Final report for NFR-project no. 163869: "The Hardangerfjord salmon lice project – 2004-2007"

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Summary

- *Methods to assess salmon lice infection on postsmolt salmon during seaward migration have been successfully developed and the industry has introduced measures to reduce the infection levels and consequently the potential numbers of salmon lice larvae in many areas. Nevertheless, the actual impact of salmon lice on wild salmonids is still uncertain due to lack of systematic investigations. In this project we have focused on the interactions of salmon lice between farmed and wild salmonids in the Hardangerfjord.*
- *In WP1, wild sea trout and Atlantic salmon were sampled by a range of methods to investigate the level of infection by salmon lice in the Hardangerfjord. The results indicate that the infection level still is too high in this region. Sea trout smolts collected from the smolt trap in River Guddal and treated chemically against salmon lice had twice as high return rate (sea survival) as the untreated control group, thus documenting salmon lice induced mortality on sea trout in this area.*
- *In WP2, control options by coordinating experimental lice treatments and examining results by different lice counting methods was explored. It was demonstrated that using Slice between November and January dramatically reduced lice population growth through the following spring. In the critical smolt run period very few adult female lice were found. Bath treatments in the same period did not give the same effect. Present monitoring guidelines specify that a sample of at least 20 fish should be taken from two pens, one presumably the most infected pen, and the other a random pen. Analyses indicated that there was no difference between mean abundances of lice in the presumed most infected and the random pen, and that clustered lice distribution within a site requires more pens to be sampled for a reasonably accurate site mean abundance to be estimated.*
- *The purpose of WP3 was to check health status of farmed and wild smolts for assessing the susceptibility to salmon lice infections. The results showed that gill aluminium was significantly higher in wild postsmolts taken in trawl compared to hatchery reared smolts in cages and the former could be more susceptible to salmon lice infestations. With respect to cataracts, samples were taken from both Sognefjorden and in Hardangerfjorden. Fish in Hardangerfjorden did not show any incidence of cataract in the eye while this was seen in Sognefjorden.*
- *In WP4 the migratory speed and route of Atlantic salmon smolt from the inner part of the fjord out to the ocean was described. In addition, individual smolt was equipped with acoustic tags to examine the relationship between swim speed, movement pattern, water temperature, salinity and light intensity. High survival rates (~80%) were recorded in Sørfjord from the release site at Odda out to Kinsarvik 36 km out from the release site. The migratory speeds through Sørfjord were ~0.65 bl/s in 2005 and 2006. Salmon smolt spent from 63 to 99% of the time at depths between the surface and 3 m depth during the first 12 hours after release. Water temperature and salinity did not seem to influence the swim depth of the postsmolt. However, variation in light intensity seemed to be a decisive the for swim depth of 50% of the examined smolts.*
- *In WP5, the abundance of infective salmon lice larvae in the fjord system was estimated by using sentinel cages with smolts at different locations in the fjord as traps for lice larvae. The level of salmon lice in the cages was low and comparable to the level of lice on wild migrating Atlantic salmon post smolts. For isotope analyses, salmon lice were sampled from farmed and wild salmon in the Hardangerfjord, and the Finlayson and Mathieson Channels, BC, Canada, and the natural abundances of δ15N and δ13C ascertained. The data suggests that there are differences between the natural abundances of δ15N between the wild and farmed salmon in BC. Further analyses are needed to obtain a definitive result.*
- *In general, the flow in the Hardangerfjord system (WP6) is complicated but less energetic with fairly low mean and maximum speeds. The mean flow pattern consists of both outward and inward currents, but the variability is large. For the period 2004-2006, the year 2006 differ with significantly less brackish water. Otherwise, the conditions are fairly similar. Low current speeds in area of Etne/Skånevikfjorden suggest retention of water masses. Particle models indicate that salmon lice nauplii will spread relatively rapidly over most parts of the Hardangerfjord.*
- *Through broad cooperation between the leading Norwegian research institutes, industry and management and experiences from adjoining projects we have in this project developed a knowledge base for the Hardangerfjord system which can be used in further management aimed at decreasing the effects of salmon lice on wild salmonids. The work will continue in the Hardangerfjord II project.*

Contents

Introduction

The Norwegian fish farming industry has shown a strong growth during the last years and in 2005, 648 000 tonnes of farmed salmonids were produced. Salmon lice infestations (*Lepeophtheirus salmonis* Krøyer) represent an important economical loss factor in Norwegian and international salmon farming industry. Given the frequently high numbers of gravid salmon lice carried by the large numbers of cultured fish throughout the year, it is likely that the development of an aquaculture industry has lead to changes in the natural host-parasite relationship, and made possible the production of large amounts of infective dispersal lice stages. As plankton, these larvae will drift and be dispersed over long distances, but apparently they concentrate near the surface by day, and probably also near pycnoclines in stratified waters. The density of infective salmon lice stages are, therefore, likely to be greatest in inshore coastal areas and fjords that are subject to constrained tidal flushing. These locations are exploited by the farming industry as well as seaward migrating salmonid postsmolts.

Salmon lice epidemics have also been described as a problem for wild salmonids. Salmon lice feed on the mucus, skin, and blood of the host fish and may cause extensive mechanical damage to the skin, as well as maladaptive physiological effects on the host. The latter are manifested as primary (e.g. high levels of the stress hormone cortisol), secondary (e.g. osmoregulatory problems) and tertiary (e.g. reduced lymphocyte-leukocyte ratio) stress responses. Based on crude estimates of how many lice a smolt can tolerate, direct parasite-induced mortality of wild postsmolt sea trout has been estimated to 30-50 % in an area with intensive fish farming activity. Some studies have indicated 48-95 % mortality of postsmolt salmon in the intensively farmed Sognefjorden, but more information about the infection dose-physiological response curve is needed to assess the losses to wild salmon populations. The latter study also indicates that the infection pressure on wild postsmolt salmon is strongly influenced by environmental factors (mainly salinity). Based on the evidence collected during the 1990's and later, salmon lice must therefore at present be regarded a major factor limiting the production potential of many wild Norwegian salmon and sea trout stocks. The problem has increased during the last decade, and while no direct link has yet been established, increasing evidence implies that the problem has some connection with the rapidly growing salmon farming industry. Measures have, therefore, been taken by the fish farming industry and management authorities to reduce salmon lice levels in the fjords and coastal current.

It is indicated that the relative contribution of lice may vary between host species, geographic area, levels of farming activity and management practises. Furthermore, hydrographic conditions and current systems seem to be crucial in the dispersal of infective lice, and will determine the risks of re-infection of hosts. In this project our aim is to establish a population dynamic base for the parasite-host system with models describing the hydrographic systems within the fjords. Currently such models are being tailored to model drift of infective lice stages and in an ongoing project in the Altafjord and the Sognefjord, the monitoring have included all the possible salmon lice hosts in a fjord system. Epidemiological models combining lice population dynamics and dispersal potential is urgently needed to understand the complex relationship between hosts and parasites. This will enable us to estimate the importance of the different hosts in the production of salmon lice and the infection mechanisms between hosts, and allow evaluation of different management strategies to reduce lice abundance on wild and farmed salmonids.

The amount of lice is, however, expected to increase as salmon production increases. Even though governmental authorities and the fish farmers have allocated large resources into reducing lice levels on farmed salmon, results from wild postsmolt trawling surveys and test fishing for sea trout are to some degree discouraging. The picture emerging indicates that the overall situation has improved in many areas but that the most negatively affected stocks will be under pressure in the foreseeable future.

In the Hardangerfjord system where the study is planned, a widespread and pronounced decrease in wild stocks of salmon and sea trout has been recognized for about a decade. Due to a generally low level of monitoring activity of wild stocks, the decline has primarily been detected through reduced river catches, but also through low counts of spawners in a couple of rivers. Simultaneously, very high infection levels of salmon lice have been recorded on sea trout in the area from 1994, which is shortly after the increase of fish farming in the area. These observations led to a strong concern about the wild stocks in the fjord, and a suggested a causal link between salmon farming and the decline in the wild stocks.

This three-year research project focuses on the interactions of salmon lice between farmed and wild salmonids in Norway including registration of salmon lice abundance on wild and escaped salmonids, optimised salmon lice monitoring and control strategies in farms, quality of farmed and wild smolts, migration speeds and routes of Atlantic salmon smolts, spread of salmon lice larvae, and physical oceanographical factors on salmon lice distribution in the Hardangerfjord. The present project has been closely coordinated with another ongoing project in the Hardangerfjord system (Institute of Marine Research) thus giving maximal advantage for both projects.

The project has been divided into 6 closely interacting work packages (WPs):

- WP 1 - Registration of salmon lice abundance on wild and escaped salmonids
- WP 2 - Optimised salmon lice monitoring and control strategies in farms
- WP 3 - Quality of farmed and wild smolts
- WP 4 - Migration speeds and routes of Atlantic salmon smolts
- WP 5 - Spread of salmon lice larvae
- WP 6 - Physical oceanographical factors on salmon lice distribution in the Hardangerfjord

Through broad cooperation among the leading Norwegian research institutes, industry, international partners and experiences from adjoining projects, we aim to further develop a model system for the Hardangerfjord and for other fjord systems globally, which can be used in management schemes aimed at minimising the risk of salmon lice infestation on wild and farmed fish stocks.

WP 1 - Registration of salmon lice abundance on wild and escaped salmonids

Øystein Skaala, Institute of Marine Research and Pål Arne Bjørn, Norwegian Institute for Fisheries and Aquaculture Research

Summary
Wild sea trout (*Salmo trutta* L.) and Atlantic salmon (*S. salar* L.) were sampled by a range of methods to investigate the level of infection by salmon lice (*Lepeophtheirus salmonis*) in the Hardangerfjord basin. The results indicate that the infection level is still too high in this region. In 2006 about 50% of the salmon smolts were infected with lice, most of the salmon smolts had infection levels that are expected to affect the fish negatively. The postsmolt of sea trout had higher levels of infection, many individuals had over 10 lice, and some had more than 100 lice. About 50% of the sea trout sampled by trawling in week 22 and 23 in 2006 had infection levels expected to inflict strong physiological stress and even lethal effects. Sea trout smolts collected from the smolt trap in River Guddal and treated chemically against salmon lice had twice as high return rate (sea survival) as the untreated control group, which gives evidence of salmon lice induced mortality on sea trout in this area.

Introduction
Already in the early 1990'ies, sea trout heavily infested with salmon lice were captured in the Hardangerfjord, and in consecutive years a discussion followed about the connection between the high infestation level observed on wild salmonids, and the apparent severe decline in spawning populations in several rivers in the inner and middle parts of the fjord system. It was further reported that sea survival of salmon populations from Hardanger was lower than for salmon stocks from other regions of the Norwegian west coast, and that the Hardanger stocks failed to respond to an improvement in ocean climate and return to more normal levels from year 2000, as did several other salmon stocks along the Norwegian coast.

Materials and methods
It is not straightforward to quantify precisely the mortality caused by salmon lice. The infection level on postsmolts can give some indirect evidence, given that a representative sampling of fish populations and their infection level can be obtained. To try and compensate for limitations in sampling methods, an attempt was also made to assess the mortality caused by salmon lice by comparing survival of smolt groups treated chemically against lice to untreated control groups of smolt collected in the trapping facilities in River Guddal.

During the project, salmon lice were counted on the most important wild species of salmonids in the fjord system, including Atlantic salmon and sea trout, as well escaped farmed salmon. To accomplish this, a variety of gear was chosen to capture specimens of various life stages from postsmolts to adults, during different seasons of the year, and at different regions and fishing stations. However, the low abundance of the populations of sea trout and salmon in parts of the fjord, posed a problem for the sampling, as the catch per unit effort were low, particularly in the areas where the decline in the populations appeared to be strongest.

The following gear types were used:
Floating gillnets for postsmolts and adult sea trout, trawling for postsmolts of sea trout and salmon, bag nets for wild and escaped salmon and "utter" fishing for sea trout (modified fly fishing from boat). Sampling sea trout was attempted in the following locations: Etne, Dimmelsvik, Enes, Maurangsnes, Mundheim, Norheimsund, Utne, Granvin and Kinsarvik. From these attempted locations, fishing stations for sea trout were established in the outer (Etne), middle (Dimmelsvik) and the inner (Maurangsnes, Mundheim, Norheimsund) areas. Fishing for salmon were conducted mainly by bag nets in Etne, at Tysnes and at Stolmen north of the outlet of the Hardangerfjord.

To investigate the mortality caused by salmon lice in the natural environment, part of the wild smolts from the trapping facility in River Guddal were treated chemically (Substance EX) against lice before released back to the river. Another smolt group was used as untreated control, and all fish were fin clipped to distinguish the two groups at return in the trap.

Infection levels on post smolts captured by trawling
Catching representative samples of fish populations may be a challenge in general, and particularly so when numbers and life stages of salmon lice are to be recorded on the specimens. Commonly

employed sampling methods such as gillnets and trawling will usually cause losses of scales and thus also losses of lice, which will result in underestimates of infestation levels. A specially designed trawl, FISH-LIFT, with a box to catch living and undamaged fish, was developed by Holst & McDonald (2000). Thus, trawling has been performed every year when wild smolts migrate from the rivers to the sea (Figure 1). The infection level has been lower than observed in some years in the Sognefjord (Table 1).

Given that the numbers are representative, the observations indicate that mortality on salmon smolts caused by salmon lice is somewhat lower than in previous years. However, the sea trout which is more stationary in the fjords compared to salmon appears to accumulate higher numbers of salmon lice (Table 2). Smolts of sea trout are often larger than salmon smolts, and therefore it is expected that sea trout also will survive with slightly higher numbers of salmon lice. Still, it has been reported that even a few lice will inflict pain and increased stress levels to the postsmolts. Preliminary results indicate that an infection level of more then 10 lice might kill the smolt due to the damage the adult lice inflicts on the salmon.

Table 1. Level of salmon lice on Atlantic salmon postsmolts and sea trout captured by trawling from 2004 to 2006.

	Atlantic salmon			Sea trout		
Year	N	Mean Lice/fish	Prevalence (%)	N	Mean Lice/fish	Prevalence (%)
2004	149	1.5	27.5	34	6.4	76.5
2005	86	0.6	15.1	42	42	66.7
2006	122	1.9	48.4	189	189	95.2

Table 2. Infection intensity (# lice per infected fish) and relative intensity (# lice per gram fish weight) in sea trout <150 gram in the Hardangerfjord in 2006. The fish were sampled with the FISH-LIFT in outer parts of the Hardangerfjord from week 20 to week 23. Length and weight (mean and SD), prevalence (percentage infected fish), and infection parameters are given.

Week	N	Length (mm± SD)	Weight (g± SD)	Prevalence (%)	Number of lice						Relative intensity			
					Mean ± SD	Median	IQR	min	max	v/x	Median	IQR	min	max
20	5	136,6 ± 11,0	22,3 ± 4,3	80	6,5 ± 5,9	4,5	11	2	15	5,38	0,186	0,5	0,115	0,754
21	19	139,1 ± 7,4	23,8 ± 3,7	89,5	19,0 ± 28,9	5	19	1	112	43,92	0,206	0,77	0,034	4,272
22	39	139,7 ± 7,0	23,7 ± 3,5	92,3	17,9 ± 16,7	12	12	2	86	15,53	0,533	0,42	0,095	5,222
23	17	141,4 ± 68,4	24,0 ± 3,9	88,2	23,6 ± 17,1	18	26	1	68	12,43	0,708	1,094	0,046	2,343

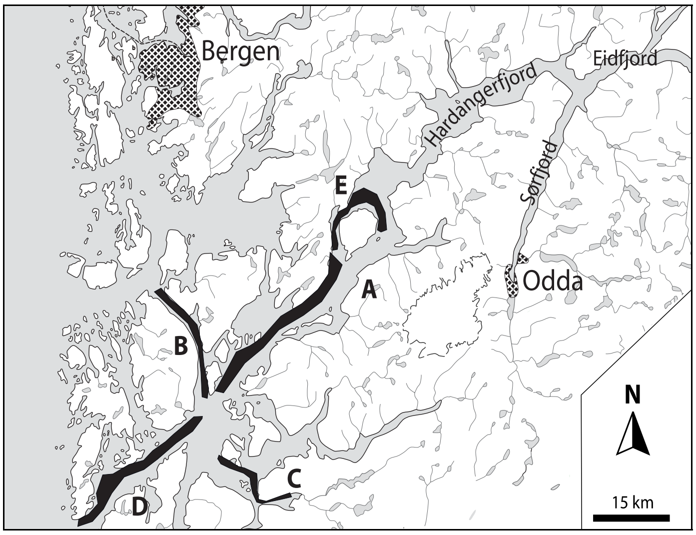

Figure 1. Post smolt trawling with the FISH-LIFT system in the Hardangerfjord, spring 2005. (Photo: Karin. K. Boxaspen)

Infection levels in sea trout captured by gillnetting and angling

To further assess the infection levels on sea trout, the following stations were sampled: outer region (the Etne fjord), the middle region (2 stations in the Kvinnheradsfjord: Dimmelsvik, Ænes), and the inner region (2 stations in Kvam: Vikøy, Mundheim and Granvin) (Table 3). Typically, the number of lice varied much among individuals within a region. For example, in the Kvinnheradsfjord (middle region), the number of lice on sea trout varied from 0 to 130 in 2005, and 40% of the sea trout had more than 20 lice. The same variation was observed in the Etnefjord (outer region).

The catch per unit effort varied much among regions, despite the fact that the fishing stations were selected in areas previously known to be good sea trout locations. The CPUE (number of trout per net and night) in 2006 varied from 0.63 Dimmelsvik, 0.10 (Mundheim) and 0.06 (Norheimsund), while we failed to obtain samples at all from Granvin, previously known to be one of the best sea trout areas on the west coast of Norway. Similar results with low CPUE in the inner stations were obtained in 2004 and 2005, which supports the statements of depressed stocks from the Rosendal area and in towards Granvin.

Table 3. Infection level (mean number of lice per fish, median and prevalence) of salmon lice on sea trout from three different stations of the Hardangerfjord basin.

	2004				2005				2006			
Station	**N fish**	**Mean # lice**	**Median # lice**	**Prev. %**	**N fish**	**Mean # lice**	**Median lice**	**Prev. %**	**N fish**	**Mean # lice**	**Median # lice**	**Prev. %**
Outer	22	23.6	16.5	95	33	22.0	11.0	91	45	16.5	9.0	89
Middle	55	9.0	4.0	78	41	20.0	10.0	88	23	15.3	9.0	96
Inner	11	9.4	6.0	73	17	8.8	0	47	6	8.0	5.5	83

In all three years, the highest infection rate was observed in the Etnefjord basin (outer region), which is a national salmon fjord. This is also in agreement with the observations of infestation level obtained from the test cages with salmon smolts. There was no clear trend in the infection level within each region, although a possible reduction in the outer (Etne) region and in the middle region in 2006. The number of fish collected in the inner region was low in all three years, possibly due to depressed stocks.

Infection on adult wild and escaped farm salmon

The infection level was also assessed in adult wild and escaped farm salmon (Table 4). Some data are still to be processed, and only the numbers for 2005 are included in the report. Due to short fishing season for bag nets, and to the fact that the season is not opened until wild salmon have passed by

Stolmen, the number of salmon caught were low. As expected, the majority of wild salmon had lice. Due to the small numbers, it is not possible to draw strong conclusions about any differences between wild and escaped salmon. In Etnefjord the infection level was similar in wild and escaped salmon, while prevalence was slightly higher in wild salmon. At Stolmen, the infection level was slightly higher on escaped salmon but the prevalence was similar on wild and escaped salmon.

Table 4. Infection level as number of lice of adult wild and escaped farm salmon in Etnefjord and Stolmen in 2005 captured in bag nets

Region	Wild salmon				Escaped farmed salmon			
	N	Mean	Median	Preval. %	N	Mean	Median	Preval. %
Etnefjord	12	12.3	5.0	83	20	12.8	1.0	55
Stolmen	4	7.5	3.5	75	12	9.7	6.0	75

Evidence for mortality caused by salmon lice: comparison of survival of smolt chemically treated against salmon lice and untreated controls

The return rate, which is reflecting sea survival, was very low for both treated and untreated groups. However, the recapture rate of the EX treated smolt group from the 2004 smolt cohort, was significantly higher than that of the untreated control group after the two first sea migrations. Mean weight and condition factor were also higher in the treated group than in control group, although not statistically significant. As the chemical treatment by Component EX is not expected to give a full protection against salmon lice, and survival of treated group was twice that of the untreated control group, the observed difference in survival between the two groups represents an underestimate of the mortality caused by salmon lice.

The recapture rate in 2004, 2005 and 2006 of the untreated 2003 smolt cohort (N=1350) was less than 3%, which is exceptionally low for sea trout. A high percentage of the trout captured in the upstream trap and in gillnet catches had open wounds behind the anal fin, an area of the body surface where lice often appear to concentrate. This observation further illustrates the damage inflicted by salmon lice. Together, the results suggest that mortality on sea trout caused by salmon lice may be 50% or more in parts of the Hardangerfjord basin.

Monitoring of environmental impacts from salmon farming in the Hardangerfjord

Salmon farming has expanded rapidly in the Hardangerfjord basin during the past 10 years, and is now one of the regions with highest density of fish farms in Norway. Several of the populations of sea trout and salmon in the Hardangerfjord are naturally small populations, and therefore also vulnerable to human activities in their habitats. The River Etneelv, which has been chosen as one of the national salmon rivers, appears to be the only river in the fjord basin with substantial numbers of seatrout and salmon spawners. Monitoring of the environmental effects of fish farming must therefore be established on a regular basis, and not only as short term, project related activities.

WP 2 - Optimised salmon lice monitoring and control strategies on farms

Rune Stigum Olsen, Hardanger Fiskehelse Nettverk (HFN), Peter Andreas Heuch, Norwegian Veterinary Institute, Crawford Revie and George Gettinby, University of Strathclyde, Scotland and Gordon Ritchie, Marine Harvest.

Summary
The purpose of WP2 was to optimise lice monitoring on farms and explore the use of wrasse as a component of a strategic approach to the control of salmon lice in the Hardangerfjord. The fish health work in the fjord is to a large extent initiated and coordinated by the Hardanger Fishhealth Network (HFN). In this work package, HFN and researchers explored control options by coordinating "experimental" lice treatments and examining results by different lice counting methods. It was demonstrated that treating with emamectine benzoate (Slice) between November and January dramatically reduced lice population growth through the following spring. In the critical smolt run period, very few adult female lice were found. Bath treatments in the same period did not give the same effect.

Present monitoring guidelines specify that a sample of at least 20 fish should be taken from two pens, one presumably the most infected pen, and the other a random pen. The accuracy of this protocol was tested by examining data sets from sites where all pens had been sampled, and data from a large set of regular farmer two-pen counting. A comparison with similar data from Scotland was also carried out. Analyses indicated that there was no significant difference between the lice mean abundances in the presumed most infected and the random pen, and that clustered lice distribution within a site requires more pens to be sampled for a reasonably accurate site mean abundance to be estimated.

Introduction
The long and narrow Hardangerfjord is a rather enclosed water body with a very high number of salmon farms per surface area (see: http://www.nina.no and the Hardangerfjord project description). The salmon lice infection pressure on wild and farmed salmonids is thus mainly determined by the abundance of lice on the farmed fish within the fjord (Heuch et al. 2005). As lice abundance can be reduced by treatments of farmed fish, there is scope for control of the total lice abundance in the fjord provided that treatments are carried out efficiently and synchronously. The success of this approach will also depend on the timing of the operation as well as environmental factors. Monitoring of the lice abundance on the farmed fish will tell whether such strategic treatments are successful.

For many years monitoring of lice in salmon farms in Norway has been done as a routine, and such monitoring is required by law. Monitoring guidelines specify that a sample of at least 20 fish be taken from two pens, one presumably the most infected pen, and the other a random pen. Monitoring allows the farmer to determine if the farm exceeds the legal threshold limits, above which control measures are required. This scheme is designed to prevent farmed fish from having lice burdens which would increase the infection pressure on wild salmonids, and to encourage lice control on the farms. Accurate figures are required for research into total lice production and population dynamics within areas. It has been shown that the similarity in lice numbers on the fish within pens, and large differences between pens will invalidate estimations of mean site abundance of lice based on two pen counts only (Revie et al. 2005). The clustering of similar fish in pens can be described by the intra-class correlation (ICC), and is necessary to take this parameter into account when sampling programmes are designed. In this WP strategic treatments were evaluated by standard lice counts, but other sampling protocols were explored by field counts and modelling.

Materials and methods

Data collection
A series of **workshops** for farmers and fish health personnel were arranged by HFN, where methodology and suggestions for improvement were discussed. Important issues have been cleaner fish and how to integrate this approach with control by chemotherapeutants, and strategic treatments in the fjord.

The HFN coordinated collection of lice data from farmers and organized **sea lice counting by special teams**. Counting teams and farm personnel/local veterinarians were trained in a standardized lice counting procedure, and reported lice numbers to HFN using standard forms. Farm stocking data, environment and treatment history were obtained from the farmers. Counting by teams was carried out from April to early autumn. In 2004, lice were counted on 20 fish from all pens in four farms, and 80 fish in all pens in one farm. This was done to simulate of different sample sizes in pens by Monte Carlo methods (Revie et al. 2007).

Experimental strategic treatments
Late Desember 2004, oral treatment using Slice (Emamectin) was carried out on 66% of the fish from the 2004 generation in 3 different periods. The rest of the fish were bath treated. The experiment was supported by Skretting, Biomar, EWOS and Schering Plough. Late December 2005, the oral treatment experiment was repeated, this time using Slice (Emamectin) on 67.3% of the fish from the 2005 generations in three different periods. The rest of the fish were treated as in 2004.

Protocol modelling
Sampling from two sites with high ICCs (Intra Class Correlation) were simulated 1000 times, comparing the mean of each sample to the true mean of the dataset. In the case of *L. salmonis* mobiles in February 2002 at site S1 (ICC = 0.35), the effect of the sampling strategy of taking 20 fish from each of 2 cages was contrasted with the sampling strategy of taking 8 fish from each of 5 cages. In the case of *C. elongatus* mobiles (ICC = 0.42) in August 1994 at site S10, the effect of the sampling strategy of taking 6 fish from each of 3 cages was contrasted with the sampling strategy of taking 2 fish from each of 9 cages.

Results

Strategic treatments
Results revealed new knowledge as to how low lice abundance can be maintained for when many sites in a fjord use the same strategy. The experiment resulted in what we believe is a historically low lice infection pressure in the important spring period when the wild fish leave the rivers and swim through the fjord. This coincides with the stocking the spring generations cages (Figures 2 and 3). The groups which did not follow the treatment strategy carried nine times as much louse as the Slice-treated fish in the middle of May, which is the month of the spring run. Six sites used wrasse the following summer, and these did not need any further treatment until after October.

Except for the spring period, the lice problem was greater in 2005 than the last two years. Some of the explanation seems to be the high salinity this winter, and the warm summer. These relationships are now being analysed in depth. A full account of the strategic treatments in the fjord can be found in Stigum Olsen et al. (2005, 2006).

Lice counting protocols
An MSAccess database was designed for the study. The data from the lice counts were collected by the HFN and subsequently fed into the database. The clustering of lice on fish was examined using the data from the all pen counts. It was apparent that the lice levels in the Hardanger data were much lower than in Scottish data used for comparison. However, significant ICCs were found for prevalence down to 21%-23%, both for chalimus and for mobile stages. ICCs did tend to be larger at higher prevalence. Scottish data were used to model different sampling strategies at high ICCs (Revie et al. 2007. The degree to which the sample means depart from the true mean is seen in a distribution plot of the deviations for each sampling strategy. The strategies use the same total number of sampled fish, but when fewer cages are sampled there is a greater chance of considerable deviation of the sample mean from the true mean. It is apparent that in most cases the estimate is 0-1 louse away from the true mean when more cages are sampled.

Statistical analyses showed that the presumed “worst” pens (in terms of lice abundance) were frequently not worse than the other sampled pen on the site.

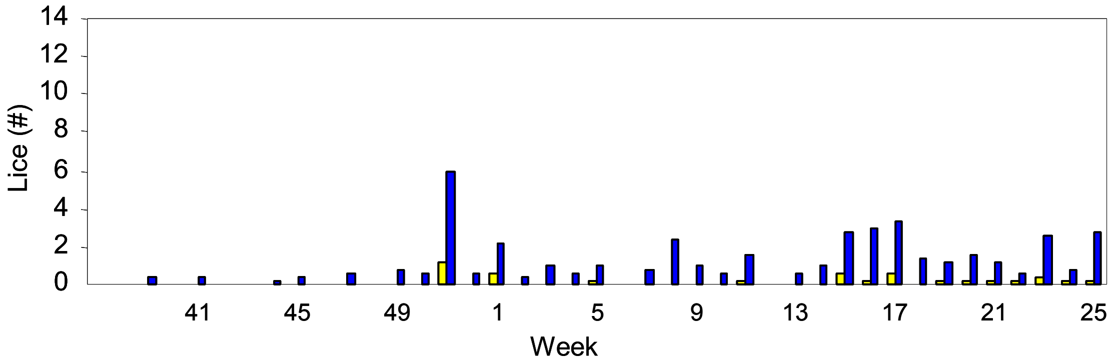

Figure 2. Mean abundance of lice on 7 different farms using bath treatment or no treatment in the winter 2004-2005. Yellow bars: adult females, blue bars: total # lice.

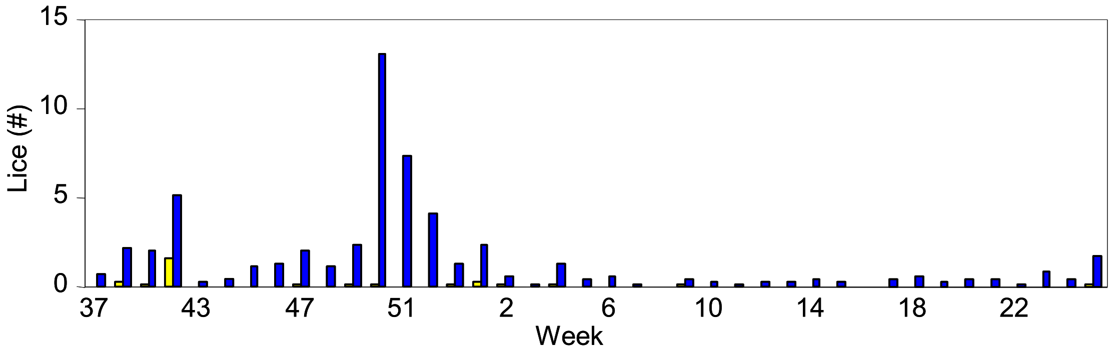

Figure 3. Lice on 17 different farms using Slice winter treatment in the experiment 2004. The treatment lasted from Nov-Jan. Yellow bars: adult females, blue bars: total # lice.

Sea lice monitoring

During 2004, counting data in farms included around 1000 fish every two weeks. A competition between the farms was established to increase reporting of lice numbers proved to be a success. In 2005, the teams counted lice on 20 sites (including 3 generations of fish) between April and August. Collected data from 2004-2005 confirmed low prevalence of lice in areas where the majority of sites followed the same strategy. Results showed that the lice problem was even smaller than 2004 for the farmed fish (2004 was also a very good year) (Figure 4). As for 2003 and 2004, it looked like there was a higher abundance of lice in the outer part of the fjord, most likely because of the higher salinity in the area, but also due to lack of cooperation from the farmers in those parts.

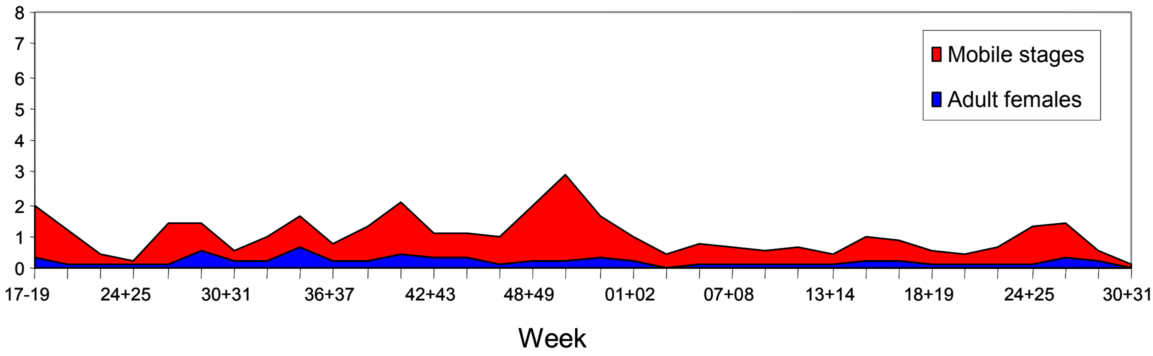

Figure 4. The development of both mobile and female lice in the whole of the fjord 2004 and 2005.

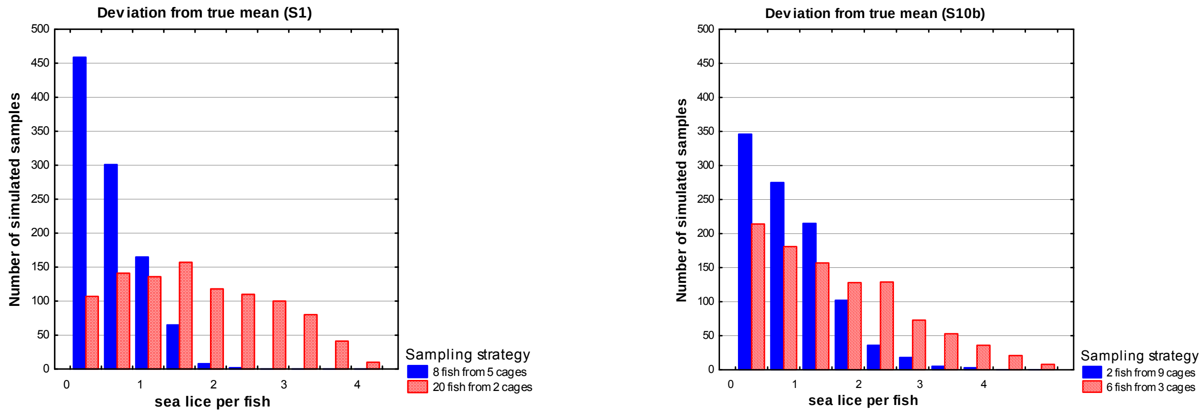

Figure 5. Results from 1000 runs of a Monte Carlo simulation illustrating the difference in sampling strategies on likely deviations from the true mean in the presence of ICC for two farms in Scotland: site S1, ICC = 0.35 (L. salmonis mobiles); site S10b, ICC = 0.42 (C. elongatus mobiles) (From Revie et al. 2007).

Discussion

The success of the winter delousing process is very encouraging for several reasons. First, it proves that a strong reduction of the abundance of egg-producing lice in winter directly lowers the infection pressure on wild salmonids. Second, it shows that strategic treatments can be extremely powerful in enclosed water bodies such as fjords and third, that the model of voluntary cooperation between farmers in such areas is both profitable for the farmers and good for the environment.

The data from this project shows that the "worst pens" assumption does not hold. All pens could be regarded as “random”. This means that the reported averages, which were supposed to be "worst case", perhaps closer to the real farm average than originally thought.

When the intra-class correlation (ICCs) is high, the "few fish per pen and many pens per farm" strategy is statistically a better option (Figure 5). However, as the cost for the farmer is related to getting the pen ready for sampling rather than the counting itself, the prevalence are lower in Norway than in Scotland and the ICCs unknown for most Norwegian sites; we recommend the previous counting methodology to be continued. Lower limits for compulsory delousing will demand new counting protocols, possibly based on prevalence. The development of such protocols is included in the Hardangerfjord II project. The work performed by HFN in this WP resulted in Hordaland fylkes miljøpris to HFN for 2004. The results are documented by Stigum Olsen (2005).

WP 3 - Quality of farmed and wild smolts

Bengt Finstad, Norwegian Institute for Nature Research

Summary

The purpose of WP 3 was to check health status of farmed and wild smolts for assessing the susceptibility to salmon lice infections by:

1. Obtaining reports describing smolt status at delivery to selected fish farms
2. Initiate analyses of the physiological status of wild smolts
3. Collection of subsamples of smolts from the postsmolt trawling (WP1) in order to estimate the frequency of eye cataract

The results showed that gill aluminium was significantly higher in wild postsmolts taken in trawl compared to hatchery reared smolts in cages and the former could thus be more susceptible to salmon lice infestations. With respect to cataracts, samples were taken from both Sognefjorden (2002 and 2004) and in Hardangerfjorden (2005). Fish in Hardangerfjorden did not show any incidence of cataract in the eye while this was seen in Sognefjorden.

Introduction

Atlantic salmon is the most sensitive species to acid water in Norway, particularly during the smolt stage (Rosseland et al. 2001). Studies have shown reduced seawater tolerance and Na^+,K^+-ATPase activity in gills in salmon smolts exposed to low pH-levels (Kroglund & Staurnes 1999). Deposition of aluminium on the gills can directly influence the ability of smolts to osmoregulate in seawater. Al-levels on the gills which not involve mortality in freshwater may lead to reduced seawater survival (Kroglund & Finstad 2003).

A high incidence of migrating wild postsmolt with "white eyes" caught in research trawls during the last years has caused increasing concern. Recent studies of wild salmon have demonstrated osmotically induced cataracts (Bjerkås et al. 2003). Based on the observed fish size and knowledge on the general migration paths of European postsmolt salmon, the fish caught in the last years' studies are considered to consist of a combination of mainly British and Norwegian stocks. Thus, the phenomenon seems not to be geographically restricted. This WP has been closely coordinated with another ongoing project in the Hardangerfjord system (Institute of Marine Research – population studies by use of the field station in Guddalselva and wild fish surveys) thus giving maximal advantage for both projects. We have also coordinated the present project against the Norwegian Research Council project (155157/120 – Water Quality – Smolt Quality) where marine survival and parasite susceptibility of salmonid postsmolts are compared to previous history in freshwater.

Materials and methods

For wild smolts there was performed physiological analyses of the osmoregulatory capacity and health status of postsmolts. This has mainly been done by measurements of gill aluminium, plasmachloride and analyses of water quality. In addition, subsamples of smolts from the postsmolt trawling (WP1) have been taken in order to estimate the frequency of cataract in the fish eye. This work package has been performed in 2004 and 2005 and with reduced activity in 2006.

Results and discussion

The results showed that gill aluminium was significantly higher in wild postsmolts taken in trawl (Table 5) compared to hatchery reared smolts in cages (Table 6). This may be due to that wild smolts had experienced a prehistory in the rivers where they had accumulated aluminium on the gills compared to the hatchery reared fish in cages where a small amount of aluminium on the gills were observed. Levels as low as 10 µg pr. gram dry weight has been reported to decrease postsmolt survival (Kroglund & Finstad 2003; Kroglund et al. 2007) and it is also seen that smolts exposed to aluminium are more susceptible to salmon lice infestations and have higher mortality (Finstad et al. 2007). With respect to cataracts, samples were taken from both Sognefjorden (2002 and 2004) and in Hardangerfjorden (2005) (Bjerkås et al. 2006). Fish in Hardangerfjorden did not show any incidence of cataract in the eye while this was seen in Sognefjorden.

Table 5. Gill aluminium (µg pr. gram dry weight) in postsmolts from the Hardangerfjord in 2005.

Trawling Station	Date	Length (cm)	Gill aluminium (µg pr. gram dry weight)	Tot. Lice/prev
2	24.05.05	15.8±6.5(12)	14.96±12.46 (4.94-51.83)	1.00(33.3)
11	18.05.05	16.7±2.4(16)	20.13±28.40(3.72-93.41)	12.44(81.3)
14	19.05.05	14.4±5.3(20)	26.62±43.89(4.07-175.84)	1.7(5)
17	21.05.05	13.7±0.7(8)	31.72±10.52(14.99-42.57)	0.13(12.5)
18	21.05.05	18.2±7.5(8)	25.16±24.62(0.69-56.40)	21.63(62.5)
21	24.05.05	12.1±0.7(6)	19.66±21.86(3.27-54.41)	0.17(16.7)
22	25.05.05	16.3±3.6(3)	5.71±1.71(4.49-7.66)	9.00(33.3)
23	25.05.05	14.5±2.9(3)	12.57±0.65(11.84-13.08)	0
24	25.05.05	16.9±4.2(24)	6.72±0.78(5.61-7.81)	1.88(29.2)

Table 6. Gill aluminium (µg pr. gram dry weight) in smolts in cages in the Hardangerfjord in 2005.

Station - 2005	Gill aluminium (µg pr. gram dry weight)	Mean # lice	Water quality (DGT)
1	2,9±1,0	1,28	
2			
3	2,8±1,1	3,26	
16	2,7±0,3	1,70	
4	8,2±14,4	3,00	
5	2,7±0,4	3,23	Al: 0.59 µg/l; Fe: 4.0 µg/l
6	4,4±3,9	1,20	Al: 0.37 µg/l; Fe: 1.0 µg/l
7	11,4±14,2	1,77	
8	3,5±2,0	1,38	Al: 0.44 µg/l; Fe: 2.0 µg/l
9	5,2±3,6	3,34	Al: 0.21 µg/l; Fe: <1.0 µg/l
15	5,4±6,3	3,29	Al: 0.23 µg/l; Fe: 2.0 µg/l
14	3,3±0,4	3,15	Al: 0.99 µg/l; Fe: 3.0 µg/l
13	2,8±0,3	6,27	Al: 0.55 µg/l; Fe: 2.0 µg/l
12	2,9±0,3	4,23	Al: 0.46 µg/l; Fe: 2.0 µg/l
10	3,4±0,7	2,95	
11	4,0±2,6	1,57	

The results showed that gill aluminium was significantly higher in wild postsmolts taken in trawl (Table 5) compared to hatchery reared smolts in cages (Table 6). This may be due to the fact that wild smolts had experienced a prehistory in the rivers where they had accumulated aluminium on the gills compared to the hatchery reared fish in cages where a small amount of aluminium on the gills were observed. Levels as low as 10 µg pr. gram dry weight has been reported to decrease postsmolt survival (Kroglund & Finstad 2003; Kroglund et al. 2007) and it is also seen that smolts exposed to aluminium is more susceptible to salmon lice infestations and have higher mortality (Finstad et al. 2007). With respect to cataracts, samples were taken from both Sognefjorden (2002 and 2004) and in Hardangerfjorden (2005) (Bjerkås et al. 2006). Fish in Hardangerfjorden did not show any incidence of cataract in the eye while this was seen in Sognefjorden.

WP 4 - Migration speeds and routes of Atlantic salmon smolts

Finn Økland, Bengt Finstad, Norwegian Institute for Nature Research, Nuria Plantalech Manel-la and Scott McKinley, University of British Columbia, Canada.

Summary
The main objective in this work package was to describe the migratory speed and route of Atlantic salmon smolt from the inner part of the fjord out to the ocean. Salmon smolt of River Lærdal (n=80) and River Flekke (n=79) origin were tagged with acoustic transmitters and released near the river mouth of River Opo (Odda) in May 2005 and 2006. The identity and time of all individual fish were recorded by fences of acoustic listening stations (VR2, VEMCO, Canada) located 2 km, 9 km and 36 km out from the release site. In the middle and outer part of the fjord, listening stations were located to identify migratory routes and speeds (numbers of listening stations: 23 in 2005 and 75 in 2006). Furthermore, individual smolt was tagged to record swim speed, movement pattern and how light intensity influences swimming depth. Salinity profiles were recorded simultaneously making it possible to identify the salinity in the water at the depth where the fish were swimming.

High survival rates were recorded in Sørfjord from the release site at Odda out to Kinsarvik (84% in 2005 and 81% in 2006) 36 km out from the release site. The migratory speeds (rate of progression out from the release area) through Sørfjord were 0.6 bl/s in 2005 and 0.7 bl/s in 2006. Smolts were also recorded on listening stations further out in the fjord and migratory speeds from all areas of the fjord could then be calculated. The exact number of fish recorded and migratory routes in the outer part of the fjord is not known since we are still waiting for data to be retrieved.

The tagged salmon smolts spent from 63 to 99% of the time at depths between the surface and 3 m depth the first 12 hours after release in the estuary. Swim depth and light intensity did not correlate for four of eight smolts. The other four smolts responded to increased light intensity by going down to deeper water. In general, all smolts avoided the surface when light intensities exceeded 200-300 W/m^2. The results indicate no preference for specific salinity concentrations with postsmolts spending on average 68 % (range of individual means, 25-100 %) of the time in salinity concentrations lower than 20 ppt. during the first hours at sea.

Introduction
Salmon lice infestation on salmon smolt migrating out from the river mouth to the ocean can cause mortality. The infestation on the smolt depends on the infestation pressure as defined by the density of salmon lice larvae's in the water were the fish is swimming and the period of exposure. In the Hardangerfjord, salmon lice infestation on postsmolts in cages has been recorded in the middle and outer areas. Combined with information about the time period the out migrating postsmolts stay in the different fjord sections, salmon lice infestation on wild smolt can be modelled. The main objective in this work package was therefore to describe the migratory speed and route of Atlantic salmon smolt from the inner part of the fjord out to the ocean.

Furthermore, salmon lice larvae seem to avoid water with less than 20 ppt. salinity. In most fjord systems there is a surface layer of brackish water. Thus, if salmon smolt migrates in water with salinity less than 20 ppt the infestation of salmon lice larvae would be reduced. We therefore recorded the geographical distribution and depth of the brackish water layer in the inner and middle part of the Hardangerfjord. Together with information about the actual swim depth of the smolt the proportion of time the smolt stayed in water with low salinity was calculated. Information on how environmental factors influences swimming depth in Atlantic salmon postsmolts are poorly understood. We therefore wanted to identify if light intensity, water temperature and salinity influences the swim depth of the smolt.

Materials and methods
A total of 159 Atlantic salmon smolt (Figure 6), reared and kept in Simadalen, Eidfjord (79 from Flekke and 80 from Lærdal origin) were tagged with internal 9 mm coded acoustic tags (2005: VEMCO, Canada; 2006: THELMA, Norway). After tagging, the fish were placed in a 400 l transport tanks and transported in groups of 22 to 26 to Odda were they were placed in holding tanks with circulating seawater for 24 hours before being released. All smolt were released in May in the period we expect the wild smolt in this area to be entering the sea. Thirty larger smolts from the River Lærdal stock were tagged with miniature depth tags from THELMA, Norway. In addition to give the identity of the fish, the

tags reported the swim depth of the fish when inside detection range of an automatic data logging station. These fish were released in groups of five during the same period. In 2006, HOBO data samplers were attached to nine moorings to record light intensity continuously during the period the tagged fish were expected to migrate.

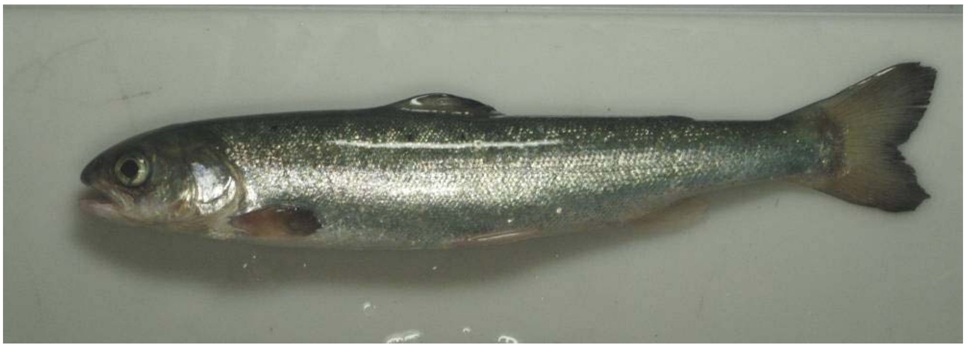

Figure 6. Cultured Atlantic salmon smolt.

Fifteen Atlantic salmon from the Lærdal stock were tagged with miniature acoustic tags recording the depth of the fish every 1 to 2 seconds. One fish at a time were released in the mouth of Eio, (Eidfjord) and the movement and swimming depth were recorded continuously. Light intensity was recorded continuously at the surface. Salinity profiles and water currents (direction and speed) were recorded along the migratory route of the postsmolt. Seven fish were followed for more than 10 hours.

A total of 23 (2005) and 75 (2006) VR2 data logging stations (VEMCO, Canada) were attached to moorings out along the expected migratory route (Figure 7). In 2005, the VR2s were placed in the area from Odda to Varaldsøy 100 km out from the release site. In 2006, the Institute of Marine Research placed VR2s in the middle and outer area of the fjord and NINA placed VR2s in the inner part of the fjord. The VR2s were attached on individual moorings on depths between 20 and 380 m. Based on range tests in Sørfjorden, all fish passing at 1.8 km, 9 km and 36 km from the release site should be recorded under normal weather conditions.

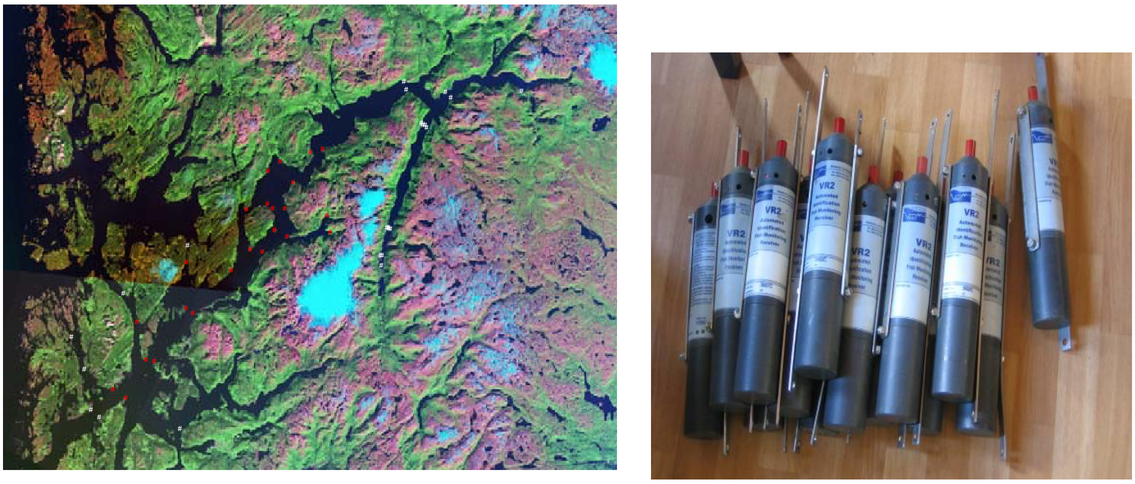

Figure 7. Location of VR2 listening stations in the Hardangerfjord in 2006. To the right is VR2 hydrophones.

Results

Both in 2005 and 2006 the Statkraft rearing facility in Simadalen was used to produce and keep the smolt until tagging. The two stocks of salmon had River Lærdal and River Flekke origin and were reared under identical condition. The only differences between the smolt were the genetical origin, one with a long and one with a relatively short distance from the river mouth to the open ocean.

Migratory speed and survival
High survival rates were recorded in Sørfjorden from the release site at Odda out to Kinsarvik (84% in 2005 and 81% in 2006) 36 km out from the release site. Both years there were no significant differences between smolt originating from the two rivers. The migratory speeds (rate of progression from the release area) in Sørfjorden were 0.6 bl/s in 2005 and 0.7 bl/s in 2006. There were no significant differences in rate of progression between smolt originating from the two rivers in any of the years. However, there was a large variation in rate of progression within the groups. Smolts were also recorded on listening stations further out in the fjord and migratory speeds from all areas of the fjord could be calculated. The exact number of fish recorded and migratory routes in the outer part of the fjord is not known since we are still waiting for data from some of the areas.

Migratory route
The migration route the first 37 km from the release area is through Sørfjorden. Here the fjord divides and the smolt have to find the way out to the middle part of the fjord by turning left. In 2005, about 50 % of the smolt where recorded in the area around Varaldsøy. Most smolt passed through the narrow strait on the northern side of the island, (approximately 70 %, but data from 2006 is still to be analysed). VR2 listening stations from the outer area of the fjord have also recorded smolts, but the final analyses will be conducted when all the data has been retrieved.

Swimming depth and light intensity
From the 14 manually tracked smolts, eight smolts were followed for more than five hours each (mean: 11 hours; range: 5-12 hours). Only these smolts are used in the analyses (Figure 8).

The swimming depth ranged from 0-7.1 m (range of individual mean swim depth: 0.5-2.3 m) and the light intensities from 0-1338 W/m^2 (range of individual averages: 112-687 W/m^2). For four smolts there was a clear correlation between swim depth and the light regime during the day- and night-time. These smolts were swimming deeper at high light intensities during day-time and closer to the surface during night.

When looking at the daytime data only, light regime and swimming depth was correlated for three of the eight smolts. During daytime, all postsmolts spent most of their time (63-99 %) between 1-3 m depth. When light intensities exceeded 200-300 W/m^2 all postsmolts stayed deeper than 50 cm from the surface.

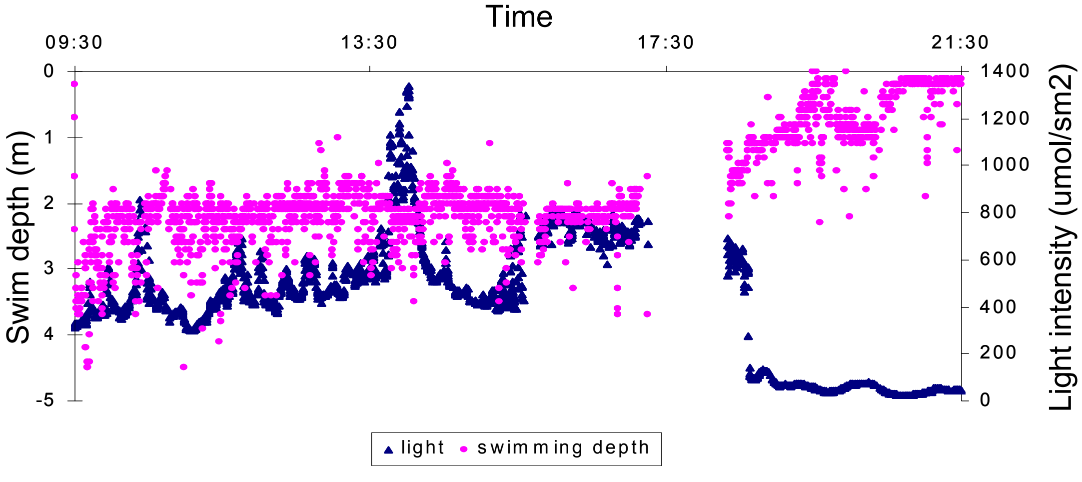

Figure 8. Swim depth from a postmolt and recorded light intensity recorded 28 May 2006.

Swim, depth, salinity and water temperature
The mean salinity where the postsmolts migrated was 20 ppt. (range of individual means, 17-23 ppt.) and the mean water temperature was 10.5 ºC (range of individual means, 9.5-12.0 ºC) (Figure 9). The postsmolts performed an average of 2.1 (range of individual means, 0.7-3.5) large vertical movements through the water column per hour. The results showed that during the migration the vertical movements performed by the postsmolts were independent of water column salinity and temperature.

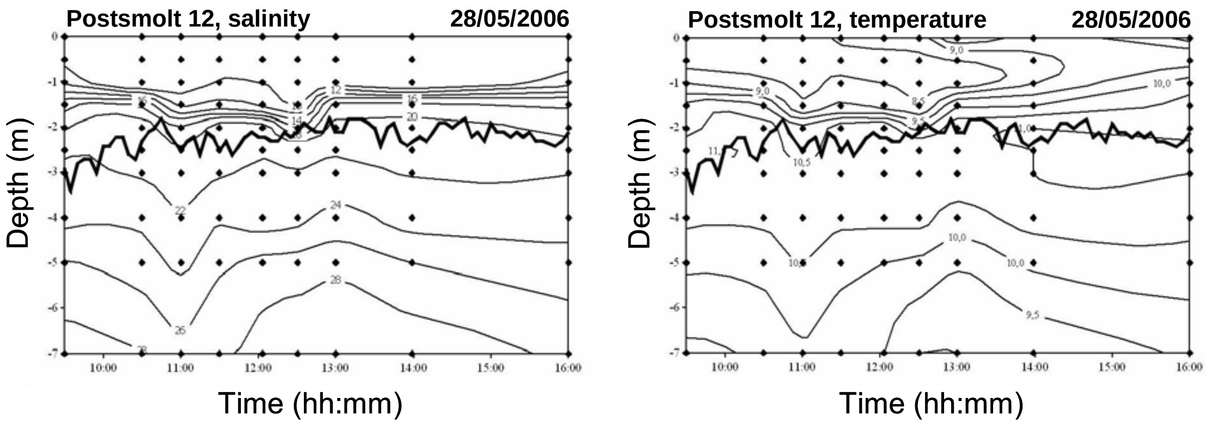

Figure 9.The postsmolts' swimming depth during transect is plotted over the contour maps of salinity and temperature. The dots indicate the time and the depth where the salinity and temperature profiles were taken. The isohalines and the isotherms were drawn with a spacing of 2 ppt. and 1 or 0.5 ºC respectively. The thick continuous line represents the depth of the postsmolts. Time scale shows local time.

Discussion

The survival of tagged Atlantic salmon postsmolts was high. Almost all the smolt released at Odda survived the first part of the migration towards the ocean through the long and narrow Sørfjorden, and almost 50 % were recorded near Varaldsøy 100 km out from the release site. The survival rate is significantly higher compared to similar studies in other fjord systems were high mortality often appear in the river mouth and the first 10 km of the migration. The high survival rate made it possible to record migratory speed and routes also in areas of the fjord far away from the release site, and smolt released at Odda could be used to record the movement in the middle and outer part of the fjord.

The migratory speed (rate of progression out from the release site) recorded in Sørfjorden were almost identical to that recorded in other fjord systems. Hence, the high survival rate is probably not a result of a fast migration through the fjord. In the Eresfjord in Møre and Romsdal, high mortality appears in the mouth of River Eira. Here large numbers of cultured salmon smolts are released every year. Saithe and cod caught near the mouth of the river have frequently either herring or salmon smolt in the stomach. This suggests that predators are attracted to the river mouth area to feed, and even with the high number of naive cultured smolt released; only some of the predators seem to switch from feeding on herring to salmon smolt during the smolt run. In the inner part of the Hardangerfjord the wild salmonid populations are weak and the salmon smolt run is presumably also small. Thus it is reasonable to suppose that fish predators in this area not have an opportunity to specialise on salmon smolts as might be the case in other fjords system. This might in turn explain the high survival rates of the tagged smolt.

It has been suggested that salmon lice larvae avoid water with less than 20 ppt. salinity. The distribution and thickness of the surface layer with less than 20 ppt. have been recorded both in 2005 and 2006 and cover a large part of the inner and middle part of the Hardangerfjord. However, the thickness of this layer is often restricted to the upper 0.5 to 1 m, meaning that smolt moving in the upper 3 m both will be in water with high salinity when they go deep and low salinity near the surface. In this project the number of times a postsmolt moves from brackish water to saltwater was estimated. In laboratory studies it has been documented that salmon lice larvae aggregate near the transition zone between water with high and low salinity. Unfortunately, data on distribution of salmon lice larvae in the water column in stratified fjords is nonexistent, but it is likely that they aggregate at certain depths, especially in areas with a brackish surface layer. If so, the swimming depth of the smolt may be important for the salmon lice infestation level.

In this project water temperature and salinity did not seem to influence the swim depth of the postsmolt. However, variation in light intensity seemed to be important for swim depth, even if this relationship only were significant for 50% of the smolt. The adjustment in swim depth with changing light intensity might be an adaptation to avoid predation, both from birds near the surface and from fish, mostly attacking from deeper waters. If so, exposure to predators is required to optimize anti-predator behaviour, and more adequate swim behaviour might be expected if wild postsmolts were tracked. Unfortunately, the acoustic tags are too large to be used on wild smolts as the fish needs to be more than 20 cm to carry the depth tag. These results are based on a limited sample size as individual tracking over longer periods is time consuming. Moreover, the weather in 2006 was unfavourable with prevailing strong winds during May. We were therefore able to obtain data from eight postsmolts only. Still, we have obtained the first data where swim depth of postsmolts can be correlated to water temperature and salinity in the water column, and to light intensity on the surface. Although a substantial amount of analyses remains before the entire data set can be presented, we expect to fulfil the objectives for WP4 as, with one exception only, the obtained data are better than initially anticipated.

WP 5 - Spread of salmon lice larvae

Karin K. Boxaspen, Institute of Marine Research and Kevin Butterworth, University of British Columbia, Canada.

This work package contains two methods for estimating dispersal of salmon lice. One is to use sentinel cages spaced out over the entire length of the fjord (WP 5.1) and the other is use of stable isotopes to assess whether the salmon lice are of farmed or wild origin (WP 5.2).

WP 5.1 - Use of sentinel cages

Summary
The main goal of this work package was to establish the abundance of infective salmon lice larvae in the fjord system by using sentinel cages with smolts at different locations in the fjord as traps. The relevant time period for this study is the month when the wild smolts migrate out to sea in the same area. The level of salmon lice has been low and comparable to the level of lice on wild migrating post smolt (see WP 1). One particular area (Etne/ Ølen basin) seems to have higher levels of lice that the rest. This needs to be addressed in more detail.

Introduction
The sampling of salmon lice larvae directly from the sea has proven to be difficult and work intensive. To use salmon smolts as attractants in sentinel cages can give a picture of the overall presence of larvae in an area and has previously been used for this purpose. The level of salmon lice on smolts in sentinel cages will elucidate what the wild fish in the same area are experiencing. The local currents and other physical features of an area can make one place different from another. The grid or coverage of sentinel cages can therefore be large. The use of sentinel cages was initiated several years ago and the method was further developed for fjord projects in joint ventures from 2002 in NFR projects were smaller cages were anchored along the fjord.

Materials and methods
To be able to hold small cages stationary in the fjord system an anchor arrangement has been developed. From the bottom up this consists of a heavy weight (train wheel, 250 kg), 10m of steel chain before a rope is applied almost to the surface. The structure is kept afloat with a 100 l buoy. Flexible rings are used as support in top and bottom of a mesh bag of 1m high to make a cage that would be able to hold small salmon. The bag is fastened in both ends with a rope and a 60 l floater on top. A steel chain of approx. 2 m is used as weight under the cage. This places the cage alongside the anchor arrangements and the structure is flexible enough to allow for rough weather. The placements of cages in the fjord are shown in figure 10.

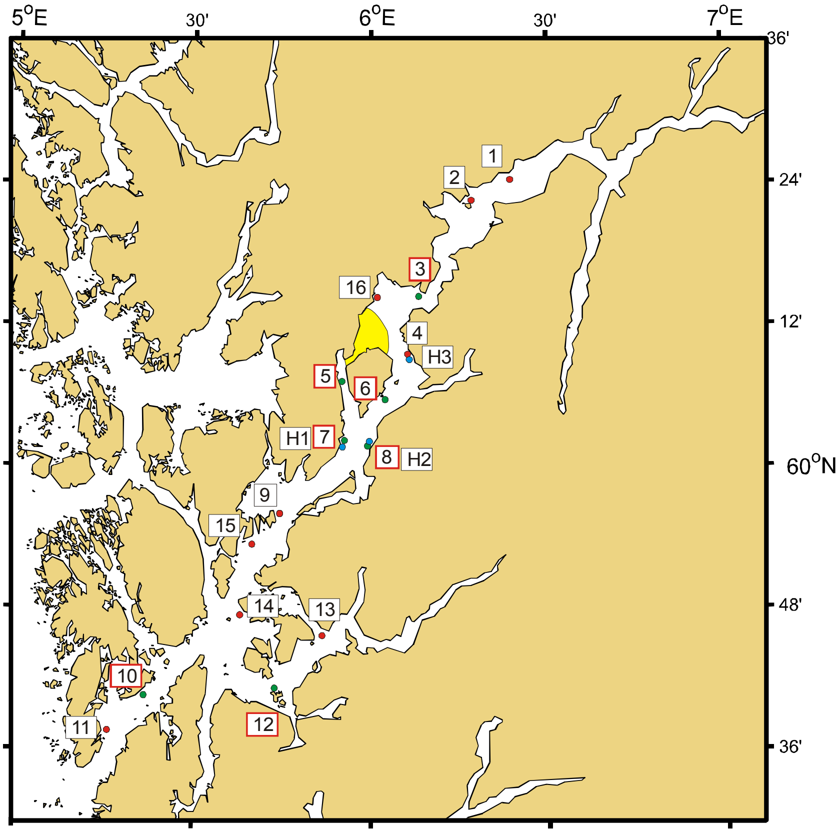

Figure 10. Geographical position of sentinel cages in the Hardangerfjord. Smolt cages containing 30 smolts each were placed in the Hardangerfjord from middle of May to middle of June. A total of 16 (15 for 2005 and 2006) cages were positioned from Tveitaneset in the inner most fjord out to Tollevik.

Results and discussion

The overall abundance of salmon lice calculated for all fish in all cages within years were 1.87 (2004), 2.77 (2005) and 0.89 salmon lice per fish (2006). The range of abundance between cages, were from 0.3 to 6.27 salmon lice per fish over all years (Figure 11). There is a tendency for higher levels in the region around the Etne – Ølen basin (cage no. from 12 to 14). Further studies over more years are necessary to elucidate the reason for this.

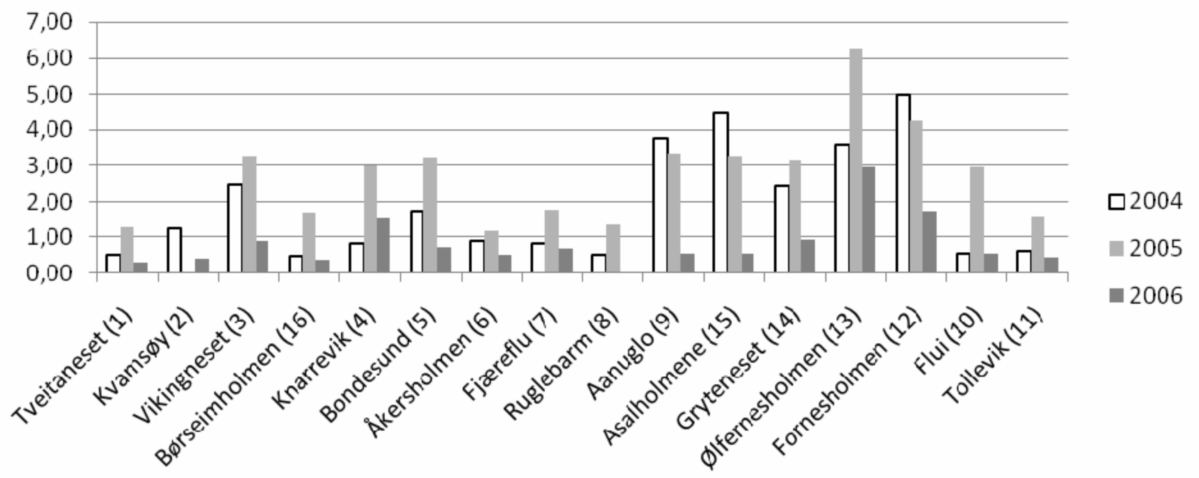

Figure 11. Level of salmon lice for 16 (15) sentinel cages and three years from the innermost part of the Hardangerfjord (to the left) and the outermost part (to the right). For exact placement within the fjord see figure 10.

Compared to earlier studies in other areas like the Sognefjord the salmon lice levels must be considered to be low. Mortality will always be dependent on not only the level of parasite but also the size of the fish. The fish in the sentinel cages were approx 60g when going to sea. These levels of lice would as such not have killed any of the fish over time.

WP 5.2 - Use of stable isotopes

Summary

Salmon lice were sampled from farmed and wild salmon in the Hardanger fjord Norway, and the Finlayson and Mathieson Channels, British Columbia, Canada, and the natural abundances of $\delta^{15}N$ and $\delta^{13}C$ ascertained. The data suggests that there are differences between the natural abundances of $\delta^{15}N$ between the wild and farmed salmon in British Columbia. Further analyses are needed to obtain a definitive result.

Introduction

We have previously successfully demonstrated the use of carbon and nitrogen stable isotopes as a tool to differentiate between *Lepeophtheirus salmonis* from different geographical areas. Our study demonstrated the use of $\delta^{15}N$ signatures as a tool to differentiate between salmon lice sampled from wild salmonids, and farmed salmonids, and between salmon lice found on the same species of commercially reared salmonid from different areas. The aim of this study was to trace the origin of salmon lice horizontal transmission, and vertical transmission between farmed and wild salmon in the Hardangerfjord using differences in stable isotope signatures.

Materials and methods

Hardangerfjord (2004/05): Adult female salmon lice were sampled from Atlantic salmon (*Salmo salar*) at Hoysten, Aplavika, Mele, Vesle Gausvik, Sagvik, Krisnes, Høylandsund, Trommo, Maradalen, Bruvik Merd, Uføro Merd, Raunevagen Merd, Bjørgo Merd and Andal Merd. Samples were immediately placed in 1.5ml centrifuge tubes containing 95% EtOH sourced from the same production batch throughout the experimental period. Samples were shipped to the Centre for Aquaculture and Environmental Research, UBC, Canada and the life stage, species and sex of the salmon lice confirmed.

Finlayson and Mathieson Channels, British Columbia, Canada (2004): Wild juvenile migrating Pink salmon (*Oncorhynchus gorbuscha*) infested with salmon lice (n = 300) were sampled and individually examined for sea lice using a jeweler's loop. The individual salmon carcasses were examined in the laboratory and all salmon lice identified to species and life stage using a binocular microscope. Overall, the proportions of life stages consisted of 26% non-mobile, 35% pre-adult and 39% adult sea lice. Additionally, salmon lice (n=70) were sampled from the salmon farm in the area of interest to provide baseline natural abundances of $\delta^{15}N$ and $\delta^{13}C$ for farmed Chinook salmon (*Oncorhynchus tshawytscha*).

All samples were subsequently analysed for the natural abundance of $\delta^{15}N$ and $\delta^{13}C$. The samples were combusted and separated using gas chromatography (GC). Subsequently the sample was passed into a continuous flow isotope ratio mass spectrometer (CF-IRMS) for analysis.

Results and discussion

All samples were successfully analysed. The samples from the Finlayson and Mathieson Channels were chosen as those to be used to assess the methodology. Sample sites were selected to be up-channel, amongst and down-channel from existing salmon farm operations. The natural abundance of $\delta^{15}N$ and $\delta^{13}C$ was similar for all six sites sampled. The natural abundances of $\delta^{13}C$ for the salmon lice from farmed Chinook salmon were similar to those of the wild pink salmon. However, the natural abundance of $\delta^{15}N$ for the salmon lice from farmed Chinook salmon included values higher than those of the wild pink salmon (Figure 12).

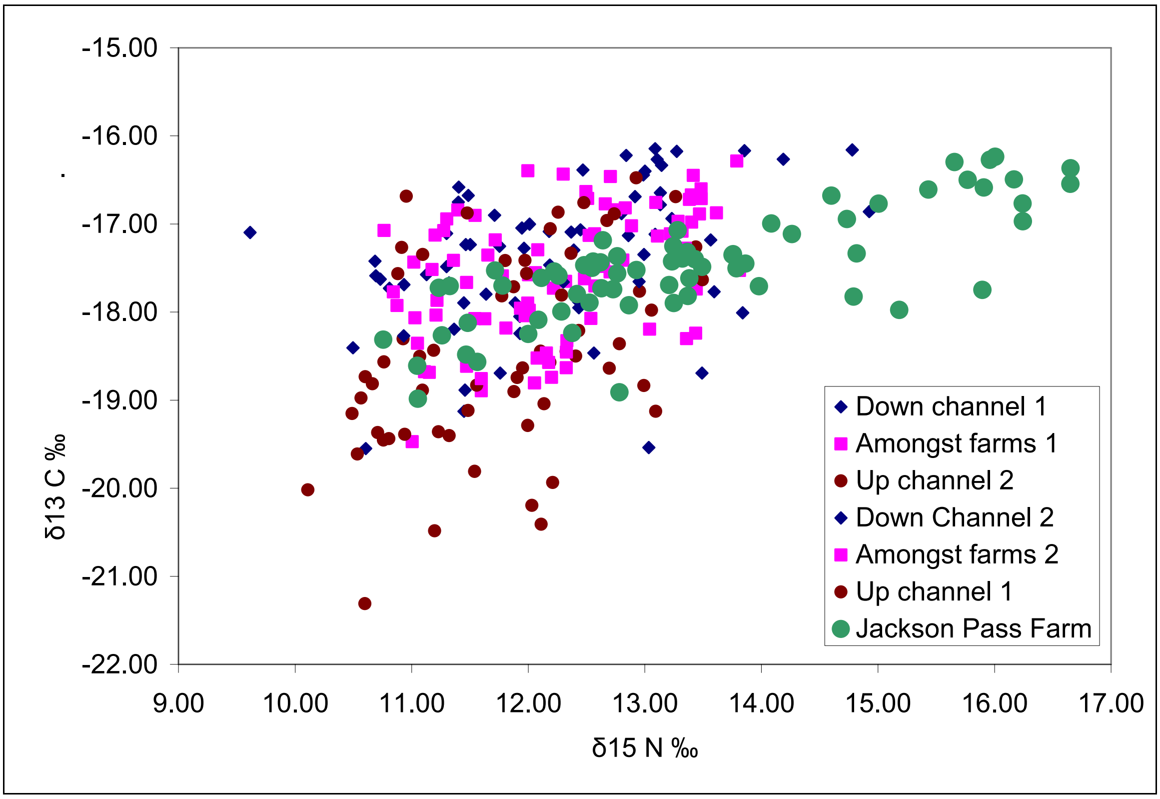

Figure 12. The natural abundance of δ^{15}N and δ^{13}C for wild pink salmon smolts (up channel, amongst farms, down channel) and farmed Chinook salmon (Jackson Pass farm) in the Finlayson Channel, Mathieson Channel and Jackson Pass.

Although the data from the Finlayson and Mathieson Channels in Canada suggests that there are some differences between the natural abundance of δ^{15}N in the farmed and wild salmon, to date it has not been possible to use this method to quantify the transfer of salmon lice between farmed and wild salmon. However, due to the complexity of the data it will be necessary to pursue further analyses before a definitive result is obtained. This will provide the rationale and context upon which the analysis and interpretation of the stable isotope samples from the salmon lice in the Hardangerfjord can be based.

WP 6 - Physical oceanographical factors and salmon lice distribution

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Summary
In general the flow in the Hardangerfjord system was complicated but less energetic with fairly low mean and maximum speeds. The mean flow pattern consists of both outward and inward currents, but the variability is large. For the period 2004-2006, the year 2006 differ with significantly less brackish water. Otherwise, the conditions are fairly similar. Low current speeds in area of Etne/Skånevikfjorden suggest retention of water masses.

Introduction
The aim of this work package is to quantify the time dependent geographical distribution of salmon lice copepodids in its pelagic stage in the Hardangerfjord. Salmon lice copepodid distribution is mainly affected by the production of eggs and larvae, temperature dependent growth rates, water salinity and the currents in the upper 10m of the fjord. Results from previous investigations in Norwegian fjords reveal possible large fluctuations of salmon lice distribution both on short time scale (days) and on inter-annual time scales. Large spatial differences can also occur. Knowledge of the physical oceanography is thus crucial to be able to explain the variability of salmon lice abundance in both time and space. Important physical oceanographical factors to consider are water temperature, salinity and water currents as well as freshwater runoff and the wind conditions. In total we have conducted 11 surveys of hydrography (88 individual stations at 8 cross-sections) and we have measured currents at 21 locations (mostly during May-June and for the surface layer). Additional data are from the IMR coastal monitoring stations, the Hardanger Fishhealth Network and the Norwegian Meteorological Institute.

Hardangerfjord
This fjord system is 170-180km from the mouth to the head at either Odda or Eidfjord. The Hardangerfjord is moderately wide, 2-5km, but with a narrow part at Jondal where the width is only 1.5 km. The sill depth is around 120-150m. The fjord has many deep basins, with the deepest more than 800 m towards the inner part (Øystese-Utne).

The fjord has a significant freshwater discharge with maximum in May-July (snow melting) and usually a minimum during the winter. The brackish water has its maximum extension typically in July-August, reaching out to Bømlafjorden. Usually the brackish layer depth is 5m. During the winter the fjord is entirely filled with coastal water (salinity > 30).

Physical oceanographical conditions 2004-2006Atmospheric conditions
The winter NAO index is a proxy of the strength of the South-Westerly winds at the Western Norwegian coast (e.g. http://www.cru.uea.ac.uk/~timo/projpages/nao_update.htm). NAO correlates well with the winter precipitation and subsequently the natural spring runoff (keeping in mind that the storage capacity of hydro electric power plants might alter the actual runoff to the fjord slightly). In 2004 and 2005, the value of the NAO index was close to zero (-0.20 and -0.11). In 2006 the NAO was negative (-0.82). (In 2007 this index was strongly positive, 1.83). The local winds at Kvamsøy (observed by met.no) show that the winds from the beginning of April to the end of June in 2006 were weaker and more Northerly (i.e. less South-Westerly) compared to 2004 and 2005. Mean wind speeds in 2004 and 2005 were 4-5m s^{-1} while only 3m s^{-1} in 2006.

Temperature
At the fjord mouth (the IMR coastal monitoring station Utsira) the water temperatures at 10m depth went from about 5 ^{o}C in April to 10 ^{o}C in June. The conditions in 2004-2006 were slightly warmer than the long term monthly mean (~0.5-1 ^{o}C) except for June 2005 which was 1.3 ^{o}C colder than the mean. Further into the fjord the conditions were comparable to those at the mouth. The temperatures at 3m depth range from about 5 ^{o}C in the beginning of April gradually increasing to ~14 ^{o}C in the end of June. In 2005 the water was warmer in April and colder in June (by ~1 ^{o}C) compared to both 2004 and 2006.

Salinity
The salinity in the fjord follows the pattern of a ~5m deep upper brackish layer ~2/3 way out the fjord, with increasing salinity outwards. Below 30-40m depth, the salinity values are less variable with values for the most above 30. The results of the surveys, although focusing on the spring conditions, show a

traditional pattern with fresher water towards the inner part of the fjord and during spring and summer. An exception was anomalously fresh water in January 2005 in the inner part due to large rainfalls that month (the similar situation probably occurred in 2006-2007 since the fall of 2006 had almost 100 days of rain in a row). We have also observed effects of the Earth rotation on the freshwater flow, with deflection of the fresh water towards the right hand shore looking in the flow direction. In particular we can see evidence of inward flowing freshwater from rivers and side fjords on the Eastern/Southern side of the fjord.

At the coastal monitoring station just outside the fjord mouth, the salinity at 10m depth were less than the long term monthly mean in 2004 for the months April-June. In 2005 the water was slightly more saline in May but much fresher (~1.5 units) in April and June. Also in 2006 the June values show fresher water at the coast but in April and May the water was 0.5-1 units more saline than the mean and 1-2 units more saline than in 2004 and 2005.

The long-sections of salinity taken from the IMR surveys show significant differences of the brackish water horizontal extension between the years 2004-2006 (Figure 13). The strongest brackish layer occurred in 2005 (especially since these data from May were taken 10 days earlier compared to the other years). In 2006, the horizontal extension of the brackish layer reached less than half way out the fjord compared to 2004 and 2005.

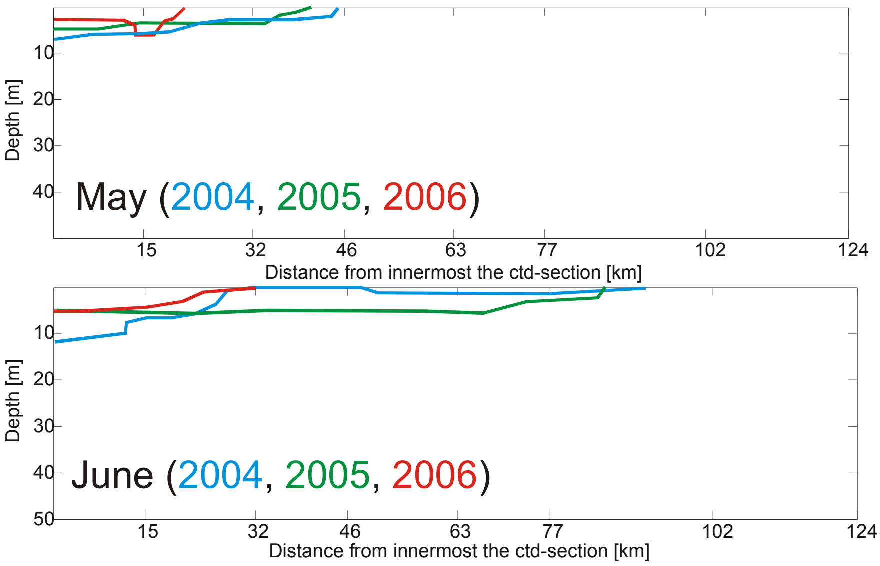

Figure 13. Horizontal extension of the 24 isohaline in May and June for the years 2004 – 2006.

Currents

A total of 21 current meter moorings have mostly measured the surface layer currents (3-5m) and for the months May to June (although three moorings are covering an extended period January to June). Typical current speeds are modest, with mean speeds around 0.1 ms^{-1} and maximum less than ~0.6 ms^{-1}. The variations are large though, with shifting conditions. The flow in the upper 10m consists of a freshwater component, a tidal component, a wind driven component and possibly various internal wave components. The actual current is a linear combination of these components. The measurements indicate no large differences in the flow statistics between the years 2004-2006.

The flow pattern in Hardangerfjord based on a combination of measurements from all years 2004-2006 shows outward flow in narrow areas with increased speed, but also inward flow (Figure 14). It should be noted that the system is undersampled by our moorings, and the presented flow pattern might be modified with increasing information (more measurements or model results).

Typically the flow in the fjord system will have land on its right side, suggesting a control by the rotation of the Earth. The freshwater driven flows seen on the salinity cross-sections are shown with blue arrows in Figure 14. In the outer part, the mean current is somewhat surprisingly into the fjord near the North-Western shore. This might be the result of topography and the surface water flowing out in the middle of the fjord and also Northwards through the narrow sounds before entering Bømlafjord (green arrows in Figure 14).

Another interesting measurement from Skånevikfjorden show low currents in this area, hence this might possible be a retention area for the water. This is to some degree supported from numerical results of primary production (the IMR-project LEIF).

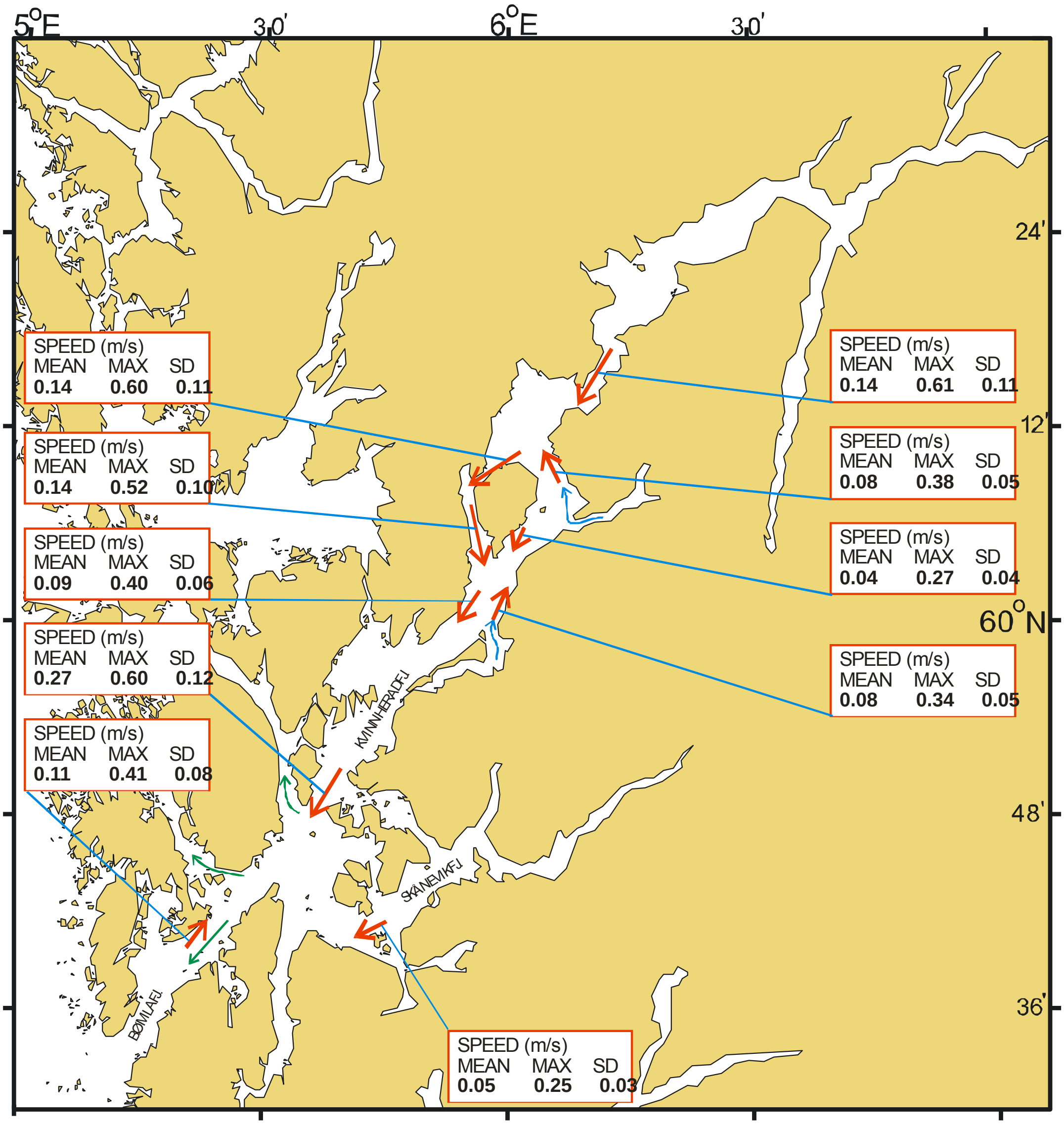

Figure 14. The flow in the Hardangerfjord system in spring as indicated from the various current measurements.

Modelling perspectives

A numerical model simulating physical oceanography and salmon lice growth and distribution has been developed for the Hardangerfjord system based on previous research in the Sognefjord. With limited resources, this model has only been tested for a few demonstration simulations. Nevertheless, the results support the findings from the Sognefjord:

1. The variability of salmon lice distribution can be large (from 0 to 100km in a week)
2. The salmon lice might move rapidly with the currents (~5km in 3hr)
3. Large inter-annual variability might occur.

The bottlenecks in the present numerical model system now are the lack of external forcing (especially wind) and the ability to utilize massive parallel super computers. These problems are addressed in the continued Hardangerfjord II project.

Below are some examples for the Hardangerfjord model system

The Hardangerfjord model implementation consists of several numerical models: A meso-scale atmospheric wind model (MM5), two levels of ocean models (4km and 20km grid resolution) to produce boundary forcing, a fjord model (the BOM) used to produce currents and hydrography inside the Hardangerfjord and a salmon lice growth and advection model.

The Bergen Ocean Model (BOM)

The numerical model used for the simulations in the Hardangerfjord is the three-dimensional, primitive equation, time-dependent, σ-coordinate, ocean circulation model named the Bergen Ocean Model. The BOM is developed by Berntsen et al. (1996). The prognostic variables of the model are three components of velocity, potential temperature, salinity, surface elevation and two variables representing turbulent length scale and turbulent kinetic energy. The BOM has an embedded turbulence closure submodel (Mellor & Yamada 1982). The governing equations are the equations for conservation of mass, momentum, temperature and salinity, along with the hydrostatic equation in the vertical and an equation of state relating salinity and potential temperature to potential density. The equations are solved by finite difference techniques on a staggered Arakawa C-grid. The time differencing is explicit.

The Hardangerfjord area is discretized on an 800 m horizontal rectangular grid using 238 x 110 grid squares (Figure 15). Vertically, 21 grid nodes were used, with the grid size (expressed in z-coordinates, assuming no surface elevation) increasing from 0.25 m in the upper few meters to a maximum of 100 m in the lower layers where the maximum bottom depth is 400 m (being fixed to this value for numerical reasons, although the maximum depth in the Hardangerfjord exceeds 800 m).

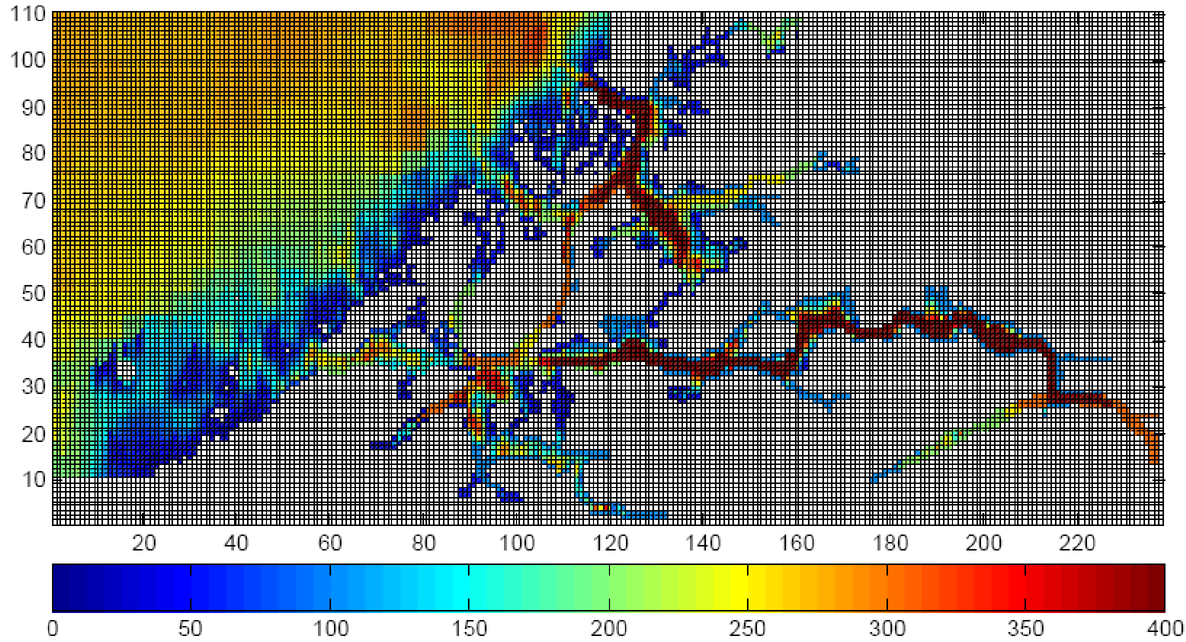

Figure 15. Horizontal numerical grid (bottom matrix) of the 800m Hardangerfjord model.

The initial conditions were of no water velocities and no surface elevation. The salinity and temperature fields were horizontally homogeneous, but with piecewise linear stratification typical for the situation prior to simulation (in this case, early spring). The open boundaries towards the coastal ocean were updated using a so-called Flow Relaxation Scheme (Martinsen & Engedal 1987) by values of sea surface elevation, horizontal velocities, salinity and temperature every 30 minutes simulated interpolated from results of a coastal ocean model covering the Skagerrak and the Western Norwegian coast. The horizontal grid resolution of this coastal area model is 4 km. Open boundary condition for the 4 km model is obtained from results of an even larger ocean model, covering the whole North Sea with a 20 km resolution horizontal grid. Wind forcing is 6 hourly fields from the 3 km MM5 model simulation. An archive of winds from 1990-2004 exists for the period April 15 to June 15.

To include the effects of solar radiation, the surface temperature all over the model domain is relaxed towards the open boundary condition values with a relaxation period of 10 days. This ensures a warming of the water masses close to the climatology. River runoff from 62 rivers and power plants were included in the simulation. The runoff values are daily mean observations from a few rivers collected by the Norwegian Water Resources and Energy Directorate, a few outlets monitored by Statkraft and others are estimates based on various observations.

The salmon lice growth and advection model

The model moves a great number of salmon lice nauplii and subsequently copepodids as particles in the upper 10m of the fjord. The currents, temperature and salinity are taken from the results of the fjord model. Each salmon lice particle is tracked and a record of position with ambient temperature and salinity as well as particle growth is kept.

The salmon lice growth is estimated based on degree days. Laboratory studies indicate that infection starts at approximately 50 degree days and ends at 200 degree days. The advection of the salmon lice particles are modelled based on three-dimensional currents with hourly time resolution. The effect of turbulence is parameterized by random walk diffusion, where each particle is given an individual axi-symmetric Gaussian random velocity every time step. This corresponds to a diffusion coefficient of 1 $m^2 s^{-1}$. Certain behaviour from natural salmon lice are incorporated in the model and some restrictions on the vertical movement are implemented. These are: 1. A diurnal migration with upward movement during day and downward movement during night, 2. Particles reaching the surface are given a weak downward movement, 3. Particles reaching 10m depth are given a weak upward movement, 4. Particles in water with salinity less than 24 are given a downward movement. This is sketched in Figure 16.

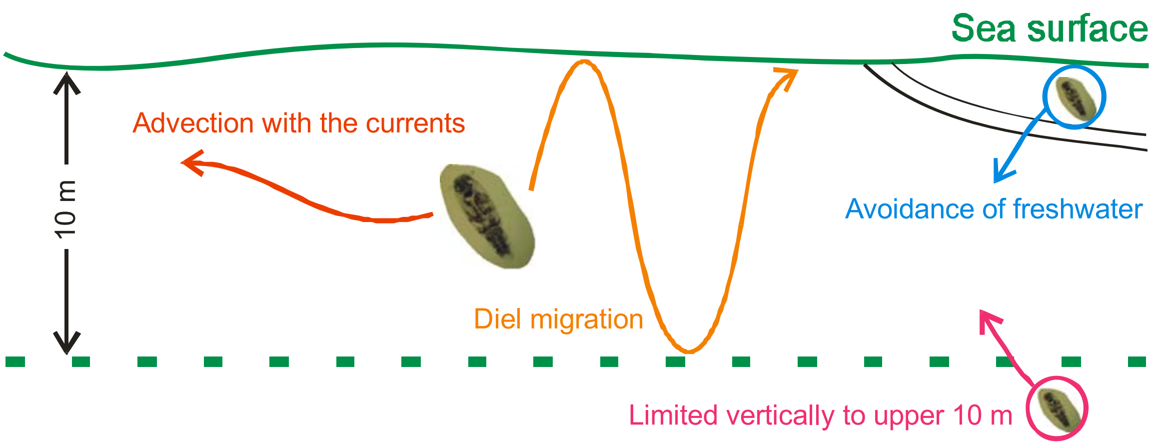

Figure 16. Principles of the advection part of the salmon lice model.

Numerical model experiments (examples given in the attached CD).

A few numerical model experiments have been conducted with the Hardangerfjord model system. Only results from the years 2001 and 2003 will be presented, and only for the spring. This is due to lack of wind forcing for other periods, e.g. 2004-2006. Illustrations of results are given below:

1. Daily mean values of the extension of brackish water at 1m depth in the fjord between May 9 and June 8, 2001 and 2003 (brakkvann_2001_2003.ppt).These simulation use realistic winds for 2001 and 2003, but the same prescribed freshwater runoff values for 62 rivers. Thus, only the variations due to dynamic forcing of the water are shown. Although the extra variations added from different runoff values might be large (ref. Figure 13) we find especially large differences between the two simulation results on a day to day scale.

2. Daily mean values of water speed at 1m depth between April 15 and June 12, 2003 (speed1m_2003.ppt). The variability of the flow in the fjord is large, and these results show

this as well as the tendency of stronger currents in the narrow parts of the fjord. In general, the currents in a fjord are composed as a sum of linear components. The most important components are freshwater driven flow and wind driven flow near the surface, the tides covering the whole depth and various internal waves connected with the actual stratification and of variable vertical extension (Figure 17). Combining these component, usually a complicated picture arise (what you actually observe).

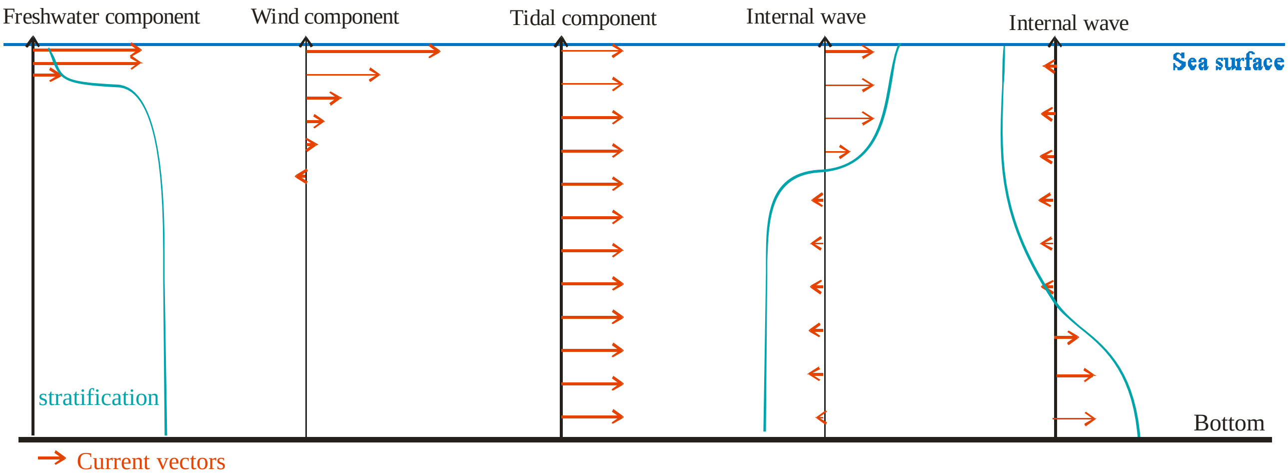

Figure 17. Main flow components in a fjord.

3. Daily mean values of the spreading of a passive tracer at 1m depth between April 15 and June 12 for 2001 (tracer_2001.ppt) and 2003 (tracer_2003.ppt). At a position north of Varaldsøy, the water is constantly saturated with a passive tracer. This tracer is then advected with the currents, and the fraction of the tracer in the fjord is shown. A value of 0.05 means that 5% of the water at that location once has been at the position north of Varaldsøy. The results show that after just few weeks fractions of the tracer can be found all over the model domain.

4. Spreading of salmon lice from the outer part of the fjord between May 10 and June 9 for 2001 and 2003 (lakselusspredning_2001_2003.ppt). Based on hourly values of currents from the fjord model, the salmon lice are spread according to the model described above (Figure 16). A total of 2000 salmon lice particles at 5 m depth were released on May 10. The trajectories of all the particles are shown in the last slide of the linked file, showing a widely spread distribution but with the tendency for a southerly and outwards distribution in 2001 and a northerly and inwards distribution in 2003, which is due to the wind conditions and the resulting currents for 2001 and 2003.

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