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Horizontal and vertical distribution of *Lepeophtheirus salmonis* nauplii and infective copepodids

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Heiti / Title

Horizontal and vertical distribution of Lepeophtheirus salmonis nauplii and infective copepodids

Horisontal og vertikal spjaðing av *Lepeophtheirus salmonis* nauplii og smittandi kopepodittum

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Samandráttur

Laksalúsin er vorðin ein alsamt størri trupuleiki í heimshøpi, og serliga eftir at týningarevni ikki hava sama virknað ímóti laksalúsini. Hetta hevur fingið alivinnuna at leita eftir øðrum hættum at basa laksalúsini. Meðan vitanin um tey fastsitandi búningarstigini hjá laksalús eru hampiliga góð, kundi vitanin um tey fríttlivandi búningarstigini verið betri. Hendan verkætlanin hevur til endamál bøta um hetta og at fáa meiri vitan um spjaðingina av nauplius og kopepodid búningarstigunum hjá laksalús, horisontalt og vertikalt í einum føroyskum alifirði. Eisini er kannað, hvussu spjaðingin verður ávirkað av streymi, vindi og hydrografi. Í kanningini eru gjørd horisontalt tóv við planktonneti, umframt var pumpa nýtt, fyri at fáa prøvar frá ymsum dýpum. Kanningin vísti, at nauplii vóru heilt niðri á 20 metra dýpi, ímeðan kopepodidarnir tóktust at vera longri uppi í sjónum. Pumpu metodan, ið var nýtt, tóktist at rigga væl, og um ein nóg stór pumpa verður nýtt, er hetta eitt vælegnað amboð til kanning av vertikalari spjaðing av nauplius og kopepodid larvum.

Summary

Through the last decade salmon lice have become an even bigger problem worldwide, especially after the parasiticides do not have the same effect on salmon lice. This has lead the aquaculture industry to new ways to overcome salmon lice. Although the knowledge on the parasitic stages is decent there is a lack of knowledge on the planktonic stages. The aim of this project is to study the distribution of nauplius and copepodid stages of salmon lice, both horizontally and vertically in a Faroese fjord. Furthermore, how the distribution connects to current, wind and hydrography. In this study samples were taken at different depths with two methods, horizontal tow and pump. The results showed that nauplii were abundant further down the water column while the copepodids seemed to be more abundant in the upper meters. The pumping method that was used seemed to function well. If the method would be improved with a larger pump it could be an excellent method in research the vertical distribution of nauplius and copepodid larva.

Introduction

The Faroe Islands is an archipelago in the Northeast Atlantic and the people there have through hundreds of years lived off the ocean. Fish farming in the Faroese has developed through half a century. The annual production of farmed salmon in the Faroe Islands is approaching 70,000 tonnes (Figure 1), which makes the Faroe Islands the fifth largest producer of farmed salmon in the world. The fish farming industry is also very important for the Faroese economy, with export value that matches the entire export value from the fishing industry.

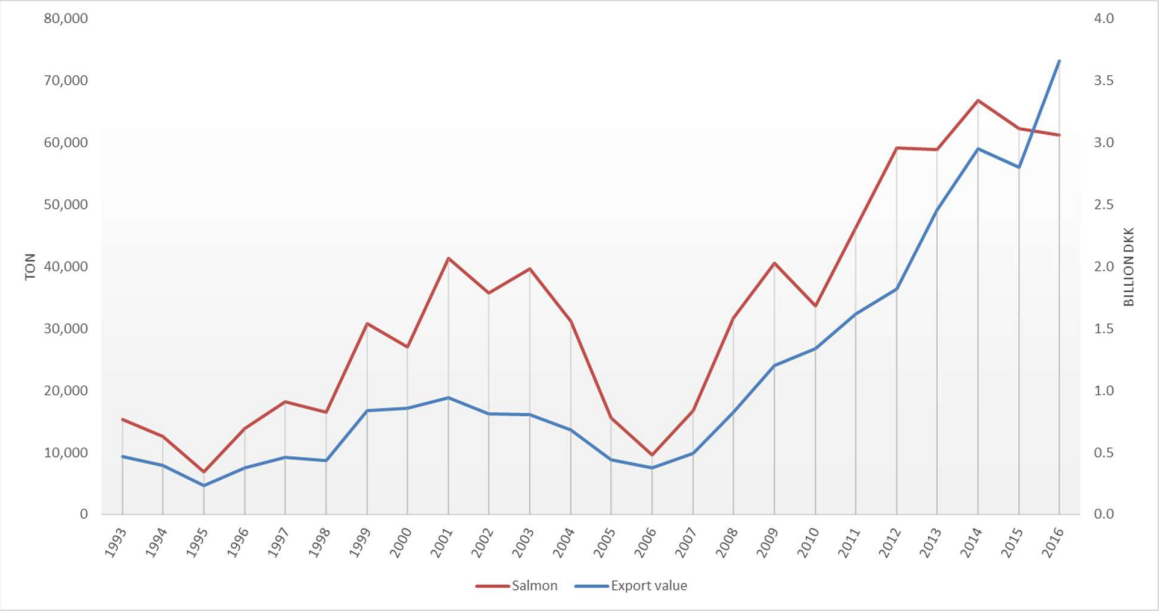

Figure 1: Quantity of salmon slaughter (red line) and export value (blue line) from 1993 to 2016. Left y-axis is in ton and right y-axis is in billion DKK. (Hagstova Føroya, www.hagstova.fo)

Through this half a century Faroese aquaculture industry has learned the hard way that fish farming is a fragile industry that can collapse overnight.

The Faroese aquaculture history can be described in three chapters. The first chapter is the period from 1980 to 1994-95. The Faroese fish farming industry originates from 1968, but the period from 1968 to 1980 was just a trial period. In 1980 there were 6 companies in the Faroese aquaculture industry, and by 1989 there were 63 companies farming on 71 different locations. This was a time of real progress with the industry managing to export 19,000 tons with a value of 600 million DKK a year. In the early 90s the salmon price started to fall because of the large amounts produced. The marked supply was too high relative to its demand. At the same time diseases and sea lice became a big problem resulting in an industry collapse in

1994-95. The rise of diseases, such as BKD (bacterial kidney disease) and furunculosis and sea lice came because there were too many firms with little to no regulation (Fosaa et al. 2006).
The second chapter is the period from 1995 to 2003. In this period the numbers of companies decreased to about 20 which is only a third of the companies of the previous period. This time around, knowledge, equipment and medicine were much better and helped the growth. By 2003 the salmon industry managed to export 60,000 tons with a value of 800 million DKK. Again, the supply became too high relative to the marked demand. At the same time there was a national ISA (infectious salmon anemia) outbreak. After 2003 the industry collapsed for the second time (Fosaa et al. 2006).
The Faroese aquaculture industry has learned from its mistakes and has since the last collapse become a well regulated and organized industry. Although the salmon farming industry in the Faroe Islands is thriving, both financially and problem wise, the salmon lice is one problem that is hard to solve. The salmon lice are a worldwide problem and not restricted to the Faroe Islands, and there is a lot of effort put into solving it.
The main focus has been on sea lice attached the salmons while it is the copepodid that is the infective stage. There is limited knowledge on the planktonic stages including the infective copepodid stage, because of difficulty in sampling sea lice in the ocean. Sampling of planktonic stages has traditionally been done with net tows, and the use of this method has resulted in different outcomes. Some studies have shown abundance of sea lice with horizontal and vertical net tows (Costelloe 1998, Penston et al. 2004, Penston & Davies 2009, Penston et al. 2011, á Norði et al. 2015). Other studies have found it difficult to get usable results (Tully & Nolan 2002). The fact that some studies get good results and other struggle to get results states a need for better sampling methods. Nilsen (2016) explored this by using four different methods. From the traditional horizontal and vertical net tows to pumping and using Go-Flo. Her results suggested that vertical net tows are the most time effective and most practical method to use.
The aim of this project was to investigate the distribution of *Lepeophtheirus salmonis* vertically and horizontally, with the two methods horizontal net tow and pump. Vertical distribution has not been well studied because of difficulties in collecting sea lice vertically. In this study a method has been developed, to pump and filter the large volumes of seawater that are necessary to study the density and depth distribution patterns of salmon lice larvae.

Background

Salmon lice biology

In the sub-phylum Crustacea and the sub-class Copepoda we find the family of *Caligidae* which is known as the sea lice family (Walter 2014). Two members of the sea lice family are *Lepeophtheirus salmonis* and *Caligus elongatus* which are the two most dominant species in the Northern hemisphere (Penston et al. 2004). *L. salmonis* is also known as salmon lice because the host of this particular species is salmonid fish. *C. elongatus,* however, is not as specific and has been found on over 80 different host species (Kabata 1979). *L. salmonis* has a greater impact on farmed fish than *C. elongatus,* and therefore in this project the focus is on *L. salmoni*s.

L. salmonis is an ectoparasite that feeds on mucus, skin and underlying tissues on their host (Costello 2006). The damage of this affects the host in a devastating way. The host will get stressed and weak. The osmotic regulation gets weaker and as will the immune system (Joensen 2013).

Salmon lice life cycle

Prior to 2013 *Lepeophtheirus salmonis* was known to have a complete life cycle of 10 stages. In 2013 Hamre et al. (2013) proved that salmon lice only have 8 stages. Two nauplius stages, one copepodid, two chalimus, two preadult and one adult stage (Figure 2). Prior to 2013 there were assumed to be four chalimus stages. Hamre et al. (2013) noticed that chalimus I and II were very much alike and they only differed in size and in degree of development of certain limbs and chalimus III and IV differed in the same way. They concluded that chalimus I-II and chalimus III-IV represent intramolt variation of only two chalimus stages. This leaves L. salmonis with a complete life cycle with of 6 post nauplii stages which also is the case for all free-living copepods (Hamre et al. 2013).

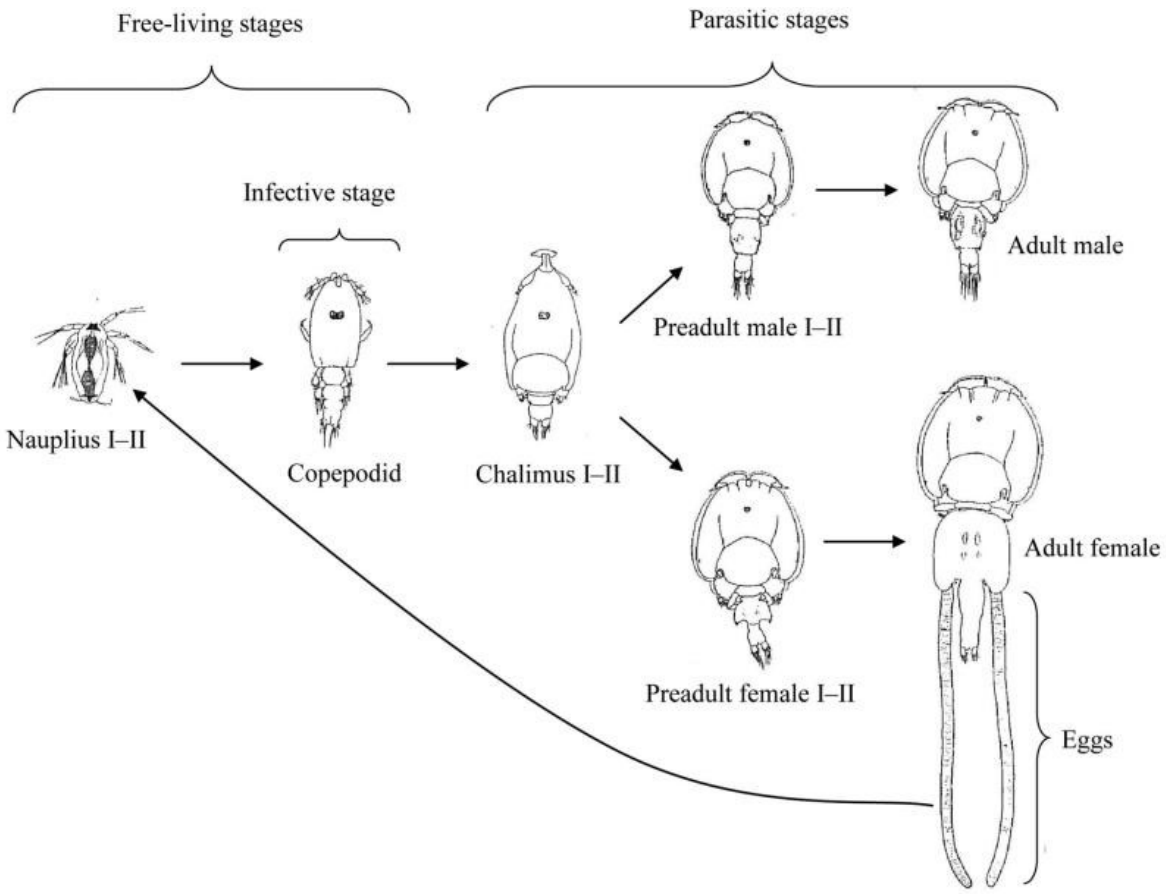

Figure 2: Developmental stages of Lepeophtheirus salmonis (diagram, not to scale, modified from Schram, 1993). (Igboeli 2014)

The adult female carries a pair of uniseriate strings that are attached to the abdomen of the female. These strings contain ~100-1000 eggs and this variation varies seasonally and of the size and age of the female. The temperature influences the growing rate of an adult female. A larger female can carry more eggs than a smaller female. Host species population and effect of parasiticide is also a factor that affects the number of eggs a female can carry (Costello 2006). The first step of the cycle is when the egg hatches in to nauplius I. Nauplius I-II are planktonic and non-feeding stages. At 7°C it takes 7 days to develop in to copepodid (Table 1, Samsing, Oppedal et al. 2016). The copepodid is the infective stage and at 7°C it can survive for about 13 days free, but must find a host within the infective window to survive (Samsing, Johnsen et al., 2016). The next step in the cycle is for the copepodid to attach to the host. When attached it develops into the first of two chalimus stages that are stationary

on the host. From there it develops into one of two preadult stages till at last it reaches adulthood. Preadult and adult salmon lice are mobile and can move to all areas of its host. The attached and mobile stages of *L. salmonis* are differently distributed on their host and this distribution varies of the size of the host and the circumstances (Jaworski & Holm 1992). The copepodids can be found in all regions of the body. However, they are mostly found on the skin, at the base of the dorsal fins. (Johnson et al. 1993, Finstad et al. 1994, Dawson et al. 1997). The mobile stages (preadult and adult) tend to settle themselves slightly behind the head (Pike et al. 1993).

Table 1: Duration of the different instars of L. salmonis at different temperatures. At 3°C the nauplii larvae did not develop to the copepodid stage (Samsing, Oppedal et al. 2016)

	Duration time (days)		
Temperature	**Nauplius I and II**	**Copepodite (infective window)**	**Larvae stages (total)**
3°C	-	-	-
5°C	11.52±1.72	10.15±4.00	21.62±9.12
7°C	7.05±0.58	12.73±2.85	19.77±2.65
10°C	3.81±0.66	13.19±2.12	17.00±2.13
15°C	2.19±0.40	9.68±1.11	11.87±1.09
20°C	1.69±0.90	6.66±0.90	8.34±0.60

Salmon lice distribution

Spatial distribution

Larsen et al. (2008, 2009) have shown that around the Faroe Islands there is a shelf front and a clockwise circulation system that separates the Faroe Shelf Water from the off-shelf waters. This creates a partial barrier which makes it difficult for off-shelf water to mix with the shelf water. This could also mean that it is difficult for planktonic organisms from off-shelf waters, like a copepodid, to establish itself on the Faroese shelf. On the other hand, the front also increases retention of the shelf water, and thus keeping larvae in the shelf water. Figure 3 is a QR code that leads to a simulation that simulates the distribution of *L. salmonis* on the Faroe Shelf. Free-living nauplii are able to travel 10-40 km from the area where they are hatched before they moult into an infective copepodid (Brooks, 2005; Stucchi et al., 2005). A dispersion study in the Faroe Islands (Kragesten et al., 2017) shows that in a lifespan of 16.7 days particles can travel up to 250 km, at least 150 km. This could suggest that salmon lice are local to the Faroese shelf. Depending on current speed and temperature these distances are relative. Sea lice dispersion in a Faroese fjord is different relative to the Faroese shelf. The fjords have different physical exposure and tidal and freshwater exchange that affect sea lice dispersion. A particle released at low exposure farming sites have a limited dispersion range, and farming sites with high exposure have a quick dispersion (Kragesteen et al., 2017). A recent study (Patursson et al., 2017) has connected physical exposure in fjords to self-infection. The conclusion was that a fjord with high exposure level has a low self-infection rate and *vice versa*. This indicates that external infection becomes a more dominant factor in exposed fjords. A fjord with low exposure level has a high self-infection and external infection is a minor factor.

Figure 3: QR code - Simulation of distribution of L. salmonis on the Faroe Shelf with different louse pressure. (Kragesten, T.) Link: https://drive.google.com/open?id=0B2IcPuFKWN9NN1ByWHl5cWgxZEE

Á Norði (2015) studied the abundance of planktonic *L. salmonis* in a farming area and found nothing when the region lay fallow and found very small numbers when there were small numbers of farmed fish. Studies also show that the nauplii stage of *L. salmonis* is often found near fish farms and farther away from the fish farms the copepodids dominate over nauplii (Costelloe et al., 1996; Penston et al., 2004, 2008; Morton et al. 2010, á Norði 2015). The

abundance of free-living stages is dependent on the abundance of the adult females (Penston al. 2014). The spatial distribution is well connected with wind direction and the planktonic *L. salmoni*s will accumulate in areas where the wind will move them. This means that salmon lice gather in patches and accumulate close to the shore (á Norði, 2015).

Depth distribution

L. salmonis has a diurnal vertical migration that is influenced by daylight. They seek upward during day and downwards during night (Heuch et al., 1995). Salmon, which is the host, has an opposite diurnal vertical migration (Bui et al., 2016). At night *L. salmonis* move downward and salmon upward and thus they will facilitate a host-parasite encounter twice a day (Costello, 2006). At low light level, the infection success rate is low (Flamarique et al., 2000; Browman et al., 2004; Genna et al., 2005) indicating that the salmon has an opposite diurnal vertical migration to protect itself from *L. salmonis* infection (Heuch et al. 1995). Salinity also plays a role in the vertical migration in the way that they avoid salinity below 27‰ (Bricknell et al., 2006). Johnsen et al. (2014) and á Norði et al. (2015) suggest a vertical migration that is connected with temperature. It seems like nauplii abundance increases in areas with higher temperature and this suggests that they move vertically to warmer areas. The seasonal distribution differs from summer and winter. The sea surface is colder, than further down the water column in the winter and *vice versa* in summer due to atmospheric interaction (Samsing, Johnsen et al., 2016). Consequences of this are an equal distribution in summer and a more scattered distribution in winter. The equal distribution in summer is due to high temperature and light above the stratification that makes the sea lice swim towards the water mass at sea surface where it will concentrate and equally distribute. In contrast, the sea lice keep away from the upper layer due to colder temperature in the winter period, and will swim deeper toward the warmer water mass below and the distribution will be scattered (Johnsen et al., 2014; á Norði et al., 2015). The reason for seeking higher temperature could be to shorten their moulting from nauplii to copepodid and have a higher fitness (Samsing, Oppedal et al. 2016).

Behavioural traits that influence host encounter

The free-living *L. salmonis* copepodid must find a host in order to survive. In order to do so they need to be in the environment of the host and to recognise its host. The copepodid behaviour is affected by physical factors such as light intensity, salinity, temperature and pressure. The copepodid does have a reverse diurnal migration (Heuch et al., 1995) which is opposite to the diurnal migration of the host (Bui et al., 2016) which increases the chance of a host-parasite encounter (Costello, 2006). Migration of the copepodid is controlled by physical factors. The copepodid seeks light intensity with optimal wavelength of 550 nm (Bron et al., 1993). Salinity has an effect on the survival of the copepodid. It has been shown that sea water with salinity below 29‰ results in a decreased survival rate (Tucker et al., 2000, Bricknell et al. 2006) and the copepodid show an avoidance at <27‰ (Bricknell 2006). Temperature has been suggested being a parameter that the nauplii seeks the highest temperature (á Norði 2015). All these factors aid in the copepodid quest to reach its host. The next step is to recognise the host. As the copepodid swim in their normal pattern they can recognise the host's odour which lead to an activation. The result is a change in swimming and sinking pattern, and the copepodid will move in a circular motion (Genna 2002). In order to attach to the host, the copepodids have to get inside the boundary layer. An increase in the hosts swimming speed will result in a thinner boundary layer. This will make it harder for the copepodid to interfere (Genna 2005).

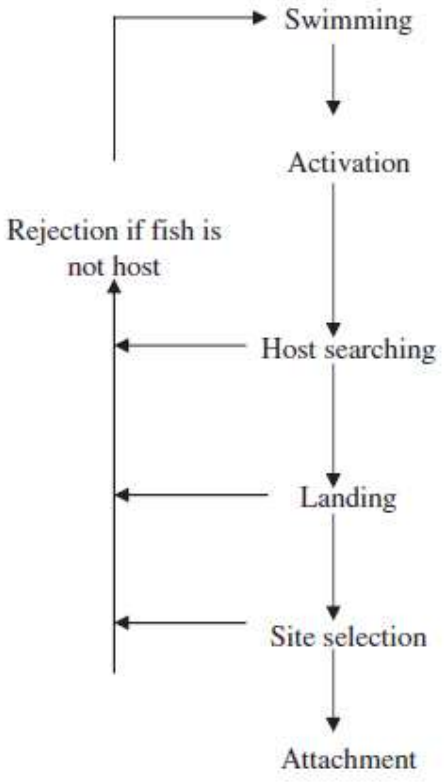

Figure 4: The process of free living L. salmonis from swimming to attachment. (Birkett 2009)

The copepodid has the ability to swim in inside the boundary layer if it is in a distance of centimetres, also they can use a 'circular attack' where it uses the current of the host (Heuch 2006). Figure 4 summarize the process of the free-living *L. salmonis* from swimming to attachment.

Material and methods

Study site

The location of our study was Sørvágsfjørður, Faroe Islands (Figure *5*). Sørvágsfjørður is one of many fjords that is a location for salmon farming. Like in many of these salmon farms sea lice are a challenge. This indicates that salmon lice larvae may be abundant in Sørvágsfirði. The first priority in choosing a study site is the high infestation rate of salmon lice. Figure 6 shows an average increase from 0.26 to 1.22 adult female *L. salmonis* from March to June followed with a decline (Figure 6). The Faroese government has a max 1.5 adult female *L. salmonis* on each salmon policy (Lúsakunngerðin 2016 § 4). The farming site in the period of this study was active. The number of salmons in the farm was 1,043,887 in average in the study period and the salmons had been there since July/August 2016. The abundance of sea lice on the salmon will be affected of the number of salmons in the farm and their size (Anderson & May 1992). This also increase the abundance of sea lice in the fjord. Furthermore, how long a farm is active is also a factor in that, the self-infection will increase with time. A study also shows the abundance of salmon lice in the fjord. During this same study current and hydrographic measurements were done, which make the physical conditions in the fjord relatively well known (Patursson et al. 2017, Simonsen et al. 2017). All these parameters make Sørvágsfjørð a good study site.

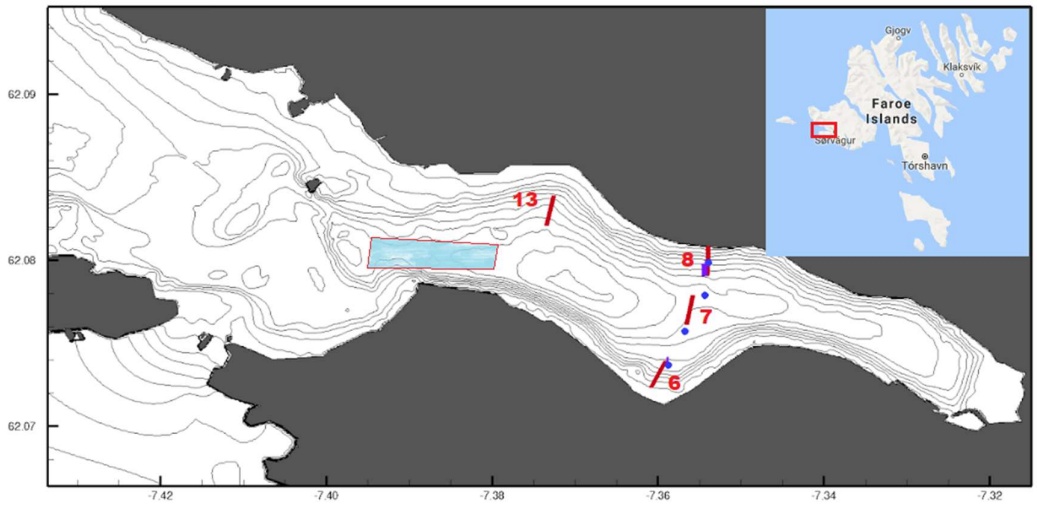

Figure 5: Map of the study site Sørvágsfjørður (Vágar, Faroe Islands). The map contains all four stations sampled in the fjord indicated with red numbers. Blue dots are CTD stations. The purple line is sampling at 10 and 20 m depth, while red line is at 0 m. A single red line indicate sampling at all depths. The blue rectangle represents salmon farming site. The purple is difficult to see, but is at station 6 and 8.

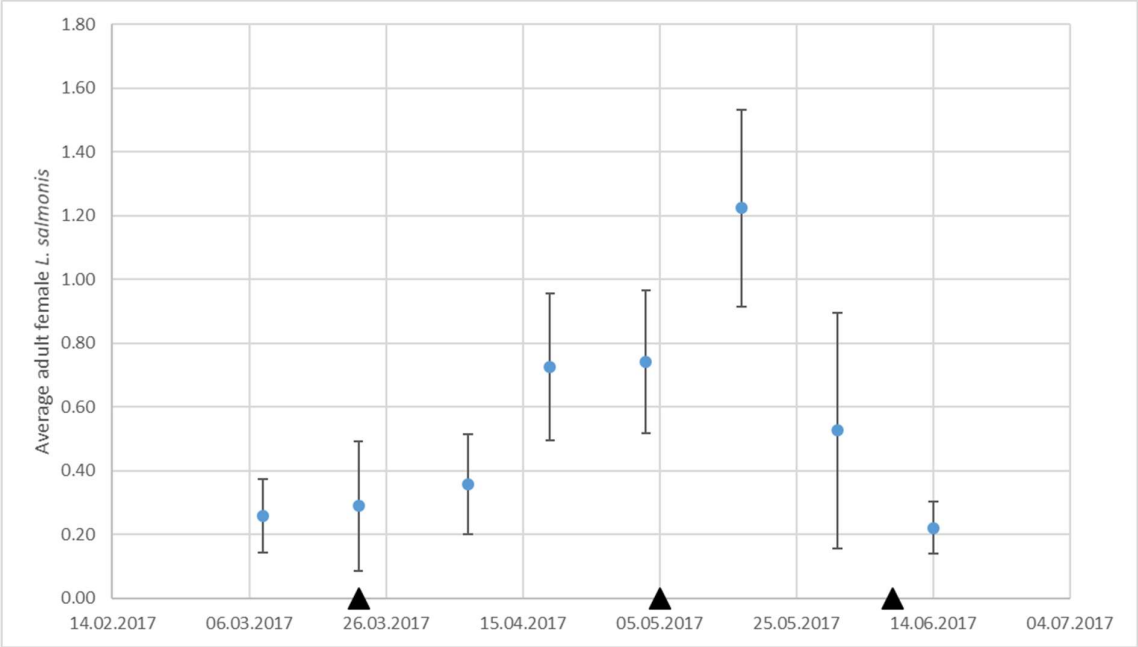

Figure 6: Average adult female L. salmonis counted on salmon in the farm in Sørvágsfirði. These data are in the study period. The black arrows on the x-axis indicate the sampling dates. (Fiskaaling)

Sørvágsfjørður (~62°4.75N, ~7°22'W) is one of 32 fjords in the Faroe Islands and is located on the western side of the islands. The length of the fjord is about 6 km, the width about 500 to 1800 m and deepest point is ~55 m. Temperature on the Faroe shelf is relatively stable all year, around 6-10 °C (Hansen 2000, Larsen et al. 2008). Like other fjords, the inner part of Sørvágsfirði including the sampling stations has an estuarine circulation that is driven by freshwater runoff that cause stratification. In the upper layer there is a net outflow of the fjord while in the deeper layer there is a net inflow. The circulation is strongly affected by the weather conditions. The weather is highly variable and wind strength, direction, precipitation, and tides may vary substantially within a short time making the fjord a highly dynamic system (Gaard et al. 2010). The circulation has been described in more detail in Patursson et al. (2017) and the general circulation in Sørvágsfjøður has been established (Figure 7). It seems like the general current in the fjord is in the form of estuarine circulation. The current that moves outward is above the current that moves inward. The outward current tends to move along the northern coast, while the inward current moves along the southern coast. The outward current spreads across the fjord. The circulation is highly affected by the weather conditions and wind in the opposite direction of the current can stop the circulation (Patursson et al. 2017). To understand the general distribution of *L. salmonis,* the general circulation is important to grasp, but the area of origin and data on stratification are also important. Á

Norði et al. (2017) made maps of the sea lice distribution on sea surface. These maps are shown in Figure 8 and are made on 4 different days with different conditions. There was little correlation between distribution of *L. salmonis* and the weather conditions. Nauplii were distributed all over the fjord, but copepodids were for the most part in the inner fjord. There seemed to be a correlation between how far in the fjord the copepodids were and the weather conditions (á Norði 2017).

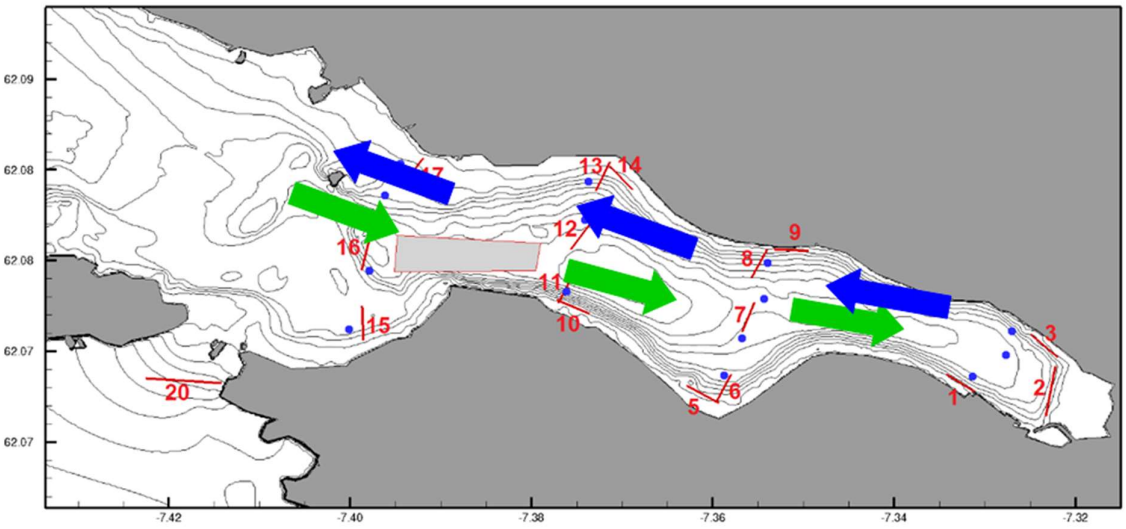

Figure 7: General current circulation in Sørvágsfirði. The green arrow indicates inward flow and blue outward flow. (Patursson 2017)

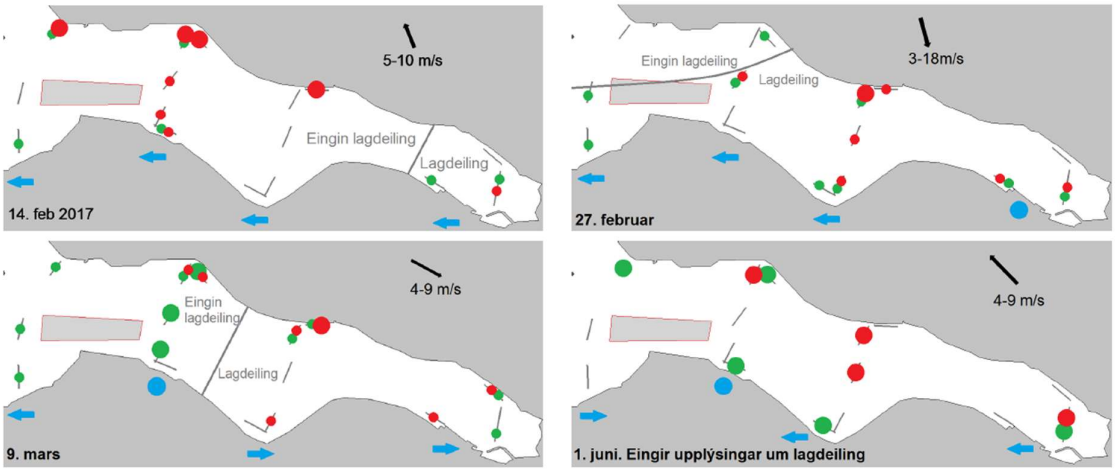

Figure 8: Distribution of L. salmonis on four different sampling days. The grey lines indicate the sampling sites. The dots are copepodids and green are nauplii, the smaller dots refer to a density of <0.1 lice m^3 and the larger dots refer to a density of >0.1 lice m^3. The darker grey line is the border between stratified waters and mixed water. The blue arrows indicate the direction of the tide. The grey rectangle is the farming site. (á Norði 2017)

Sampling

Samples were obtained by two methods, horizontal net tow and pumping. On each station both methods were used. The net tow was only used to sample on the sea surface while the pump was used to sample at sea surface, 10 and 20 meters. The samples were stored in ethanol for later analyses in laboratory. The sampling was done on three occasions. The first sampling was done in early spring (22.03.17). The second was in late spring (05.05.17) while the third was done in early summer (08.06.17). All samplings were done in daylight (9 am to ~6 pm) and the weather was similar on each sampling day, except for the wind direction. Sunny with air temperature at 7°C and a light breeze of ~5 m/s from an eastern, northern and western direction.

Net tow

The plankton net had a mesh size of 150 µm with a mouth diameter of 50 cm and a length of 1.5 m. A flowmeter was attached to the net mouth, measuring the volume of filtered seawater at each tow. The distance of each tow was ~200 m with a towing speed of 1.5 kn. The net tows were only done just below the surface (top 0.5 m) at each station (Table 2, Figure 9). This was due to complications using net tows in the depth. After each tow, the net was rinsed to ensure everything went in the sampler.

Figure 9: The horizontal net haul was dragged from the back of the boat.

Table 2: Overview of stations and methods for sampling in Sørvágsfirði

Date	Stations	Method	Depth (m)	Sampled volume (m^3)	Wind dir.
22.03.2017	6, 7, 8	Horizontal net haul	0	30-36	N
		Pump	0	33	
		Pump	10	33	
		Pump	20	33	
05.05.2017	6, 7, 8, 13	Horizontal net haul	0	18-22	N-E
		Pump	0	33	
		Pump	10	33	
		Pump	20	33	
08.06.2017	13	Horizontal net haul	0	12-13	E-N-W
		Pump	0	32	
		Pump	10	32	
		Pump	20	17	

Pumps

On the three occasions three different pumps were used. Each sample was obtained by pumping about 33 m^3 of seawater through a net with a mesh size of 150 µm. This process was done at the sea surface (~0.3 m depth), 10 m and 20 m depth.

The first pump was a gasoline driven pumped with a capacity of 100 m^{-3} h^{-1} that was positioned on the deck onboard the boat. At the input, a long hose was attached that was lowered to the wanted depth. The hose was lowered with a rope, marked with the wanted depths. As a precaution, the echo sounder was also used to monitor the depth. From the output, a shorter hose was attached to a water dispenser where the net was attached. The water dispenser was to prevent the high pressure from the pump and protect the net and the organisms. This setup was not optimal in that it used too much space and was difficult to manoeuvre.

Figure 10: The pump (ESP) from the third setup with a spiral hose attached that leads to the water dispenser.

On the second sampling day, the gasoline driven pump was replaced with an electrical submersible pump (ESP). This ESP had the same pumping capacity as the previous one. This replacement made it more manageable onboard because the ESP is placed in the sea, i.e. outside the boat (Figure 10). Another detail that was improved was the hose. Instead of having a 30 m long hose that was difficult to manoeuvre it was cut into smaller parts that were 5 meter each. This made the work with the hose much more manageable.

On the third setup the ESP was replaced with another ESP with a greater capacity (128.5 m^{-3} h^{-1}) which reduced the pumping time for each sample by 5 minutes (Figure 11 and Figure 12 demonstrates the setup).

Figure 11: The water dispenser with a net attached that collects the sample.

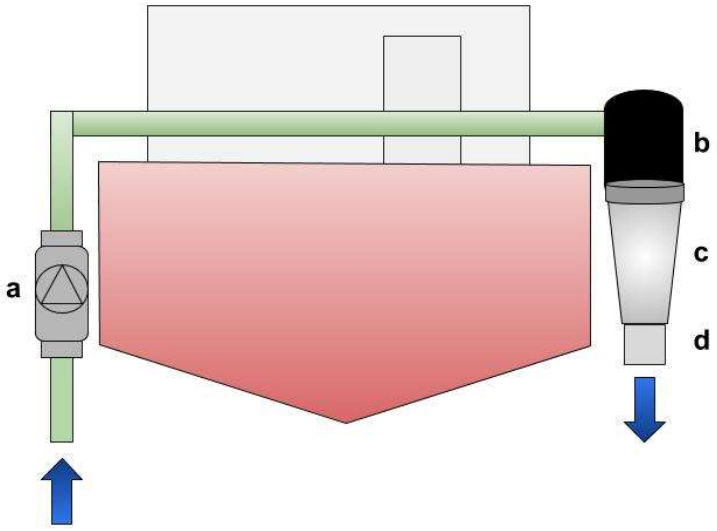

Figure 12: Sketch of the pump setup. The arrows indicate the direction of the seawater into the ESP (a) through the PVC spiral hose to the water dispenser (b) down the net (c) to the sample filter (d).

Analysing and identification

As a preparation to the analysing and identification of the samples, Danielsen (2013) and Schram (2004) were studied. In an addition, egg strings from salmon lice were hatched and studied closely under a stereo microscope. The purpose of this preparation was to be able to distinguish and identify salmon lice from other zooplankton, the nauplii stage from the copepodite stage and *L. salmonis* from *C. elongatus* in the *in situ* samples.

Figure 13: A picture taken with a stereo microscope of two L. salmonis copepodids.

The samples from the net tows and the pumping were preserved in 99.9% ethanol. At the laboratory, each sample was rinsed with water into a beaker before analysed thoroughly under a stereo microscope. The samples were analysed in counting chambers where the lice were separated, identified and counted. A later examination was done to distinguish *L. salmonis* from *C. elongatus* (Figure 13). This was done by analysing both species pigmentation. Although preserved in ethanol the pigments were relatively visible and that made it possible to distinguish the two species by this method. Although formaldehyde is a better preserver, ethanol was better for this study. "*Formaldehyde removes the pigmentations of the lice, therefore making it difficult to separate L. salmonis from C. elongatus in preserved samples*" Nilsen (2016). By using ethanol, the vanishing of pigmentation was not a problem in this study. Figure 14 shows the laboratory setup (a) and *L. salmonis* nauplii and copepodid (b).

The weight was measured of each sample by filtrating it on filter paper and drying it at 65°C for 64 hours.

Figure 14: (a) Setup of the identification of salmon lice and (b) a photograph of a L. salmonis nauplius (left) and a copepodid (right)

Data Sampling Equipment

A Seabird 25 CTD equipment was used to sample the hydrographic conditions. The CTD was only used on the first sampling day and on all stations. With the CTD data depth profiles of temperature and salinity were made. Due to unavailability of CTD, temperature logger data was acquired from loggers in the fjord. The temperature loggers were moored at 5, 10, 15, 20 and 42 meters depth close to SV11 (Appendix C) measuring every five minutes.

Current data was acquired from a ADCP (Acoustic Doppler current profiler) measuring instrument that was active from a former study (Patursson, 2017). The ADCP measured the current of the water column from 6 to 46 meters.

Results

Hydrography

The weather on the three sampling days was quite similar with good weather conditions.

On 22.03.2017 the wind was from a northern direction forenoon and from a western direction in the afternoon. The samples were taken from 9 am to 7 pm. The average wind speed was 5.5 m s^{-1}. On 05.05.2017 the most part of the forenoon was calm weather and the average wind speed was 1.4 m s^{-1}. The wind was from a western direction. On 08.06.2017 the wind direction on midnight was a northern that turned into an eastern mid forenoon for two hours. Then the wind direction turned into a western where it stayed for the rest of the afternoon. It was calm weather with an average wind speed of 2.2 m s^{-1}. On the second and third day the samples were taken from 9 am to 5 pm. There was little to none precipitation on any of the sampling days.

The CTD measurements were only taken on the first sampling day due to unavailability of the CTD equipment. Salinity and temperature did not vary much. The variation was 34.75-35.00‰ in salinity with the fresher water above, and the temperature varied 6.45-6.85°C with the

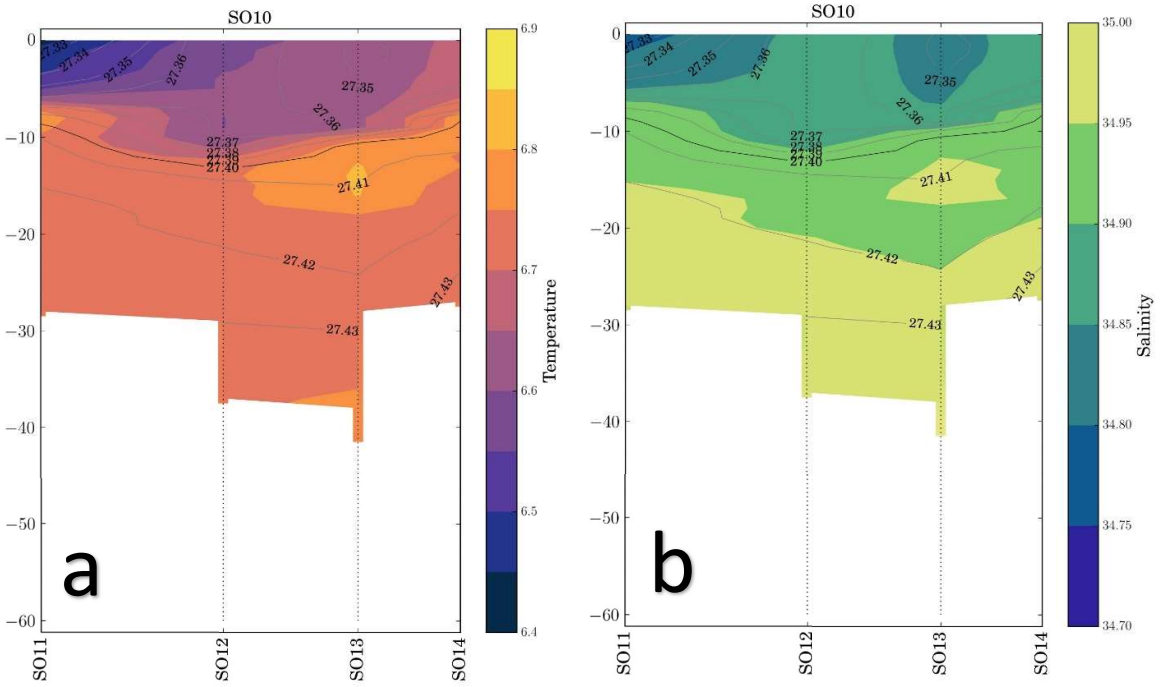

Figure 15: (a) Temperature and (b) salinity cross section from Sørvágsfirði on 22.03.2017. SO10 (SO11 - SO14) is a cross section at sampling stations SV6, SV7 and SV8. Density (isopycnals) are on both panels. S011 is on the southern side and SO14 is on the northern.

colder water above. The CTD measurement showed a stratification on 9-10 m depth close to the northern and southern coasts, but the stratification seemed to be a little deeper in the middle of the fjord, about 12 m (Figure 15).

To study the hydrography conditions in the fjord without CTD equipment, temperature loggers were used. On the first sampling day the variation in temperature was low with a variation of a half degree. Figure 15 (a) shows that the temperature was lowest in the upper 5 meters, especially in the southern part of the fjord. However, since this also was the water with lowest salinity, the density was lowest too in the upper 5 meters.

Second (Figure 16, b) and third (c) sampling day had a higher variation in temperature with a variation of one degree. At this point it was warmest at the upper meters and colder further in the depth. It is interesting to see that the temperature seems to be stable throughout the day in the May and June period, but as the evening progresses there seems to be a rise in temperature that settles after a short period.

Current measurements were only done on the first sampling day due to unavailability of the ADCP instrument. The overall current direction, was inward the fjord, in an eastern direction, deeper in the water column and outward the fjord, in a western direction, at the surface. The weakest current rate was measured in the middle of the water column and the strongest at the surface. The current on 21.03.2017 and 22.03.2017 was overall weak with speeds of 0.01-0.05 m/s all over the water column except for the surface. The speed on the surface of the column was 0.1-0.16 m/s with some short periods with over 0.2 m/s (Figure 17).

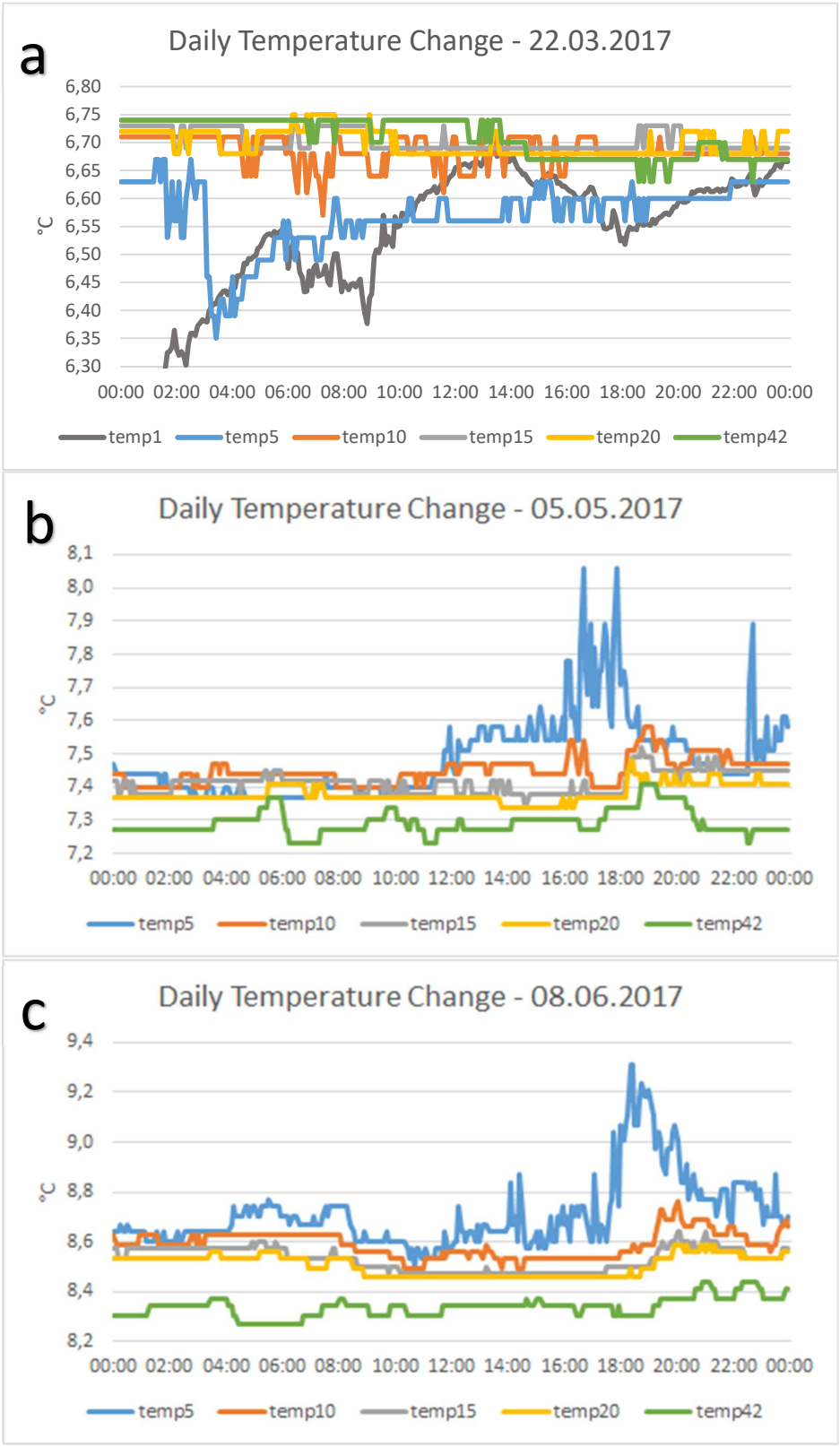

Figure 16: Daily temperature profile from three sampling days near SV11. Dark grey indicate temperature on 1 m, blue 5 m, orange 10 m, grey 15 m, yellow 20 m and green 42 m depth. (a) The first, (b) second and (c) third sampling day.

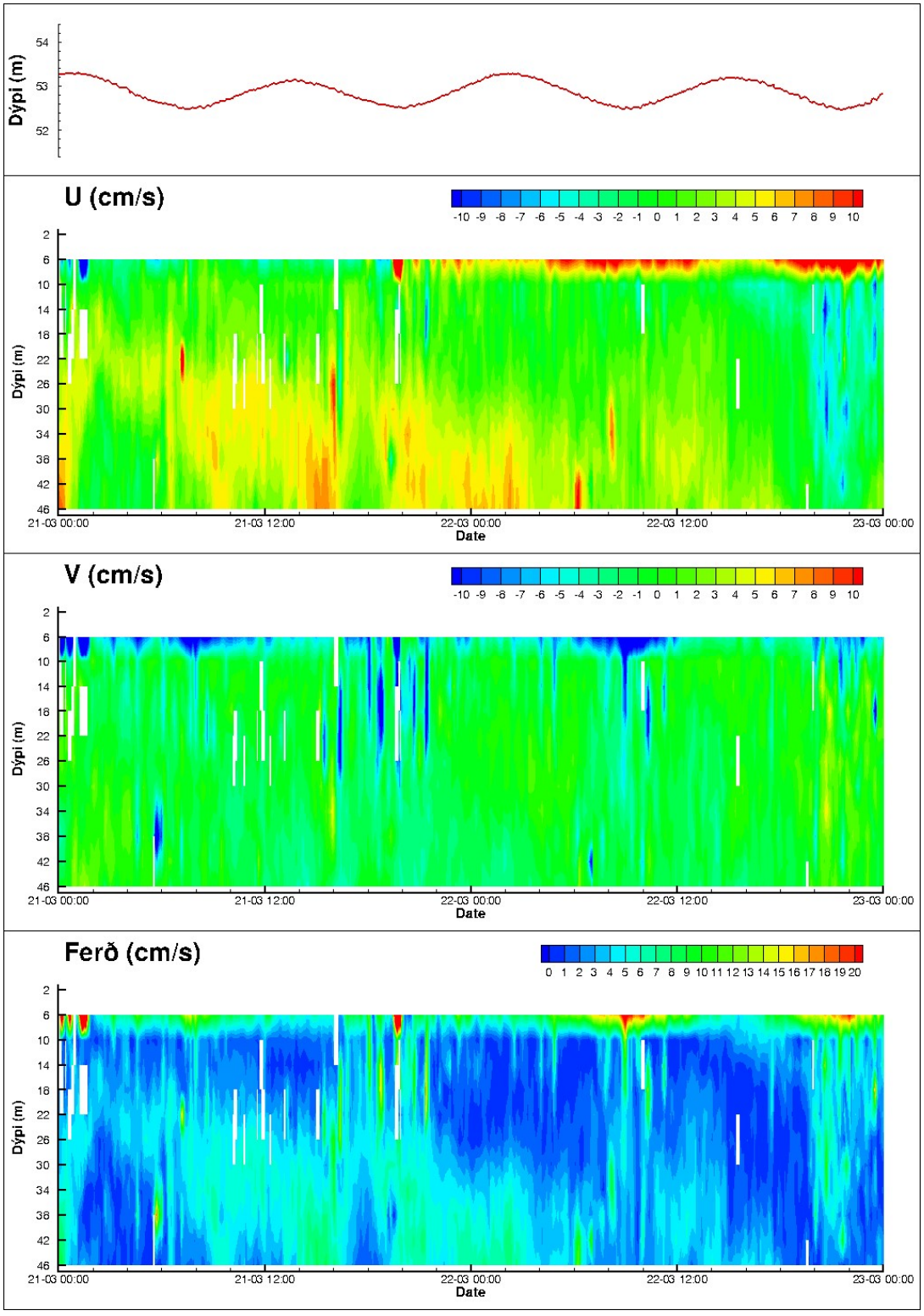

Figure 17: Contour plot of speed in east-west direction (top), speed in north-south direction (middle) and current speed (bottom). In the top and middle plots, the yellow and red indicate the speed in the northern and eastern direction, and the blue in a southern and western direction (shown in the colour scale). In the bottom plot the blue is low and red high current speed. The white areas indicate that there is no data available or the data is unusable. The y-axis is depth in meters. Measuring site: 62°04.715' 07°22.519'

Salmon lice

Overall, in three sampling days, 34 samples were taken. *L. salmonis* nauplii were found in 9 of the 34 samples and *L. salmonis* copepodids were also found in 9 of the 34 samples (Table 3).

Table 3: Table of how many samples, L. salmonis were found in, on each sampling day. (Appendix B)

Data	Samples	With *L. Salmonis*	Without *L. Salmonis*	With nauplii	With copepodid	Max found in sample
22.03.2017	12	7	5	5	5	4
05.05.2017	16	4	12	3	1	4
08.06.2017	6	3	3	1	3	4

Comparison between net tows and pump

At sea surface pump and horizontal net were used and there seemed to be a difference between the two methods. In the first sampling day, the pump seemed be the more efficient method, catching 8 sea lice. In contrast to the horizontal net that only caught one. However, in our second and third attempt there were only two salmon lice found on the surface, one with each method. By comparing the average sea lice caught with the two methods the pump seems to be the better method. The pump managed to catch an average concentration of 0.027 salmon lice /m^3 while net tow caught 0.013 salmon lice/m^3 (Figure 18). By testing the *L.* salmonis concentration data from the net tow and the pump with a t-test, the p-value

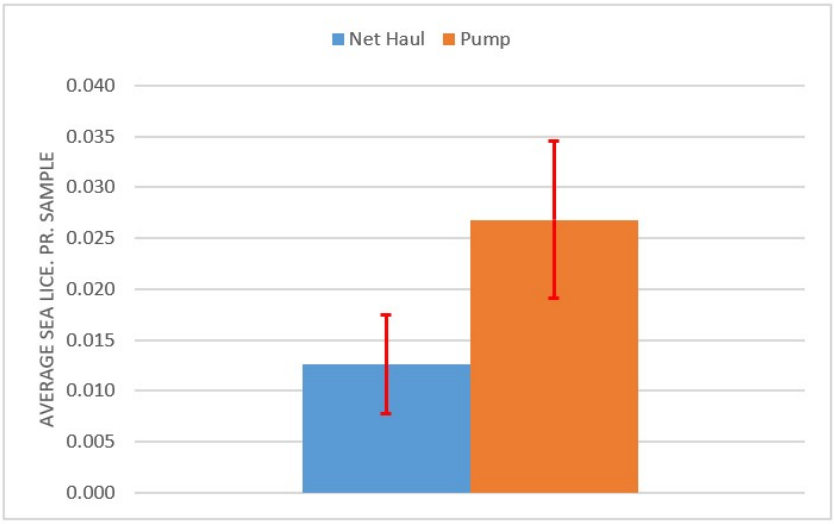

Figure 18: Average lice pr. m³ with standard error.

Table 4: The volume of the pump and net with its filtering efficiency on the three sampling days.

Date	Net Haul Effect	Net Haul Volume (m³)	Pump Volume (m³)	Detection limit
22.03.2017	76-88%	30-36	33	
05.05.2017	48-55%	18-22	33	0.03-0.08 ind/m³
08.06.2017	28-32%	12-13	32	

was 0.39 which is higher than 0.05 (alpha) and therefore no statistical significant difference was between the net tow and the pump. With no significant difference between the two methods the two data sets can be used together (Appendix E). The results from the filtering efficiency of the net tow (Table 4) show that it lowered throughout the season while the pump was steady on 100% efficiency. In Table 4 the filtering effect is shown from the sampling dates and they show a clear indication. In March, the net tow effect varied between 76-88% and lowered throughout the season. In June the effect was only 28-32%. With a lower effect the volume in each sample with net tow will be lower. This will affect the detection limit of sea lice to a higher value. With a full effect the detection limit was 0.03 ind./m^3 and with the effect of 30% the detection limit was 0.08 ind./m^3.

Table 5: Dry weight samples from net and pump at sea surface.

	Net (mg/m³)	Pump (mg/m³)
Min	1.5	2.1
Max	12.5	17.7
Average	4.8	5.4
Median	3.7	3.7

There was large variation in dry weight of the samples that varied 1.5-17.7 mg/m³ (Table 5). The variations came from unwanted material, such as fish eggs and sand, that affected the weight. There seemed to be one outlier in each method and calculations showed that they were minor and major outliers. Without these outliers the average was the same and the p-value became very close to 1 (Table 5). In our observations with the stereo microscope the samples at sea surface with net tow had high quantities of fish eggs and chained formed phytoplankton and likewise the pump also had high quantities of fish eggs and sand. Phytoplankton was not an issue in the pump samples as they were almost free from them. In contrast, the net tow caught high quantities of phytoplankton that made the samples more difficult to go through. The pump samples at 10 and 20 m were very similar, very clean and had a large number of zooplankton. The samples obtained in early spring were dominated by barnacle larvae while the samples obtained in late spring and early summer contained zooplankton of various kinds, mainly the copepod *Pseudocalanus*.

Depth distribution

L. salmonis were found at all depths and with both methods. Overall the highest density was found in deeper waters at 10 and 20 m. While sea lice were not as often found at sea surface. In Figure 19 concentrations of *L. salmonis* are shown. The three sampling occasions show variation in density and location. On first sampling day *L. salmonis* were found at almost every station (SV6, SV7 and SV8) while on the second sampling day *L. salmonis* was scarce at the same stations. The span was 0-0.12 salmon lice/m³. On the second day, an additional station SV13 was sampled and showed *L. salmonis* with a concentration of 0-0.12 salmon lice/m³. On the third day SV13 was the only station sampled and did not show the same concentrations. This time it varied 0-0.16 salmon lice/m³ which was the highest density found. *L. salmonis* were found at all depths. These results show a high temporal variation.

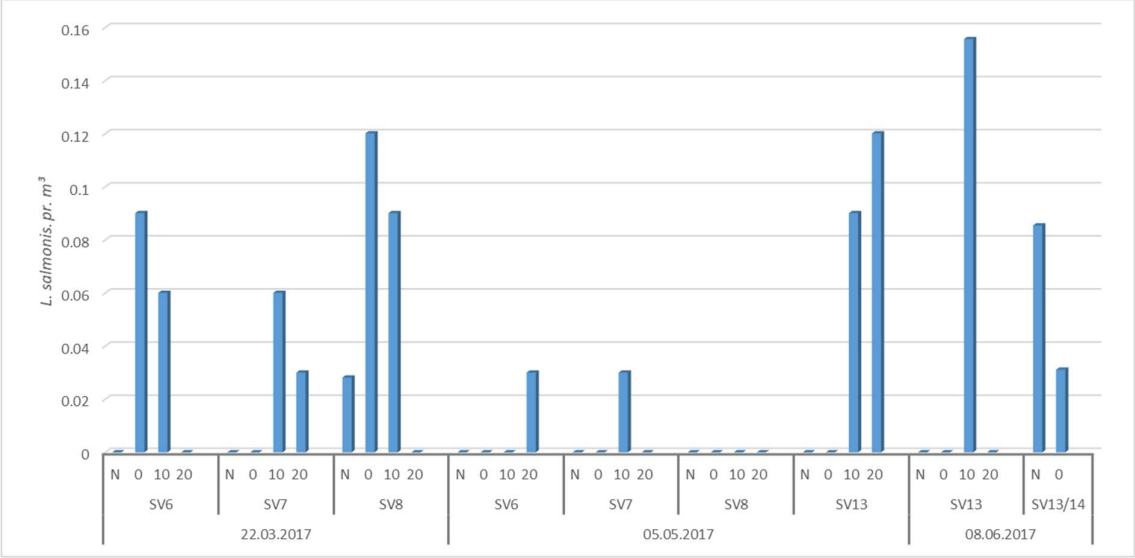

Figure 19: L. salmonis concentration on the three different sampling days (Appendix A).

The depth distribution of *L. salmonis* copepodid seemed to be similar on the first and third sampling day, but the same similarity was not found on the second. On the first sampling day 0.16 copepodids /m³ were found at sea surface and 0.09 at 10 m. On the third sampling day 0.12 copepodids /m³ were found at sea surface and 0.12 at 10 m. The difference on the second sampling day was that the density was much lower relative to the first and third sampling day. Only 0.03 copepodids /m³ were found at 10 m and nothing at sea surface and 20 m. On all three sampling days, there were none found at 20 m. The nauplii did not have a similar depth distribution on all sampling days. On the first sampling day 0.09 nauplii /m³ were found on sea surface, 0.12 at 10 m and 0.03 at 20 m. On the second sampling day 0.09 nauplii

/m³ were found on 10 m and 0.16 on 20 m. On third sampling day only 0.03 nauplii /m³ were found at 10 m and nothing was found elsewhere (Figure 21).

Figure 20 illustrates the average concentration of *L. salmonis* at all depths with both methods. The highest density of both nauplii and copepodid was found at 10 m. It seems like the higher densities of nauplii were found further down the water column while higher densities of copepodids were found in the upper 10 meters. There were no copepodids found at 20 m. A ANOVA test showed no statistical significant difference between the different depths, neither nauplii (p-value = 0.57) nor copepodids (p-value = 0.23) (Appendix E). T-tests were also used between the different depths and did not show any statistical difference.

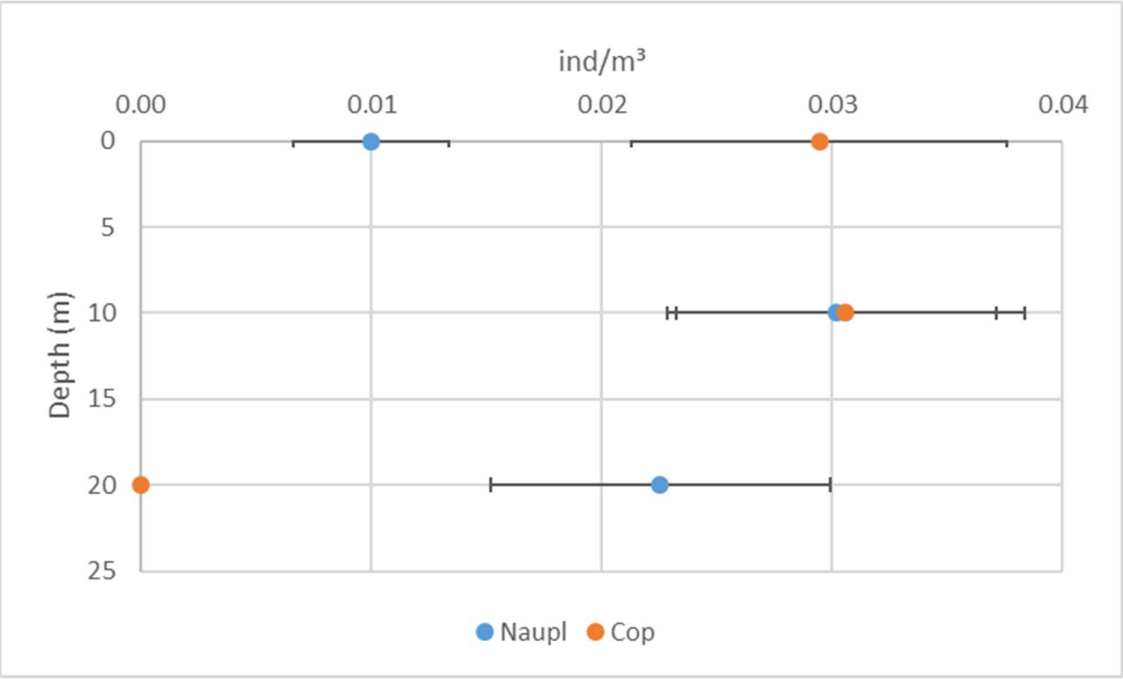

Figure 20: Average depth distribution from all sampling days with both methods.

Spatial distribution

The distribution of salmon lice in Sørvágsfirði at all station on all sampling dates is shown in Figure 21.The first sampling day (red) salmon lice seemed to be dispersed across the fjord. Salmon lice were found at all stations and at all depths. The density and depth distribution were quite similar on the southern and the northern coastal line while in the middle of the fjord the salmon lice were deeper. The second sampling day (yellow) showed the opposite tendency with salmon lice not being as dispersed. Most of the salmon lice were found on the northern coastal line (station 13) especially deep in the water column. Little to no salmon lice were found at other stations. On the third sampling day (green) samples were only taken at one station at the northern coastal line and the samples showed high density on sea surface and 10 meters (Figure 21). The wind direction while the samples were taken on each day was somewhat variable but mainly from a western direction with a wind speed at 1.4 - 5.5 m/s^{-1} (Appendix D).

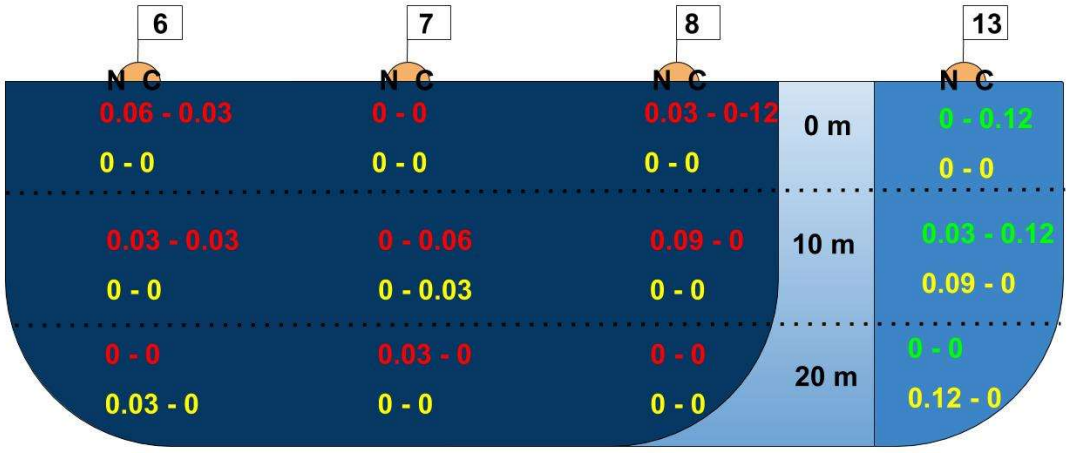

Figure 21: The distribution of salmon lice in Sørvágsfirði at all station on all sampling dates. The colours indicate the different sampling days. Red 22.03.2017, yellow 05.05.2017 and green 08.06.2017. The top numbers are the stations while coloured numbers are the salmon lice concentrations. The number on left is nauplii (N) and right copepodid (C). Example 0.06 – 0.03 is 0.06 nauplii/m^3 and 0.03 copepodid/m^3.

Discussion

Previous studies have shown that it is difficult to study the vertical distribution of salmon lice, and therefore there is a lack of results on this subject. However, this study has demonstrated that it is possible to study the vertical sea lice distribution with the right method. The high variation in sea lice abundance compared to the low number of samples makes it difficult to make conclusions about the vertical distribution in Sørvágsfirði. Nevertheless, the results can be used to make indications on the depth distribution of *L. salmonis.*

Evaluation of the pump

Horizontal net tows close to surface have been the most established method in sampling sea lice (Costelloe et al. 1998, Penston et al. 2004, Penston & Davies 2009, Penston et al. 2011, á Norði et al. 2015). However, sampling on specific depths has proven to be difficult with the use of net tows. This leads to other alternatives like a pump that collect samples from specific depths. Pumping useable amounts of seawater needs a fairly large and heavy pump. However, once the preparations have been made this is an easy and well applicable method to use.

Table 5 indicates the quantity of the samples with horizontal net and pump at sea surface are very much alike with a p-value of 0.99 (Appendix E). However, the samples taken with the pump had little or no phytoplankton in contrast to horizontal net. The reason could be that the pressure from the pump destroyed certain kinds of phytoplankton, but there was no indication of damage on zooplankton and sea lice. Single celled plankton were not found in either pump nor the horizontal net. Single celled plankton did not have any influence on the sampling as they were moved straight through the plankton net. However, the horizontal net samples contained large numbers of the phytoplankton group diatoms in contrast to the pump. Diatoms form colonies, usually in the shape of chains. Turbulence produced by the pump destroyed these colonies of diatoms making the pump samples much cleaner from phytoplankton, but the horizontal net tow did not destroy diatom colonies. The fact that the pump disintegrated the diatom chains proved to be an advantage. Clogging did not become an issue with the pump and the analysis of the samples were easier in that the samples were cleaner. This shows that it is increasingly difficult to take samples with horizontal net in that there is a possibility of clogging. Sampling in the summer showed that it did clog after

sampling a volume of 5 m^3 (á Norði personal communication). The pump does not have a clogging problem, making it possible to use in the summer when the horizontal net is not usable.

A recent study in Norway tried to use a pump, but did not show promising results (Nilsen 2016), most likely because of the volume pumped. Nilsen (2016) used a bilge pump that pumped 1,000 L for each sample while in this study ~33,000 L were pumped. In Nilsen's (2016) study the detection limit was 1 sea lice/m^3. Studies from the Faroe Islands and Scotland (Penston et al. 2004, 2011, á Norði 2015) - as well as our study - show that the concentrations are way below 1 sea lice/m^3 therefore volumes that are sampled need to be reasonably high. Previous studies have not managed to test deeper waters for sea lice, and the research has been focused on the upper meters of the water column assuming that sea lice are most abundant in the upper few meters (Costelloe et al. 1998, Penston et al. 2004, Penston & Davies 2009, Penston et al. 2011, á Norði et al. 2015, Nilsen 2016). It seems that the methods sampling in the depth have not been sufficient in that the volumes have been far too small. With the pump in this study the volume was large, and our study has shown that sea lice occur in the same concentrations or even higher at 10 m and 20 m than at the surface. Thus, the depth cannot be ignored in future studies. The pump has the ability to sample on specific depths which has proven to be difficult in the past (Nilsen 2016). However, there is a skepticismin sampling sea lice on a specific depth because sea lice are believed to patch up. Sampling on specific depths can result in missing the patches (Asplin et al. 2014). In this study, rather than placing the pump at one specific depth, the pump was placed at a specific depth and moved over a distance in the 20 minutes each pump sampling was performed. This increases the chances of obtaining patches.

Vertical distribution in the water column

The results of the vertical distribution showed that the highest density of both *L. salmonis* nauplii and copepodid were found at 10 meters depth. Overall, the higher densities were found further down the water column and lower densities were found at sea surface. The nauplii were found at all depths, but showed higher density in the depth. However, copepodids had a tendency to accumulate in the upper meters and were not found at 20 meters (Figure 20). A stratification was detected on first sampling day (no data available on the other sampling days) at ~10 meters. This could be a reason that the highest density was found at 10 meters of both *L. salmonis* nauplii and copepodid. The stratification was shallower on both coastal lines where salmon lice were found at the sea surface meanwhile in the middle of the fjord where the stratification was deeper there were no sea lice at sea surface.

There seemed to be a correlation of the depth of the stratification and the depth of *L. salmonis* found. The depth distribution between nauplii and copepodid on the first sampling day was that nauplii were deeper while copepodids were found shallower (Figure 22). The explanation for this could be that nauplii seeks the highest temperature which was the deeper layer (varies from season) to shorten their moulting time. This corresponds to the suggestion by á Norði et al. (2015), that the nauplii seek the highest temperature. Despite a higher temperature at 20 meters there were found higher densities of nauplii at sea surface rather than at 20 meters. The cause can be that nauplii are bad swimmers and at not able to withstand the currents. The copepodids were in higher densities in the upper layers. This increases the chance for a copepodid to encounter the host - a parasite-host encounter. Light intensity is the factor that controls the mechanism so that the copepodids behaviour is that it seeks upwards during daylight (Heuch et al. 1995). On the three sampling days it was

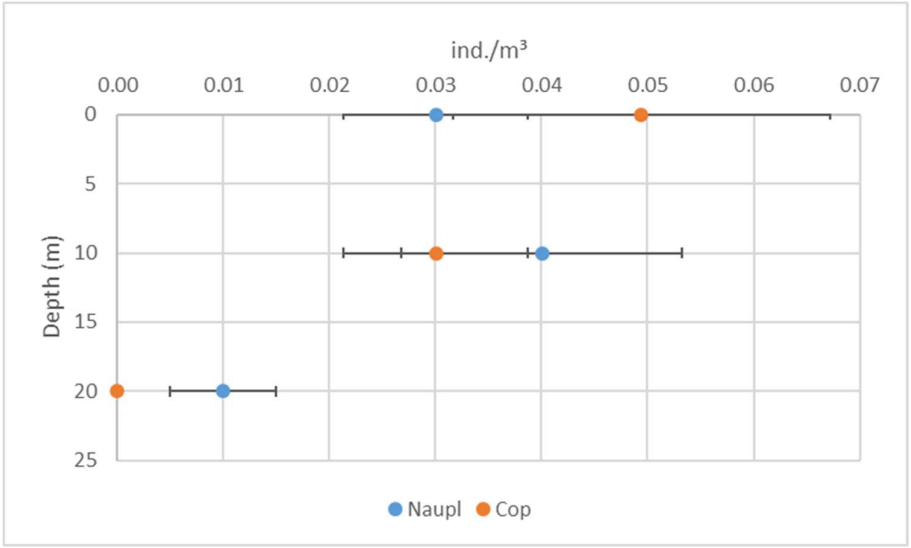

Figure 22: Depth distribution of L. salmonis at first sampling day 22.03.2017.

noticeable that no copepodids were found at 20 meter depth. This indicates that they do not go that deep. One explanation for this could be that all samples were taken on the same period of the day. If the diurnal migration is taken into consideration the copepodid will always be at that approx. depth that period of the day. If some of the sample were taken during the night the scenario could potentially be different, since Heuch et al. (1995) states that the copepodids seek upward during daylight and downward during night.

Most investigations of sea lice have focused on the upper few meters, based on the general assumption that sea lice are most abundant there (Heuch et al. 1995, Hevrøy et al. 2003, McKibben & Hay 2004, Penston et al. 2004). Methods developed to prevent sea lice have also focused on the upper few meters of the water column. Skirts and 'snorkel' cages are two methods that are to keep the salmon from sea lice in the upper few meters. The methods show that they reduce the sea lice numbers, but they will never completely solve the issue. This is because they are designed to prevent sea lice in the upper few meters, but as this study shows sea lice can be found at least at 20 meters depth. This study shows that the nauplii are most abundant at 10 meters depth and can as well be found at 20 meters depth. When positioning farming sites, the knowledge of the horizontal and vertical distribution of sea lice must be taken into consideration so that the sea lice pressure is as low as possible. A more effective method could be to use a closed unit for the salmon where they pump water from the depths below occurrence of the nauplii.

Horizontal distribution

The horizontal distribution did not show the same tendencies on all sampling days. The wind direction was western the two first sampling days. The third day it was calm weather with an average wind speed of 2.2 m s^{-1} and variating wind direction. The first sampling day, at sea surface, sea lice were equally abundant on the northern and the southern coastal line while completely absent in the middle of the fjord. With the same wind direction on the second sampling day there was not a single sea lice found on sea surface. On the third sampling day only one station was sampled, and a low density was found of copepodids.

With a western wind direction, it could be expected that the sea lice were equally distributed on both coastal lines with a high density of nauplii on the southern and copepodids on the northern. A study by Patursson et. al (2017) explains the current in Sørvágsfirði and shows

that it goes more inward on the southern and outward on the northern coastal line. The nauplii is hatched from the farming site then travels inward on the southern side and outward on the northern side until moulting into a copepodid. The first sampling day, at sea surface, showed this tendency. The horizontal distribution of nauplii and copepodid on first sampling day showed a clear indication, that further away from the farming site the nauplii – copepodid ratio was 1:3 and closer to the farming site it was 2:1. This corresponds with other studies (Costelloe et al. 1996, Penston et al. 2004, 2008, Morton et al. 2011, á Norði 2015). On the second sampling day no sea lice were found at sea surface. However, Figure 6 showed higher sea lice pressure on the second sampling day, therefore one should expect to find a high density of sea lice. A possible explanation for this could be that they were elsewhere in the fjord. A stratification could be the reason that they were further out in the fjord. On the second sampling day there was another station sampled further out in the fjord and showed higher densities of sea lice at 10 and 20 meters indicating that they could be found further out in the fjord.

Dispersion

The current pattern mentioned by Patursson et al. (2017) could suggest a dispersion pattern of sea lice. The sea lice would travel inward on the southern side and flushed out of the fjord on the northern side, and the residence time would be short in the fjord. It does not seem to be the case that the sea lice are flushed out of the fjord, but they are maintained in the fjord. The average current speed in the upper meters in Sørvágsfirði is ~5 cm/s. With a temperature of 6°C a nauplius would travel in average 32 km before moulting into a copepodid. With 8.3°C it would travel 21 km. This indicates that a nauplius would travel the length of the fjord many times (Brooks 2005, Stucchi et al. 2005, Kragesten et al. 2017). The diurnal vertical migration (Heuch et al. 1995) could be an explanation to how *L. salmonis* is able to maintain in the fjord. The ability to move vertically will decrease the time at which *L. salmonis* is moved out of the fjord. If *L. salmonis* only stayed horizontal the flushing process would happen much faster as they would be moved straight out of the fjord. The vertical movement also increases the possibility to get caught by a current moving inward the fjord. Sea lice moulting is affected by sea temperature. The fact that the ocean is warmer in the summer and colder in the winter

makes the moulting in late winter half of what it is in late summer. With these different moulting times should increase the flushing in the winter and decrease in the summer.

The exposure of the fjord is also a parameter in the quest of sea lice to maintain in the fjord. Particles released in a low exposed fjord had a high residence time in the fjord (Kragesteen et al. 2017). This suggests that sea lice in Sørvágsfirði have a high residence time as the fjord is low exposed. A salmon farm in a low exposed fjord will have a high self-infection (Patursson et al. 2017). Sørvágsfjørður, being a fjord that has a low exposure, makes it a fjord with high self-infection. The high self-infection could also be expected because sea lice have a high residence time in the fjord. In our study we were able to see the high residence time by examining *L. salmonis* nauplii – copepodid ratio. Close to the farming site the ratio was 2:1 and farther away the ratio changed to 1:3. This suggests that they maintain in the fjord.

Conclusion

Using a pump and pumping for samples at specific depths, rather than towing for samples the traditional way, has made it possible to study vertical distribution of sea lice. This study was able to find sea lice vertically down to 20 meters, something that has not been quite manageable in the past. Assuming that sea lice are most abundant in the upper few meters is not valid. Our study has found evidence to the contrary that sea lice are just as abundant further down the water column. Nauplii seemed to have a different depth distribution relative to copepodid. Nauplii were more abundant further down the water column while copepodid were in the upper meters. No copepodid was found at 20 meters depth.

This study has developed a new method to study sea lice distribution that shows great potential. With further improvements it could be even more effective and could be the method for future studies. A pump with larger capacity would make the method more effective, by sampling a larger amount of sea water over a shorter time span.

There were no clear indications of the physical conditions influencing the horizontal or vertical distribution of *L. salmonis*. Further studies could take the physical conditions into consideration how they influence the vertical and horizontal distribution. Furthermore, studies could also study in full the diurnal vertical migration of *L. salmonis* and otherwise connecting *L. salmonis* behaviour to its vertical distribution.

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Appendix A

			Volume	Conc. Nau	Conc. Cope	Conc. Total
		N	30,7	0	0	0
		0	33,3	0,060	0,030	0,090
		10	33,3	0,030	0,030	0,060
	SV6	20	33,3	0	0	0
		N	36,1	0	0	0
		0	33,3	0	0	0
		10	33,3	0	0,060	0,060
	SV7	20	33,3	0,030	0	0,030
		N	35,5	0	0,028	0,028
		0	33,3	0,030	0,090	0,120
		10	33,3	0,090	0	0,090
22.03.2017	**SV8**	20	33,3	0	0	0
		N	18,6	0	0	0
		0	33,3	0	0	0
		10	33,3	0	0	0
	SV6	20	33,3	0,030	0	0,030
		N	21,7	0	0	0
		0	33,3	0	0	0
		10	33,3	0	0,030	0,030
	SV7	20	33,3	0	0	0
		N	22,4	0	0	0
		0	33,3	0	0	0
		10	33,3	0	0	0
	SV8	20	33,3	0	0	0
		N	22,3	0	0	0
		0	33,3	0	0	0
		10	33,3	0,090	0	0,090
05.05.2017	**SV13**	20	33,3	0,120	0	0,120
		N	13	0	0	0
		0	32,125	0	0	0
		10	32,125	0,031	0,125	0,156
	SV13	20	17,13	0	0	0
		N	11,7	0	0,085	0,085
		0	32,125	0	0,031	0,031
08.06.2017	**SV13/14**					

Appendix B

22.03.2017

Sample nr.	Station	Depth(m)	*L. Salmonis* Nauplius II	*C. Elongatus* Copepodid	*C. Elongatus* Copepodid	
12	6	Glúp	0	0	0	
9	6	0	2	1	1	
10	6	10	1	1	1	
11	6	20	0	0	0	
4	7	Glúp	0	0	0	
1	7	0	0	0	0	
2	7	10	0	2	0	
3	7	20	1	0	0	
5	8	Glúp	0	1	0	
6	8	0	1	3	0	
7	8	10	3	0	0	
8	8	20	0	0	0	
		Sum:	8	8	2	**18**

05.05.2017

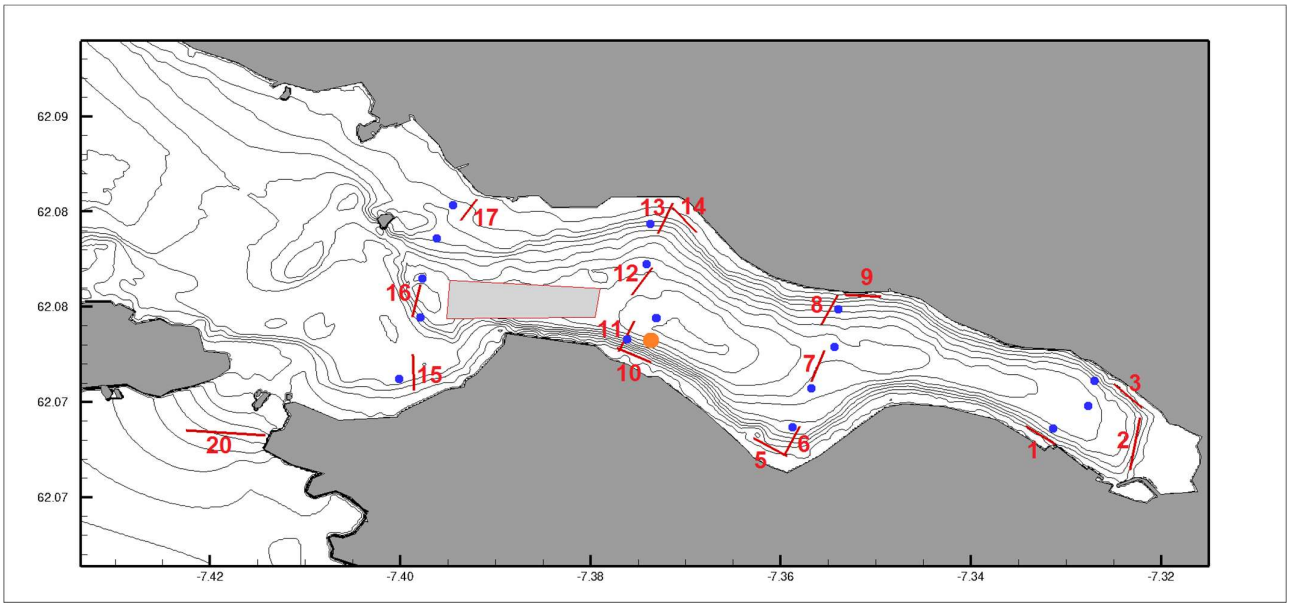
Sample nr.	Station	Depth (m)	*L. Salmonis* Nauplius II	*C. Elongatus* Copepodid	*C. Elongatus* Copepodid	
12	6	Net haul	0	0	0	
9	6	0	0	0	0	
10	6	10	0	0	0	
11	6	20	1	0	0	
4	7	Net haul	0	0	0	
1	7	0	0	0	0	
2	7	10	0	1	0	
3	7	20	0	0	0	
5	8	Net haul	0	0	0	
6	8	0	0	0	0	
7	8	10	0	0	0	
8	8	20	0	0	0	
16	13	Net haul	0	0	0	
13	13	0	0	0	0	
14	13	10	3	0	0	
15	13	20	4	0	0	
		Sum:	8	1	0	9

08.06.2017

Sample nr.	Station	Depth (m)	*L. Salmonis* Nauplius II	*C. Elongatus* Copepodid	*C. Elongatus* Copepodid	
1	13	Net haul	0	0	0	
2	13	0	0	0	0	
3	13	10	1	4	0	
4	13	20	0	0	1	
5	13	Net haul	0	1	0	
6	13	0	0	1	0	
		Sum:	1	6	1	8

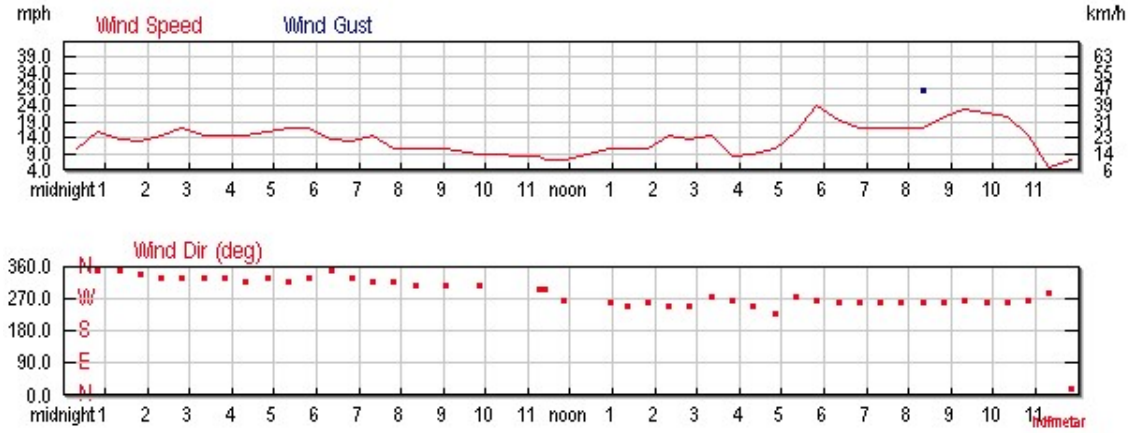
Appendix C

The orange dot indicates where the temperature equipment was placed and is placed close to station SV11.

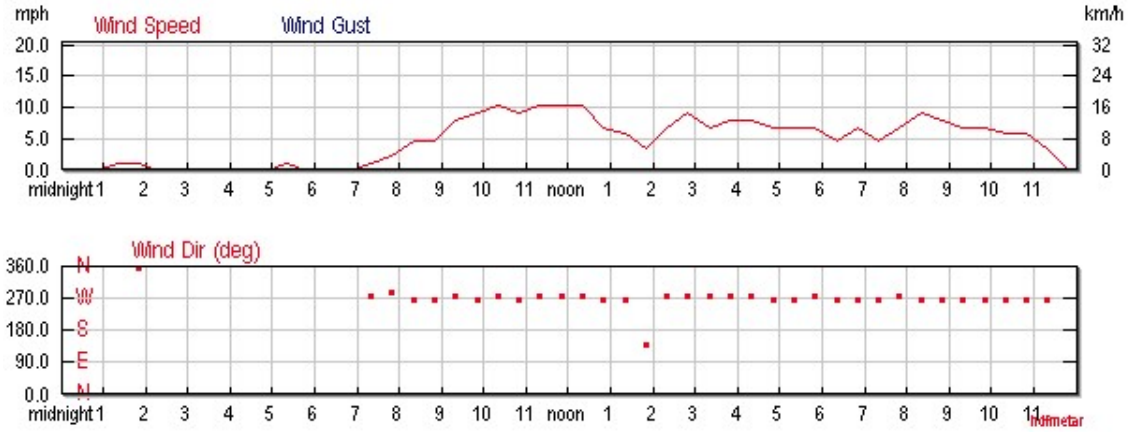


Appendix D

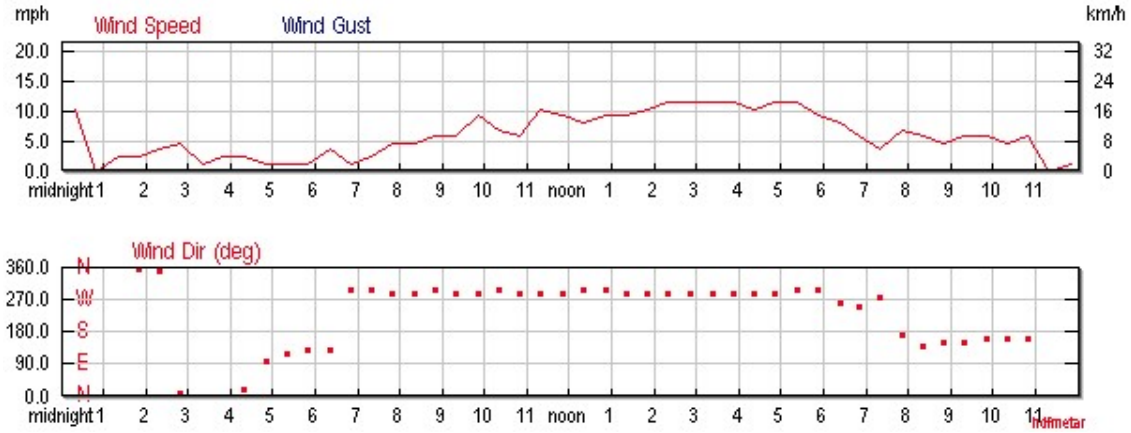
22. March 2017, Vagar **Source: www.wunderground.com**



05. May 2017, Vagar



08. June 2017, Vagar



Appendix E

Figure 18: Average lice pr. m³ with standard error.

t-Test: Paired Two Sample for Means		
	Net tow	*Pump*
Mean	0.012626567	0.026815
Variance	0.00083297	0.00213
Observations	9	9
Pearson Correlation	0.281223518	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.904638368	
P(T<=t) one-tail	0.196042458	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	**0.392084916**	
t Critical two-tail	2.306004135	

Table 5: Dry weight samples from net and pump at sea surface.

	Outliers				
		Net Haul (mg/m³)		**Pump (mg/m³)**	
		1.5		2.1	
	Q1	2.0	2.6	2.2	2.2
		3.2		2.3	
		3.2		3.1	
		3.7		3.7	
		4.0		5.3	
	Q3	5.8	6.4	5.4	5.9
		7.0		6.3	
	Outliers	12.5		17.7	
	median:	3.7		3.7	
	Q3 - 1Q =	3.8		3.7	
	Multipli 1.5	5.7		5.5	
	Inner fence:	0	12.1	0	11.4
	Multipli 3	11.4		11	
	Outer fence:	0	17.8	0	16.9
Average with outlier:		4.8		5.4	
Average without outlier:		3.8		3.8	

With outliers		
t-Test: Paired Two Sample for Means		
	Net Haul	*Pump*
Mean	4.773390112	5.356817877
Variance	11.29496398	23.95195117
Observations	9	9
Pearson Correlation	0.965516455	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.937536381	
P(T<=t) one-tail	0.187959748	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	**0.375919496**	
t Critical two-tail	2.306004135	

Without outliers		
t-Test: Paired Two Sample for Means		
	Net Haul	*Pump*
Mean	3.80916644	3.811705397
Variance	3.345621006	2.817826273
Observations	8	8
Pearson Correlation	0.920232736	
Hypothesized Mean Difference	0	
df	7	
t Stat	-0.010031452	
P(T<=t) one-tail	0.496138051	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	**0.992276101**	
t Critical two-tail	2.364624252	

Figure 20: Average depth distribution from all sampling days with both methods.

Anova: Single Factor

Copepodid

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0	8	0.14829	0.01854	0.00173
10	8	0.24463	0.03058	0.00192
20	8	0	0	0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00380	2	0.00190	1.55889	0.23376	3.46680
Within Groups	0.02557	21	0.00122			
Total	0.02937	23				

Anova: Single Factor

Nauplius

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0	8	0.09009	0.01126	0.00050
10	8	0.24134	0.03017	0.00155
20	8	0.18018	0.02252	0.00174

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00145	2	0.00072	0.57360	0.57208	3.46680
Within Groups	0.02649	21	0.00126			
Total	0.02794	23				