass was depleted within the first 30 m in the mid section of the farm (Strohmeier et al., 2005).

The size of the farm should therefore be taken into consideration and - if possible - the farm should be positioned perpendicular to the mean current directions. From the four sites where we have done our research, Skálafjørður showed the best growth, and had an average speed of ~6 cm/s. An average speed of 6 cm/s might very well prove to be quite low and result in low phytoplankton availability inside the farm.

Our results indicate that the presence of eider ducks at some locations may be a major limiting factor for the survival of the settled mussel and for growth, and therefore some action to limit the presence of eider ducks is vital. One option may be having nets around the farms. Another option is to sink the vertical line below the sea surface, as was done in Skálafjørður, and is often used in other countries. Finally the farms could be placed in an environment, where few eider ducks and other predators are expected. The open ocean might be such an environment, but the low chlorophyll *a* concentrations on the Faroese shelf might be a limiting factor of growth. Chlorophyll *a* concentration measurements on the central Faroese shelf in 1997 showed that during spring the concentration was ~0.6 µg/L, in summer it increased rapidly to ~2.6 µg/L in early-mid June. The average concentration during winter was ~0.2 µg/L (Gaard, 2000). Furthermore this would be complicated, partly due to extreme wave and current exposure and partly because larval concentrations are expected to be too low in these areas.

Most likely due to low temperatures in Faroe Islands compared to farming areas in southern Europe, the spawning of the mussels occurs at a later date. As seen in our studies, and in fig. 4.15, the growth period during the first summer is therefore limited and the growth is much higher the second summer. The late spawning causes a short growing season and poor exploitation of the spring bloom the first year. If spat is produced on land in artificial environments, these can potentially be deployed at an earlier date ensuring a higher growth the first year. The higher growth expected by a earlier deployment of spat, is also indicated by the decrease in shell length with deployment date on fig. 3.19. If the spat is deployed in e.g. the beginning of March, few larvae of barnacles are expected in the fjords (fig. 1.5) and the mussels might therefore win the competition for space to the barnacle larvae. Another positive factor is that maybe jellyfish would not be able to influence the number of settling on the ropes. However, this may be a too costly method for commercial mussel production.

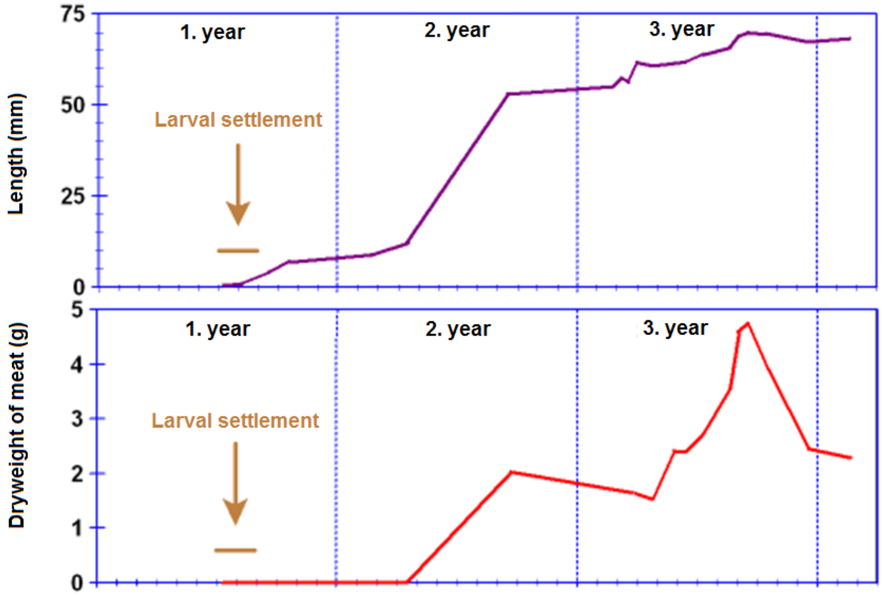

Fig. 4.15. Length (mm) and dryweigt of meat (g) of cultivated mussels in Trongisvágsfjørður, Faroe Islands, 1., 2. and 3. year (Gaard, 1986)

China is the largest producer of blue mussel and its culture technique depends on a high proportion of spat being produced from hatcheries (FAO, 2004). New studies on triploid sterile *M. edulis* have shown their growth benefits and lack of reproductive capacity compared to diploids (Brake et al., 2003). By genetic engineering sterile spat might be produced, so that the mussels do not use energy on the production of eggs and sperm the second year, and thereby a higher growth would be expected. Most of the fjords in the Faroe Islands have fish farms, and the increase in mussel spat expected in a fjord with a large mussel farm, would most likely be a problem as a lot of growth on the fish farm nets already is a major issue. This problem would increase with more settling of mussels on the nets, and therefore a mussel farm with sterile mussels would be of high interest in the Faroes. However, again here, the economic perspective regarding commercial mussel farming would be questionable.

One of the largest problems for fish farming is sea lice, and since mussels feed on the sea louse, they may reduce the amount of lice in the fish farms (Molloy et al., 2010). It is, however, not yet known whether mussels have the potential to remove and inactivate free-swimming sea lice at a rate and quantity that is sufficient to decrease the sea lice density sufficiently at the farm sites. The mussels would decrease the amount of uneaten fish food (MacDonald et al., 2011), and reduce the environmental impacts of the fish farm. Also the growth of the mussels would be higher, especially during winter, when phytoplankton concentrations in Faroese fjords are low. A potential problem in multi tropic farming would be that the particulate matter from fish food does not drift far from the fish cages (á Norði et al., 2010), and therefore the mussel farm has to be very close to the fish farm, potentially reducing the current and possibly the oxygen supply to the fish farm.

The latest in aquaculture research in the Faroes is the possibility of open ocean fish-farms. If the open ocean fish-farms prove to be successful, a possibility might be to try this as a multi trophic farm. The high current forces might reduce the impact of the mussel farm on oxygen supply etc., as well as the high current forces might make the dissolved matter from fish food drift farther from the fish farm, improving the growth of the mussel highly as the chlorophyll *a* concentrations are low on the Faroe Shelf. This would also require that the settlement was done elsewhere as no/few mussel larvae are expected in the open ocean.

5 Conclusion

Our conclusion is that the growth measurements, especially in Skálafjørður are satisfactory for commercial farming. The mussels would have grown to a market size (~50 mm) within ~1.5 years (two summers). The spat settlement would also be sufficient. In Skálafjørður there is no fish farming at the moment due to the risk of oxygen depletion in the stagnant bottomlayer and due to bad experiences regarding fish health and growth in former times. The assumption that Skálafjørður is satisfactory for a possible industry is nevertheless dependant on the fact that the environment is the same in future years as when we did our measuments. Factors that might change:

- The competition by tunicates and especially barnacles was none in Skálafjørðurin and this might be different between years.
- The current speed would decline through a large mussel farm, and a lower current speed might reduce the phytoplankton availability and the growth of the mussels.
- No eider ducks were observed at the mussel site in Skálafjørður, and a possible amount of eider ducks at another year could have fatal consequences for the settlement of mussel, as could be seen in Sundalagið.
- A possible oxygen depletion below the mussel farm because of the waste from the mussels might have a big impact. However, in total, mussel farms take up organic particles from the environment, and therefore oxygen depletion due to mussel farming is unlikely.

For the future there are still a lot of issues that must be known, before starting commercial farming, e.g. what equipment to use. Measurements must be made for a longer period (for years) to get better information about the environmental conditions, and to get some more growth measurements, to make sure that the growth is as good as proposed and somewhat stabile from year to year. Also CTD measurements must begin earlier in the spring and must be done more regular through the whole year, than was done in this experiment and the same is for current measurements, to get a better understanding of the spawning. In addition there are some problems that must be solved, such as how to avoid the eiders, which will be attracted to a mussel farm. It would also be of interest to find out what factors influence barnacle growth and abundance in a fjord, as well as tunicates and jellyfish, because it is of high significance to avoid these, to get a better growth of mussels. Another thing of great importance is to find out how big a farm can be in a particular fjord in relation to the current speed that is necessary to avoid phytoplankton depletion. Finally it would be exiting to make more studies in mussel farming at more open sites in the Faroe Islands, in the opportunities of multi-trophic farming and if mussels can remove sea lice from fish farming areas at a sufficient rate.

6 References

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