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Migration and predation of Atlantic salmon smolts from Vosso

Final report FHF project #900778




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Contents

Abstract

In English: *The goal of the current project was to examine the migration, survival and predation of wild and cultivated smolt from the Vosso system and to evaluate whether predation from sea trout in the Vosso estuary is a bottleneck that hinders the restoration of the Vosso salmon. Our study suggests that survival of cultivated smolt through the estuary of Vosso is low (< 20 %) and may potentially be dependent on smolt migration speed through the complex fjord system. The current trout population in the Vosso system seems to be at historically low levels and it is most likely the reason for the relatively low catches of trout observed within Bolstadfjorden. The results indicate that trout aggregate in areas where acoustically tagged smolt disappear which suggests that predation from trout can partly explain the mortality of smolt through the estuary. However, tag losses related to these aggregations are not particularly high compared to estimates from other studies. In conclusion, it is not apparent from the results in this study that predation from trout in Bolstadfjorden alone can explain the low recruitment of salmon to the Vosso system. The release of cultivated smolt in the river yields very low returns due to fact that few fish are able to navigate through the estuary. Moreover, we cannot conclusively answer to what degree this applies to the wild smolt, however there are indications that navigation and survival of wild fish are higher than cultivated fish. Our results also suggest that the output of wild salmon smolt from the Vosso river is low compared to the estimated potential for smolt production and is an important subject that requires further evaluation in order to increase our understanding of what is needed to re-establish and sustain a viable salmon stock in the Vosso system.*

In Norwegian: *Hovedmålet med prosjektet var å studere vandringen, overlevelsen og predasjon på vill og kultivert laksesmolt fra Vossovassdraget og evaluere om predasjon fra sjøørret i Bolstadfjorden er en flaskehals som hindrer reetableringen av vill laks til vassdraget. Overlevelsen av kultivert og merket smolt gjennom Bolstadfjorden og forbi Stamnes var lav (< 20 %), og er sannsynligvis koblet til at laksesmolten har en lang oppholdstid i estuariet. Sjøørret bestanden i Vossovassdraget virker til å være i dårlig forfatning sett i forhold til historiske fangster. Dette kan være en av årsakene til at fangstene av sjøørret i Bolstadfjorden var lave. Samtidig viser merkeforsøk på sjøørret og laksesmolt at en del av de merkede laksesmoltene forsvinner i de områdene sjøørreten samler seg i Bolstadfjorden. Det er derimot ikke noen oppsiktsvekkende høy estimert dødelighet knyttet til disse aggregeringene i Bolstadfjorden sammenlignet med dødelighets estimater fra andre estuarier. Vi konkluderer med at det ikke virker til at den nåværende predasjonen fra sjøørret i Bolstadfjorden hindrer en reetablering av vossolaksen. Det er derimot åpenbart en lav overlevelse gjennom estuariet av grupper av kultivert smolt som blir sluppet i vassdraget. Vi har ikke resultater som med sikkerhet kan si hvor overførbart dette er for villfisk. Resultatene våre indikerer derimot at overlevelsen til villfisk gjennom estuariet er høyere enn kultivert fisk. Estimater for hvor mye vill smolt som vandrer ut av vassdraget var betydelig lavere enn det forventede potensiale for smoltproduksjons i Vossovassdraget, og dette misforholdet bør undersøkes nærmere.*

Extended summary

The population collapse of the Vosso salmon and threats to the stock

The Vosso salmon is one of Norway's most best-known runs of salmon because of the huge size the fish attain. Its lifecycle is distinguished by the long ocean residence of a high percentage of the run, resulting in the large average size of returning spawners (10-11 kg). The salmon stock in the Vosso River system collapsed at the end of the 1980s. The cause of the population decline was not identified, but all fisheries for Vosso salmon were terminated starting in 1992. In order to secure the stock and to reduce the risk of genetic impact from escaped farmed salmon, a brood stock population was established in the National Live Gene Bank for wild Atlantic salmon. Motivated by the large biological, cultural and economic value of the Vosso salmon, the Norwegian Directorate for Nature Management initiated an interdisciplinary project in 2000 called the 'Vosso project' to identify threats and implement a long-term plan for the restoration of a sustainable run of Vosso salmon.

Over the next decade, several man-induced impacts and threats were identified; water regulation for hydropower purposes (including flow adjustments and temperature changes), habitat degradation, acidification causing aluminum to accumulate on fish gills both in fresh- and brackish water, effects of sea-lice transmitted by salmon farms on migrating smolts and the genetic threat posed by escaped farmed salmon entering a decimated spawning stock (see Table 1 for details and Figure 1 for a map of the region).

Figure 1 The Vosso river and fjords were known for its large sized salmon. Unknown photographer.

Efforts to restore the Vosso salmon

In parallel to the work of identifying the man-induced impacts, a work plan was designed to implement the restoration of the Vosso salmon. The plan relied on two pillars; firstly, all human-induced threats had to be minimized or mitigated by efforts by all stakeholders based on the principle of "best practice". Secondly a large cultivation effort to reintroduce salmon from the living gene bank was initiated. Eggs were transferred from the gene bank to the local Voss hatchery and subsequently planted as eyed-eggs, or stocked as fry or smolt. From 2008, the project was defined as going into a new phase, where the knowledge accumulated in the ongoing project was used to initiate an up scaling of the already proven successful enhancement method based on towing cultivated smolts to the coast before release. This up scaling was financed by the fish farmers and the Aquaculture and Fisheries research fund (FHF) after long and heated debates of the effect of fish farming on the wild population of Vosso salmon. The fish farmers formed a conglomerate of companies called "Vossolauget", which also was the start of a more involved participation by the fish farming industry into the restoration of the Vosso salmon. While there are still debates, communication in the

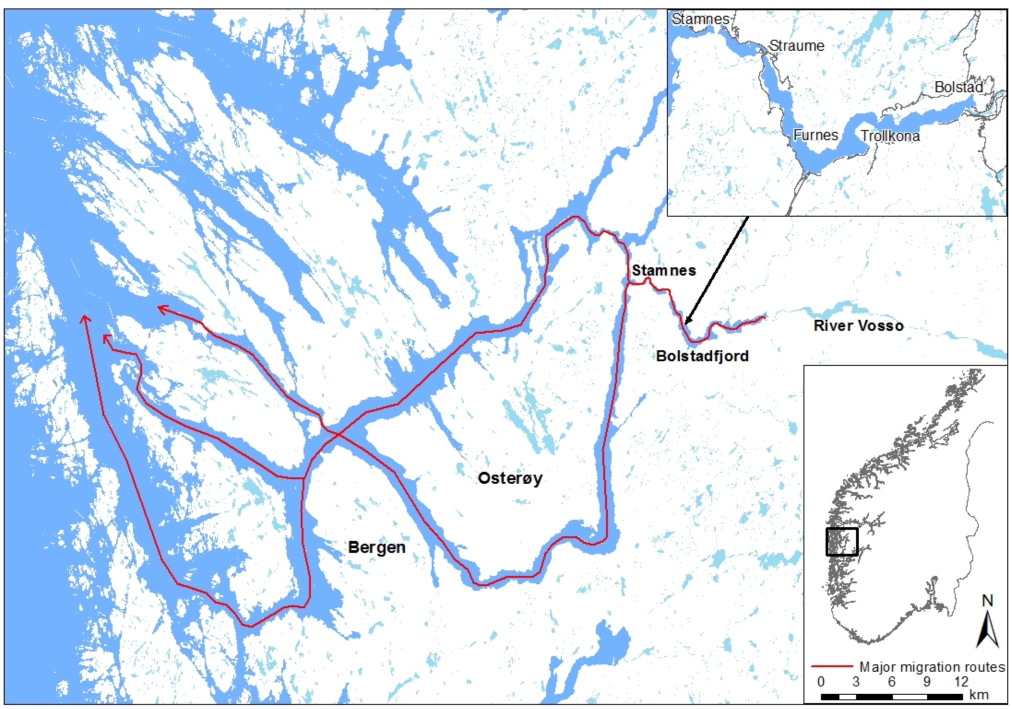

Figure 2 Map of region and location of River Vosso. The estuary of the Vosso river, Bolstadfjorden, is shown in the upper right corner. Red line indicates the major migration routes of the Vosso salmon smolt. The inner fjord system surrounding the island "Osterøy" is brackish with a salinity < 20 ppt.

current structure of the Vosso project has been much more constructive, and in 2011, this joint effort received the "Environmental Award" from the Norwegian Directorate of Fisheries due to its unique cooperation.

Cultivated smolt as a means to enhance the stock

A major challenge in the reintroduction of salmon in Vosso has been that releases of cultivated smolt in the river have yielded relatively few returning adult salmon. Of a total of 110 000 hatchery smolt released in the river from 2000-2011, only six have been recaptured as returning adults. This issue was identified early in the project and consequently numerous scientific and public debates were conducted relating to this problem. The results of low survival of cultivated Atlantic salmon smolt were, at the time, not unique to this river system (Finstad & Jonsson 2001), and similar results from other regions are also seen (Kallio-Nyberg et al., 2011). Consequently a acoustic-tagging study of both cultivated smolt and wild smolt in 2003 was conducted to identify were the smolt would disappear. A further goal was to evaluate whether the results obtained with cultivated smolt apply to wild fish. The results were surprising as a large proportion of the fish were found to stop and disappear in Bolstadfjorden (10 of 100 smolt registered outside the estuary), mainly at the river outlet, and some of the fish also never made it out of the river. This was the case both for wild and cultivated salmon. Abnormal behavior of fish migrating towards the river outlet after entering the Bolstadfjorden was observed, and was by some interpreted as predation from sea trout (that is the

Figure 3. A large scale cultivation effort has been of core value to restore the salmon. In this picture, the smolts are pumped into a special "smolt-tank" for subsequent release after the perforated tank is towed out the fjords. Photo: Helge Haukeland

Table 1. Summary of threats, relevant time period of negative effects, and associated mitigation efforts in the ongoing Vosso project. The list is arranged chronologically, based on the starting point of negative effects (modified from Barlaup,2013).

Threats and impacts	Onset of possible negative effects	Mitigation measures
Hydropower development - Affecting ca 30 % of the salmon production area in the watershed - Reduced smolt production in the impacted river sections - Hydrological alterations in the river and the fjords	Evanger power station began in the years 1969-1977.	Operation of Voss Hatchery with stocking of one-summer-old salmon since 1990. Since 1998 based on material derived from the National gene bank and planted as eggs, or stocked as fry or smolts. Habitat adjustments in the Teigdalsriver.
Salmon lice infestations - Experiments based on groups of released smolt in the years 2001-2010 found that the salmon lice induced mortality was 32 %, and that the effect of salmon lice increased the age of returning salmon (Vollset et al. 2014). - Frequent observations of sea lice on wild salmon, sea trout, and escaped farmed salmon and rainbow trout in the smolt-migration route	Establishment of net pens for aquaculture along the out-migration route of the smolt since the mid-1980s.	An upper limit for the number of lice allowed per farmed salmon was introduced in the second half of the 1990s. Nordhordaland Fish Health Network was established in 2005 with yearly synchronized sea lice treatments. The Food Authorities started its own 'lice campaign' in 2007. Continues and ongoing R&D by fish farming companies to control salmon lice. No area specific mitigation according to wild fish has been implemented.
Acid rain caused by long transported emissions from industry - Deterioration, i.e. acidification, of water chemistry. Aluminum accumulate on fish gills in both freshwater and brackish water with possibly negative effects on quality and survival of smolt (Barlaup et al., 2013)	Situation assessed as possibly damaging starting in the late 1980s. Worst conditions measured during the first half of the 1990s.	Continues liming with doser, i.e. lime added to water passing through the Evanger power station between 1994 and 2005. Clear improvement of water quality following reduced acid rain. This led to the end of liming in 2005. Thereafter, the national water chemical monitoring program has reported conditions to be acceptable for salmonids.
Escaped farmed salmon in the spawning stock - Crossing between farmed and Vosso salmon has affected the genetic makeup of the salmon stock (Glover et al. 2013). - Competition between offspring of wild and farmed salmon.	Farmed salmon have dominated samples of the spawning stock in the 1993-2009 period.	Removal of farmed salmon caught during the sampling of the stock since 1991 until present. Ongoing R&D by fish farming companies to prevent escapees. Increased spawning stock due to cultivation has decreased the relative contribution of farmed fish into the spawning stock in the years 2011-2013.
Dredging of Lake Vangsvatnet and road building - Temporarily increase in mortality due to stranding of juvenile fish affecting the year classes 1988-1990 - Loss of important spawning area at the outlet of lake Vangsvatnet	Road building with embankment along lake Vangsvatnet in 1989. Dredging of Vangs lake in the winter of 1991.	Plan to restore the spawning area at the outlet of lake Vangsvatnet by adding ca 350 tons of spawning gravel during winter 2014.

acoustic tags had also been ingested by the predators, and these were being tracked). However, a live salmon caught in Bolstadfjorden 9th July, also indicated that some of these tagged fish were alive but not migrating, and that the tags were seemingly strongly affecting the small wild fish. On the other hand, a sea trout with up to 14 smolts (not tagged) in its stomach was identified in the estuary close to the river outlet (2010 & 2011: 13 trout with average 2.1 smolt per stomach were evaluated), while very few smolts were identified in sea trout during trawling in the region downstream from Bolstadfjorden (2011: 116 trout with average 0.05 smolt per stomach). These findings indicated that predation from sea trout on smolt could pose a significant mortality factor in the estuary. Parallel efforts have been made to increase the survival of cultivated smolts. Experiments wherein smolt are towed in a custom made tank and released downstream, demonstrated that the return rates were much higher (3.8 times) when fish were released in the outer, more saline, parts of the fjord (Barlaup et al. 2013). These release groups were also partitioned into categories of treated (with Slice ©) or not treated against salmon lice, and it was demonstrated that salmon lice in some years can impose a substantial additional mortality in the outer fjords (Vollset et al. 2014). Consequently, the up-scaling of cultivation efforts financed by fish farmers based on the principle of towing treated smolt to the outer fjord has been shown to be a relatively efficient enhancement method that bypasses, although not resolving, whatever issue the smolt are encountering in the fjord. The high numbers of spawners returning from these releases (in the years 2009-2013) have so far secured a spawning stock above the spawning target set for the Vosso River in the years 2011-2013. As a result, a major increase in natural recruitment and densities of juveniles in the years 2012 and 2013 was recorded, and a corresponding increase of the smolt run is expected for 2014. However, the pivotal question related to the survival of smolts through the estuary remains unanswered.

The predator hypothesis

One hypothesis that has emerged for the low survival of smolt through the estuary is that currently there is heavy predation from trout on salmon smolt in the estuary of Vosso (the predator hypothesis). This can be explained by (a) that predation mortality in the inner fjord system is strongly density dependent causing higher prey mortality at low concentrations and/or (b) that the predation rate on salmon smolt has increased. The second explanation can further be further subdivided either into (b1) a *reproductive numerical response* (Hassell 1966), (b2) an *aggregative response* at small spatial and temporal scales (Hassell and May, 1974), or (b3) a *prey switching* by important predators (Murdoch et al., 1975). See also Hunsicker et al. (2011) for a more recent summary. To phrase it in the context of the Vosso salmon: If the numbers of salmon smolt decrease, we would expect the number of predators per smolt to increase, given that the predator also targets smolts when their abundance is low (a). If predator abundance increases

Figure 4. The characteristic narrow fjords which constitute the first 100 km of the migration route for the smolts as they start their seaward migration. Photo: Bjørn T. Barlaup.

locally, either by increasing in numbers (b1) or aggregating more in the estuary during the smolt run (b2) we would expect a higher predation on smolt. If prey abundance of an alternate prey decrease, we'd expect predation on smolt to increase (b3). These hypotheses are not mutually exclusive and can all, in theory, affect the survival of smolt.

Sprat as a prey refuge for sea trout?

The fjords of western Norway were known for rich sprat fisheries prior to the mid 1980's. In many western Norwegian fjords, including the Osterfjord system, the sprats stocks showed a declining trend from late 1980's to about 1990. The abundance of sprat was most likely low in the system as compared to the pre 1970 period. Furthermore, sea trout is known to be a predator on sprat. The predator hypothesis suggests that the decline of the sprat stock in the Osterfjord system could have led to a prey switch in Vosso sea trout towards Atlantic salmon and sea trout smolts. Predation on smolt may be a short-term and easily accessible prey item that sea trout (and other predators) can capitalize on. The presence of sprat in the system, could have been a prey refuge for the smolt.

As mortality from predation on migrating smolts is usually thought to be density-independent (or negatively density-dependent), variation in such mortality will affect spawning stock variation and can therefore have important management implications. Consequently, correct estimation of mortality trends during estuarine migration is critical as it lays the foundation of how to weigh potential impacts from other mortality factors such as salmon lice (Krkosek et al.,

Figure 5. Sea trout has been identified as a predator in the estuary of the Vosso River, Bolstadfjorden. Photo: Tore Wiers.

2013) or marine survival (Friedland et al., 1993; Peyronnet et al., 2008).

Objectives of the present study

The goal of this current project was therefore: (1) to examine the migration, survival and predation of wild and cultivated smolt from the Vosso system (2) evaluate whether the predation in the Vosso system is a bottleneck that hinders the restoration of the Vosso salmon and (3), evaluate these results according to the predation hypothesis.

The report has been structured into 5 chapters, each of which tries to evaluate a different aspect of the project. **Chapter one** focuses on the predation community and density of predators in the estuary of Vosso and in two similar estuaries, **Chapter two** focuses on the mortality and migration of cultivated and wild smolt through the estuary of Vosso, **Chapter three** focuses on the potential aggregation of trout in the estuary of Vosso and in two similar estuaries **Chapter 4** focuses on examining the migration of smolt by acoustic methods, while **Chapter 5** focuses documenting the historic trend of sprat in Osterfjorden, sea trout in Vosso, and the potential trophic link between these two species and the survival of salmon smolt. In addition, a study was conducted to evaluate the potential density-dependent survival of smolt by releasing different sized smolt groups. However, results from this experiment will not be available until 2016 and will therefore not be reported here.

In the following section the most important findings from each chapter are summarized

Chapter 1 - Composition of piscivorous fish communities in three estuaries in the Osterfjordsystem during the smolt run.

The main predators identified in the Vosso estuary were trout in Bolstadfjorden, and cod, pollock and saith at the region of the sill at Stamnes. The catch per unit effort of trout in Bolstadfjorden was relatively low compared to the Dale or Arna estuaries. This may reflect that the current stock of sea trout in the Vosso river system is at a low level of abundance compared to historic catches. The density of cod on the shore slope at Stamnes was relatively high compared to the shore slopes in Dale and Arna, and is most likely a potential area of smolt predation.

Chapter 2 - Estuarine migration speed and mortality estimates of Atlantic salmon smolt from the Vosso river based on acoustic transmitters and multiple recaptures in large trap nets.

Similar to results from releases of cultivated smolt groups and earlier tagging studies, survival of cultivated smolts tagged with acoustic devices were low (80 % and 88 % were not registered outside the estuary in 2012 and 2013, respectively). An elevated tag loss was identified on the shore slope of Stamnes, which corresponded to the aggregation of cod documented in Chapter 1. Results from the ratio of cultivated and wild fish in four trap nets along the estuary indicate that the proportion of cultivated fish decreased the further the trap was located from the river, and that a large proportion of the cultivated fish resided for a long time in Bolstadfjorden before leaving. Migration speed based on acoustic tags through Bolstadfjorden was low, but increased significantly when the few fish that survived the estuary entered into the fjordsystem outside. We suggest that the high mortality observed may be partly explained by a long residence time in Bolstadfjorden. Capture-mark-recapture estimates indicate that the wild smolt run from the Vosso River is currently at a lower level than expected, and needs to be further investigated.

Chapter 3 - Estuarine habitat use of brown trout (Salmo trutta) and its potential overlap with and predation on Atlantic salmon smolt.

The tagging study of trout suggested that 48% of the fish that were caught in the estuary during the smolt run remained in the estuary (last recording 1. July). In comparison 90 % of the fish tagged in Dale remained in the estuary, while 9 % of the fish in Arna remained in the estuary. Fish caught earlier in the season with a lower condition index were more likely to migrate to the outer fjord than fish in higher condition and fish tagged later in the season. The fish caught in the estuary were therefore most likely a combination of migratory fish leaving and returning from the outer fjord system, and potentially a component staying the entire season in the estuary. There was a pattern of loss of tagged salmon smolt in the same area where there was an aggregation of sea trout in both 2012 and 2013. However, there was no apparent aggregation of trout at Stamnes where we observed significant smolt tag loss. We therefore suggest that predation at Stamnes is mainly by marine fish, and that different predators may be important at different locations along the migration route of smolt.

Chapter 4 - Acoustic investigations on smolt migration dynamics in the Bolstadfjord

Acoustic investigations using echo sounder observations and sonar tracking of acoustic tags were conducted to study the migration of smolts through Bolstadfjord from May to June 2012. Large aggregations of smolts were observed at Bolstad Bay coinciding to the release of 30.000 smolts at Vassenden on the 21st of May. A much lower flux of smolt schools were observed at Straume as compared to at Trollkona. This may indicate either a significant loss of smolts between the two positions or a slow migration of individuals through Bolstadfjorden. Individual tracking of fish a few days after the large release of smolt indicated that single individuals that were identified did not swim directionally towards out of the estuary. These results corroborate the large tag loss and slow migration of smolt through the estuary.

Chapter 5 - Characteristics of the sprat and sea trout stocks in Osterfjorden from 1960 to present

Several independent sources of quantitative and qualitative catch statistics, the lack of sprats appearing in our trawl surveys, and disappearance of sprats in the stomach contents of predator fishes in the Osterfjord system suggest the sprat stocks decreased significantly in the fjord system sometime around 1985-1990. It is suggested that the decrease in sprat abundance could have led to a heavier predation on Atlantic salmon and sea trout smolts due to the lack of sprat as an alternative prey during their initial marine migration.

Regarding the slow migration and high mortality of smolt through Bolstadfjorden

While predation by trout (and marine fishes like cod) is most likely the direct cause of death for most smolts that disappear in the estuary, there are reasons to believe that the observed behavior of fish spending up to 3-4 weeks navigating through the estuary is maladaptive. For example, survival was higher in 2012 than 2013, which also corresponded to a lower migration speed of tagged cultivated fish in 2013. We cannot clearly quantify whether the slow migration and subsequent high mortality of cultivated smolts is also the case for wild smolt. However, results from ratios of wild versus cultivated smolts in trap nets, and capture of wild fish compared to estimated smolt run from the river, clearly demonstrates that the survival of wild fish is higher than cultivated fish. Studies on released groups of smolts generally show that survival is lower in cultivated versus wild conspecifics (Jonsson et al., 1991). For example, Kallio-Nyberg et al. (2011) estimated that for similarly sized wild and cultivated fish, the survival of wild fish was 18 times higher than cultivated fish in the Simjoki River. Our study suggests that the difference between the two groups may already be apparent after their first migration through the estuary. A possible explanation for the difference between the cultivated and wild fish may be their physiological or behavioral state. While the cultivated fish in the Vosso river are thought to have the correct NA+,K+-ATPase activity, other physiological or behavioral variables may deviate from the wild fish. For example, Vainikka et al. (2012) demonstrated that the migration behavior of cultivated Atlantic salmon smolts was more directional and faster in fish with restricted food rations prior to release.

Increasing the understanding of how individuals cope with environmental challenges relative to their predispositions is especially important when data from maladapted or multiple stressed individuals are used to infer patterns of survival in wild populations. In some cases such mortality estimates can draw attention away from other equally important threats when managing fish stocks because they suggests a doom and gloom situation. Efforts must therefore be made not to focus solely on data based on cultivated or handled fish, but also on captures or observations of wild fish when possible.

Concluding remarks and suggestions for future work

This study has demonstrated that the salmon smolt from the Vosso river are preyed upon by both trout and marine fishes (mainly cod) during their estuarine migration, and suggests that the survival through the estuary is linked to how fast the smolts are able to navigate through the complex fjord system. It is uncertain whether this is an artefact of cultivation and to what degree this relationship also applies to wild fish. A prey switch of trout from sprat to salmon smolt, as suggested by the predator hypothesis is plausible; however, the current trout population in the Vosso system seems to be at low level and is most likely the reason for the relatively low catches of trout in Bolstadfjorden observed in this study. Even so, the Bolstadfjorden is a relatively large estuary and may attract predators during the smolt run that can capitalize on easily accessible prey. Indications of aggregation of trout in areas of tag loss partly support this. Combined with the observation that the release of cultivated smolt in the river yields low returns due to low survival in the estuary, we conclude that our results on predation point to a complex predator-prey relationship impacting survival of salmon smolt rather than the single factor of predation by trout. A pivotal question that remains is to what degree this applies to the wild fish.

Our results also suggest a low smolt output of wild fish from the Vosso river, and needs to be further evaluated. The current situation with an increased spawning stock due to the high cultivation efforts in the Vosso River offers a unique opportunity to investigate through a large natural experiment, how increased spawning populations in the river system will affect the smolt production, and subsequent recruitment from wild fish production. To be able to appropriately study this, we suggest initiating a program that documents the wild fish smolt production and follows the migration of wild fish from the river in subsequent years after the restoration program.

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Chapter 1

Composition of piscivorous fish communities in three estuaries in the Osterfjordsystem during the salmon smolt run.

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Abstract

A survey was conducted to identify the most common piscivorous fish that could potentially prey on Atlantic salmon (Salmon salar) smolt during the smolt run in three estuarine systems in Osterfjorden (Vosso, Dale and Arna). The main area of interest was the estuarine system of Vosso (Bolstadfjorden), where a large re-establishment project of the Vosso salmon is taking place. The main predatory species in the system were brown trout (Salmo trutta) and three gadoid species; cod (Gadus morhua), pollock (Pollachius pollachius) and saith (Pollachius virens). Bolstadfjorden was characterized by relatively low CPUE (catch-per-unit-effort, fish caught per hour) of trout compared to Dale and Arna, and relatively high CPUE of gadoid species (Stamnes) compared to the two other estuaries. Average smolt per stomach were 0.67 (n=3) in trout caught in Bolstadfjorden, and 0.16 (n=81) of cod caught at Stamnes. Standardized gill net fishing and catches from a large trap net supported the notion that the density of large trout (>35 cm) in Bolstadfjorden was relatively low during the smolt run. This is most likely linked to the poor condition of the sea trout population in Vosso.

Keywords: Predation, atlanti salmon, smolt, migration, estuary

Introduction

Marine survival estimates from cultivated and tagged smolts released in the Vosso River have been invariably low during the period 2000-2012 as reflected by no or very low numbers of recaptured salmon (<0.01 %). Tagging studies of cultivated smolt indicate that most of the mortality of the tagged fish occurs between the river mouth and a few kilometres after marine entry (J.C. Holst pers. comm.). This is in accordance with other studies, which suggest that large numbers of smolt disappear during the transition from the river to the ocean (Dempson et al., 2011; Thorstad et al., 2011a; Thorstad et al., 2011b; Thorstad et al., 2012a; Thorstad et al., 2007). The estuaries seem to be especially important areas for aggregations of marine fishes below the halocline, and trout are often observed here above the halocline. The estuary may therefore be viewed as an important transition zone where the migrating smolts simultaneously face both a physiological challenges related to adapting to saltwater, and an increasing density of predators (Handeland et al., 1996).

While predation on Atlantic smolt near river mouths and in estuaries is well documented (Hvidsten and Lund, 1988), predator community structure and composition may vary greatly between systems. The estuary of the Vosso system consists of a relatively narrow 20 km long and 160 m deep fjord, Bolstadfjorden, with a shallow sill separating it from the Osterfjord. During flood tide, some saltwater enters into the fjord and sinks to the bottom. This creates a strong and consistent halocline with H_2S-rich bottom water that seldom gets exchanged. Consequently, it is believed that relatively few marine fishes reside inside Bolstadfjorden, whereas it is suspected that large numbers of trout reside in the freshwater layer. Outside the sill, anecdotal information suggests that there is an aggregation of cod and other marine fish living below the halocline.

The main goal of this study was to describe the predator communities in the estuary of the Vosso system, defined as the Bolstadfjord including Stamnes, compare it to two other estuaries within the same fjord system (Osterfjorden), and evaluate which are the most important potential predators in Bolstadfjorden.

Material and methods

Several fishing methods were used to get representative samples of the potential predators in the three estuarine systems during the smoltrun (April - June). First, standardized trolling and jigging equipment were distributed among local fishermen, along with instructions for use. They were instructed to fill in standardized forms including soak time of lures. Three different lures were used for trolling and three different lures for jigging. Jigging was conducted on the shore slope outside the river mouth, while the trolling was conducted from the river mouth to a few km outside. In the case of Vosso, the shore slope was defined as the shore slope at the end of the sill region of Bolstadfjorden (Stamnes) since few marine fishes has been observed inside Bolstadfjorden. Similarly, Stanghelle was defined as the shore slope in Dale (Fig. 1).

Catch-Per-Unit-Effort (CPUE) of the piscivorous community was calculated by dividing the number of sea trout, marine fish by the soak time of lures (minutes) for both jigging and trolling. Two rods were used per boat, thus the CPUE is a conservative estimate.

Secondly, a large trap net was used to catch pelagic fish close to Furnes in Bolstadfjorden (Fig. 1). Description of the trap net can be found in Barlaup et al. (2013). The trap used at Furnes was modified so that the lead net was 10 meter deep (compared to 5 meter in the original design). The trap net was operated from 11. May to 3. July in 2012 and 5. May to 30. June in 2013, to cover the smolt run of the Vosso salmon (Median date= ~17. May, Barlaup et al. 2013)

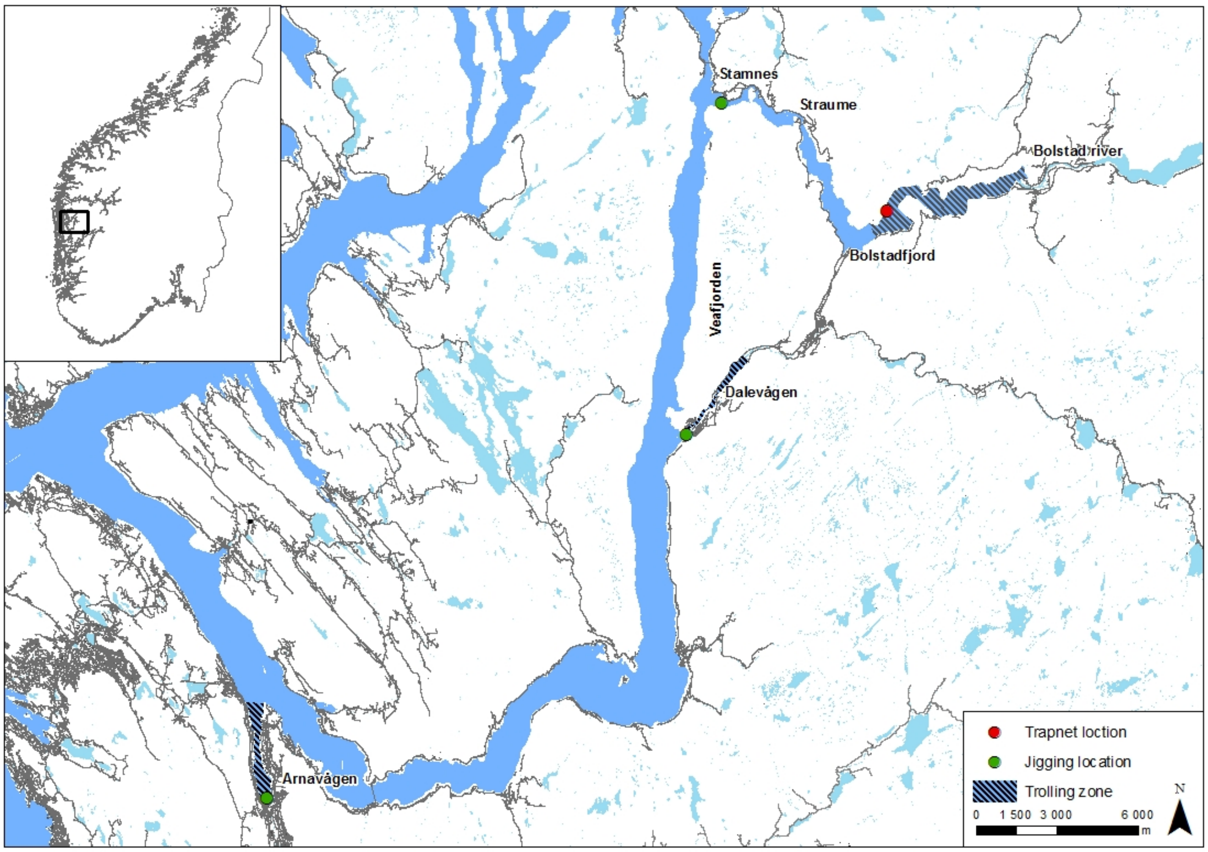

Figure 1. Map of sampling sites after predators. Trolling is indicated with a zone wherein the trolling was conducted, while jigging is indicated with a dot (green) which also indicates the location of the shore slope. In addition, the trap net at Furnes in Bolstadfjorden is indicated with a red dot.

Thirdly, to get a better representation of the size distribution and density of sea trout in Bolstadfjorden, standardized gill net fishing was conducted twice during the smolt run period in Bolstadfjorden. In the first period, 24-26 April, 40 effective gillnet-nights were conducted (gillnet-nights = number of gillnets × number of nights), while in the second period, 29-31 May, 38 effective gillnet nights were conducted. The gillnets used were multimesh nets consisting of a mesh size of 5-6,25-8-10-12,5-15,5-19,5-24-29-35-43-55 mm. The gillnet was 1,5 m deep, and had a mesh area of 3,75 m^2 with a total area of 45 m^2 (Fig. 2).

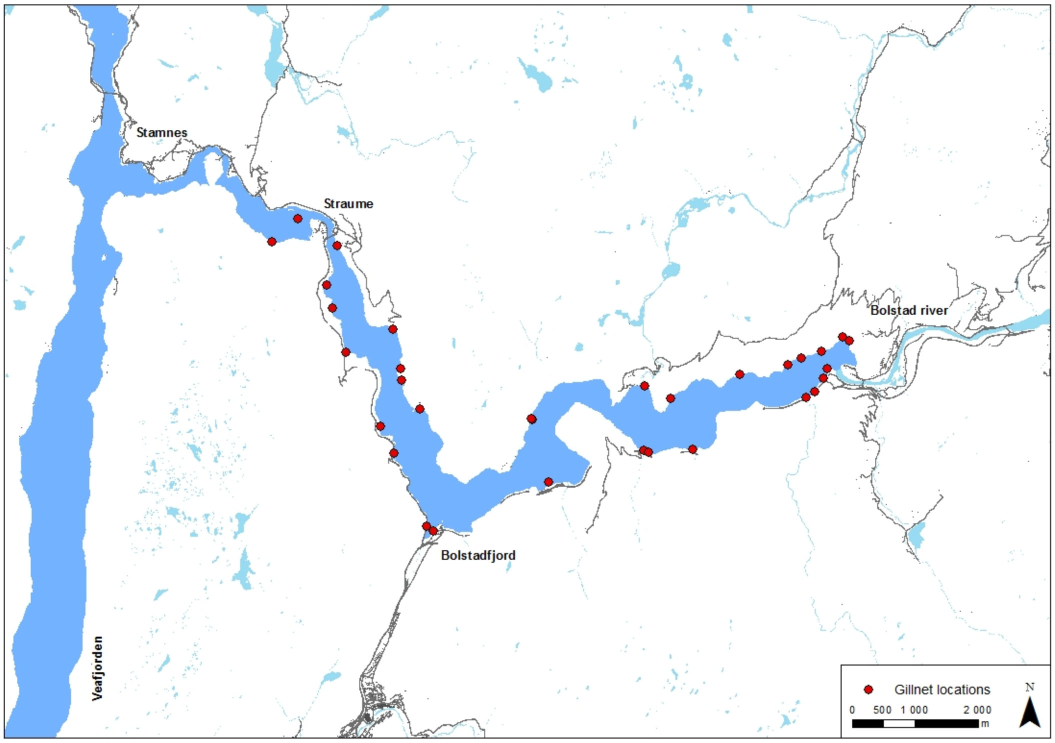

Figure 2. Gillnet locations in Bolstadfjorden , the estuary of Vosso, in 2012.

All fish caught during trolling and jigging were analysed for stomach contents. All sea trout had their stomachs flushed and were subsequently released, while marine fishes were euthanized with a blow to the head and the stomach dissected. The stomach content was frozen and analysed later in the laboratory. In a few cases fish that had been recently eaten, or regurgitated were still in the mouth or oesophagus of the predator. These fish were also included in the stomach analysis.

Results

Comparisons of catches in estuaries

In total more than 500 hours of fishing were conducted by both staff from Uni Research and IMR, and local personnel. However, the effort varied strongly between estuaries since the fishing was based on organized fishing by locals. In the following text we have focused on comparing the catches from trolling and jigging in the estuaries and shoreslope of Dale, Arna and Vosso. Marine fishes include (*Gadus morhua*), pollock (*Pollachius pollachius*) Saith (*Pollachius virens*), Whiting (*Merlangius merlangus*) or Haddock (*Melanogrammus aeglefinus*), if no species names are indicated. In addition there were catches of Cusk (*Brosme brosme*) and Grey gurnard (*Eutrigla gurnardus)*. However these individuals were too small to be defined as predators (Fig. 3, Table 1). Mackerel, herring, sprat and several different flatfish species were also caught. However these were not observed as potential predators on smolts and were therefore excluded from further analysis.

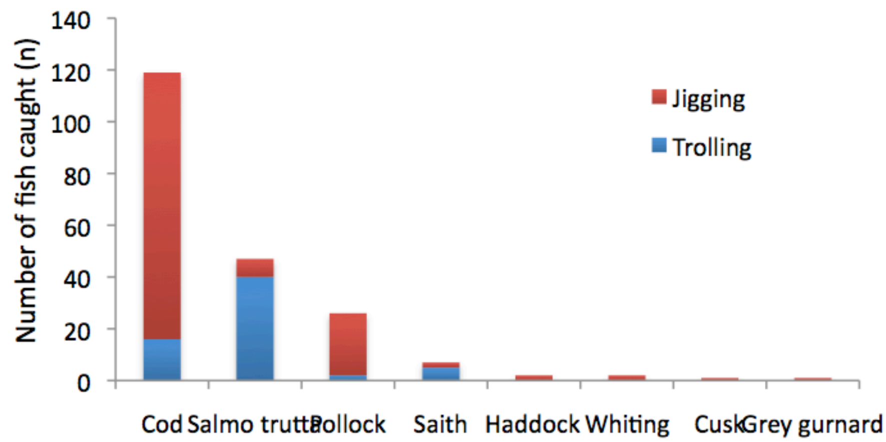

Figure 3 Species distribution of potential predators caught in the estuaries of Vosso, Arna and Dale.

Table 1. Potential predatory fish species caught by trolling and jigging in the estuary of Vosso, Dale and Arna from 1. April – 1. june.

Common name	Species names	Trolling	Jigging	Total (n)
Cod	*Gadus morhua*	16	103	119
Salmo trutta	*Salmo trutta*	40	7	47
Pollock	*Pollachius pollachius*	2	24	26
Saith	*Pollachius virens*	5	2	7
Haddock	*Melanogrammus aeglefinus*	0	2	2
Whiting	*Merlangius merlangus*	0	2	2
Cusk	*Brosme brosme*	0	1	1
Grey gurnard	*Eutrigla gurnardus*	0	1	1

Catches of sea trout during trolling were highest in Dale and Arna, and relatively low in the estuary of Vosso (Bolstad) (Fig. 4). In fact, only 4 sea trout were caught in Bolstadfjorden during the whole fishing season which amounted to more than 85 hours of fishing. Adding another 50 hours of trolling conducted by IMR (but with somewhat different gear) would decrease the CPUE estimate by half (since no fish were caught), strengthening the notion that the abundance of sea trout in Bolstad was low.

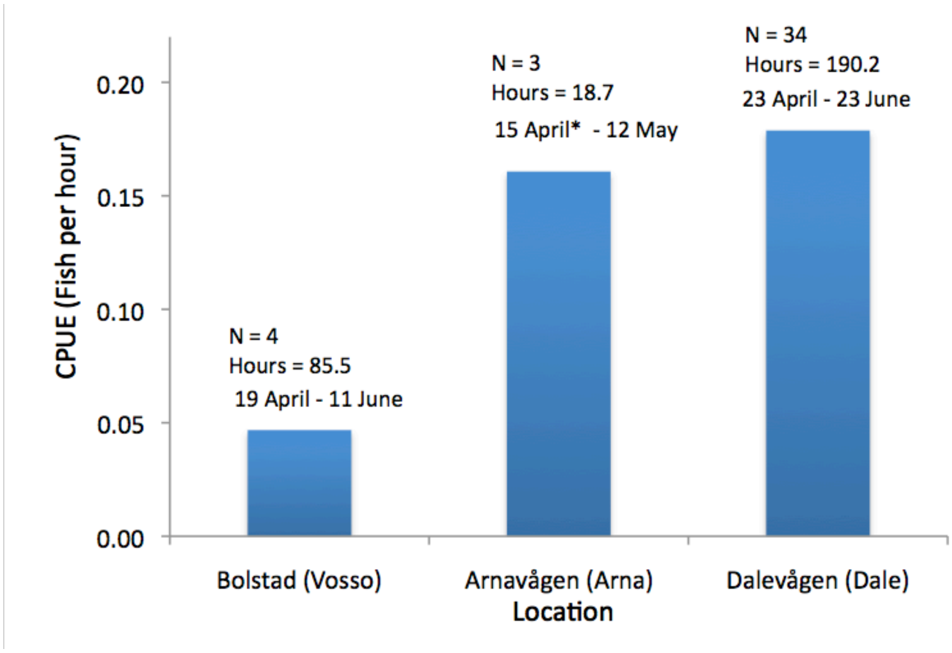

Figure 4 CPUE (Catch per hour) of sea trout caught by trolling in the estuary of Vosso, Arna, and Dale. Number of fish caught (N), hours fished (Hours) and fishing period is indicated above each bar. * some uncertainty regarding the first day of fishing.

Catches of marine fish during jigging was highest at Stamnes (shoreslope of Vosso), and comparably low at Arna and Stanghelle (shoreslope of Dale) (Fig. 5).

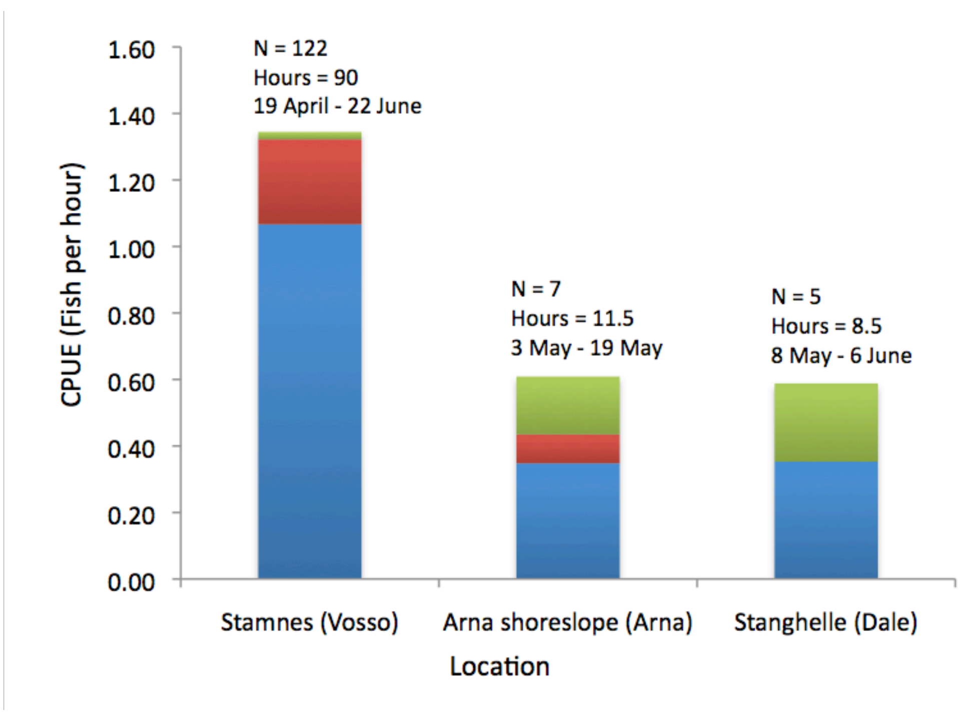

Figure 5 CPUE (Catch per hour) of cod (blue), pollock (red) and other marine fish (green) caught by jigging in the estuary of Vosso, Arna, and Dale. Number of fish caught (N), hours fished (Hours) and fishing period is indicated above each bar.

Since sea trout was especially important in this project, as they have been suggested as an important potential predator of smolt during their migration through Bolstadfjorden, we also present the catchability of the three different lures for Dale and Bolstad used during trolling. Results suggest that "wobbler" and "silver-lure" (silvery reflection) were most efficient for trout, while the wobbler was also quite efficient for marine fish. In fact more cod than trout was caught by the wobbler inside Bolstadfjorden during trolling. Sprat used as a live-bait lure was less efficient (Fig. 6).

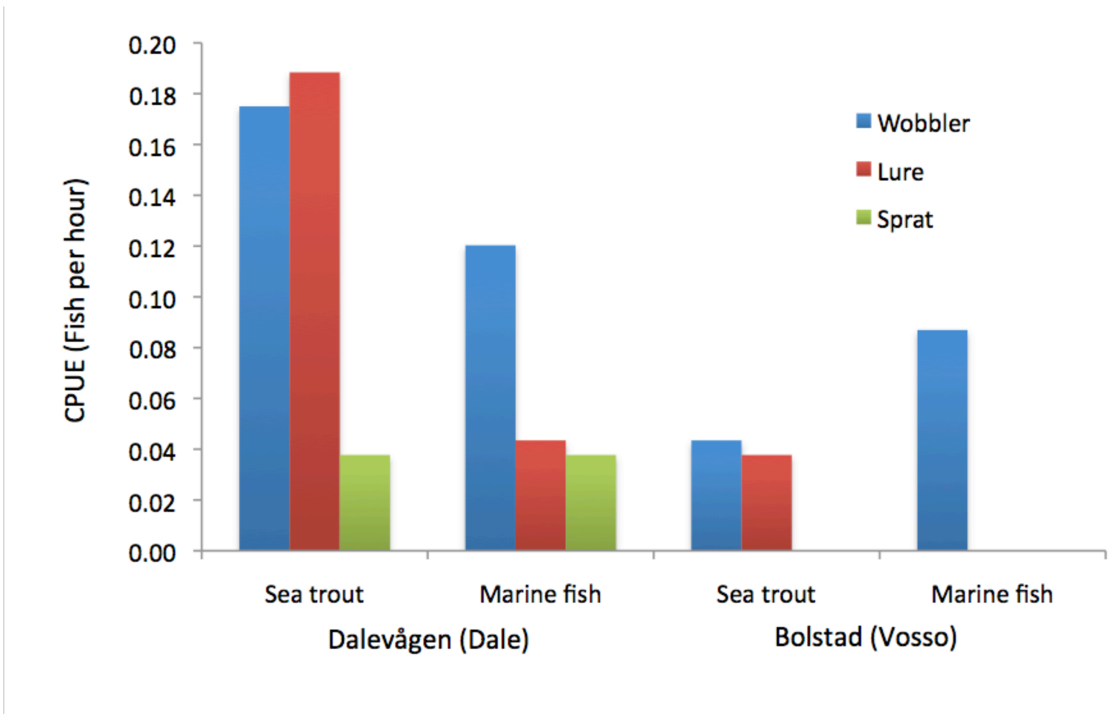

Figure 6 CPUE (Catch per hour) of sea trout and marine fish (cod, pollock and saith) for trolling in Dale and and Bolstad depicted for the three different lures used during fishing: Wobbler (wobbler), a metal lure (lure) and frozen sprat (sprat)

Trap net catches

In total during 2012 and 2013, 78 and 43 trout above 35 cm were caught and released in trap nets located at Furnes, with a max size of 68 and 63 cm respectively (Fig. 7). The average size decreased during the sampling period most likely reflecting a high number of trout smolt (10-15 cm) being caught late May and June (Fig. 8 & 9)

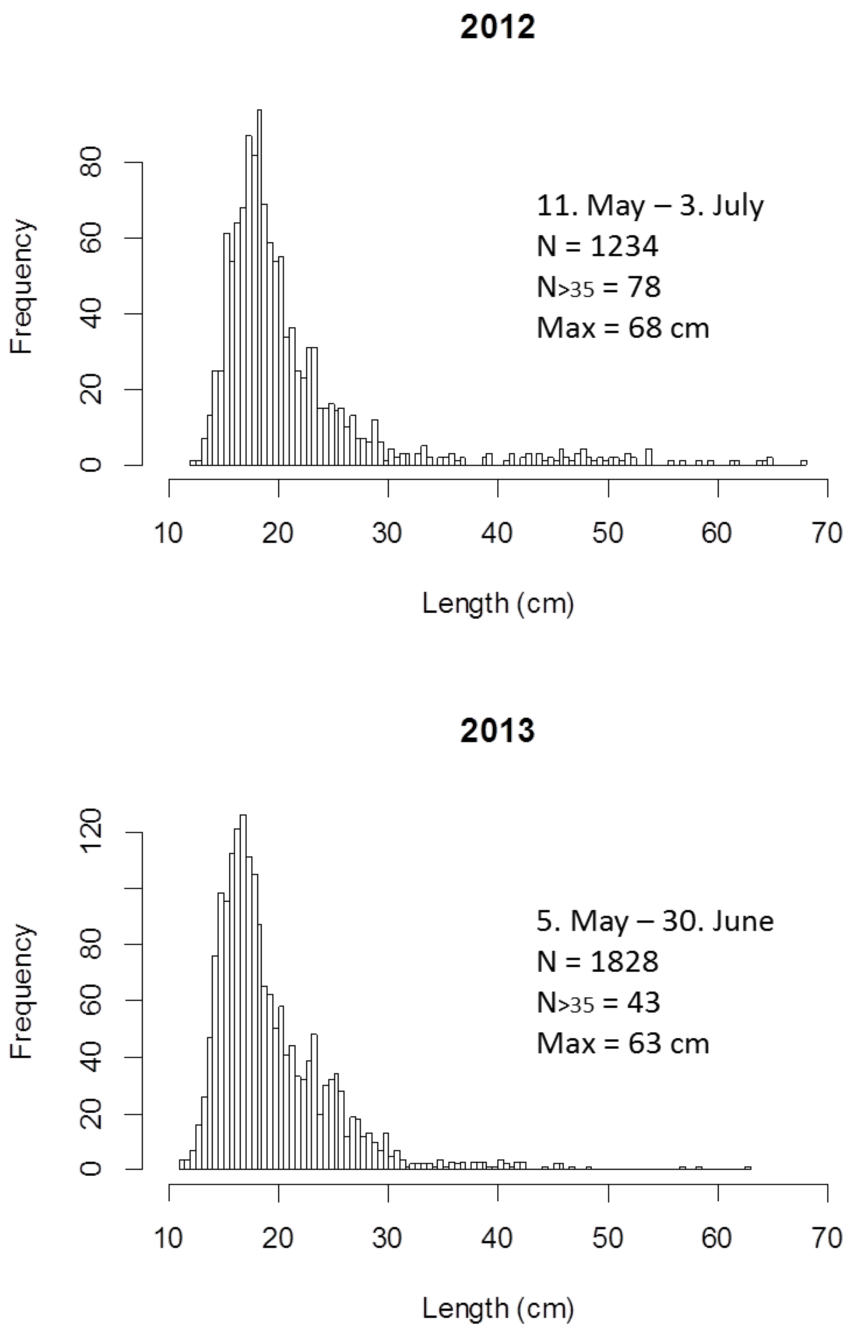

Figure 7 Length distribution (cm) of trout caught in the trap net at Furnes in 2012 (upper panel) and 2013 (lower panel).

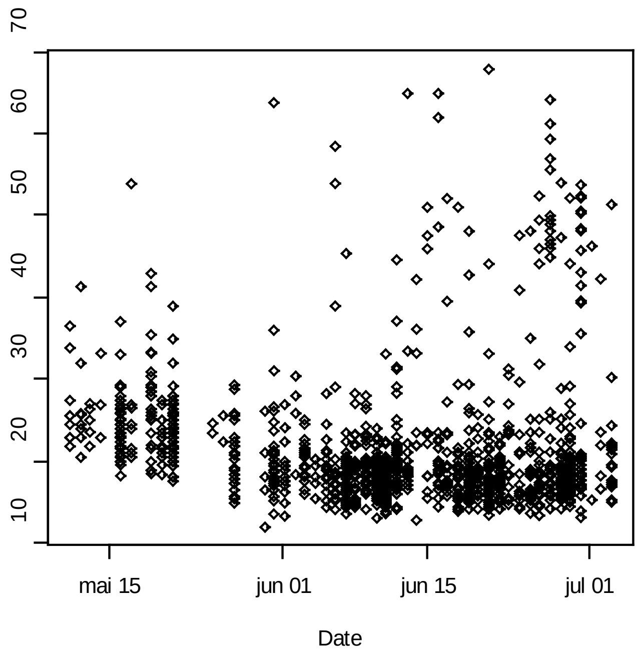

Figure 8 Length (cm) of trout caught in the trap net at Furnes from 11.05.12 – 03.07-12.

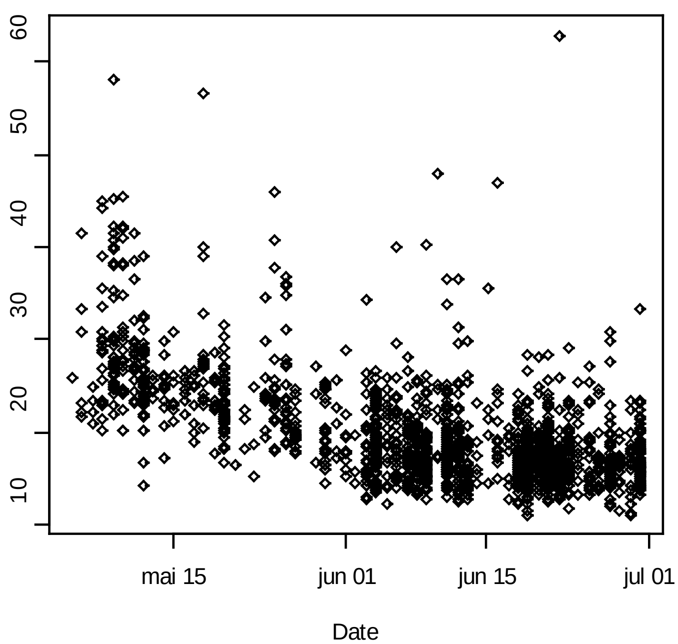

Figure 9. Length (cm) of trout caught in the trap net at Furnes from 06.11.12 – 30.06.13.

Gillnet fishing in Bolstadfjorden

In general the results from the gillnet fishing reflected the results from trolling by demonstrating that the abundance of large sea trout, which we would expect to predate on smolt (>35 cm), was relatively low in both fishing periods (First period N = 11, second period N= 7). The overall density of trout in the two periods was 11.8 trout per 100m^2 gillnet area, and 22.6 trout per 100m^2 gillnet area, respectively (Fig. 10 & 11). There was a high abundance of trout in the size range 10-15 cm at the in the second period. These are most likely smolts of sea trout (Fig. 11). There were no catches of salmon smolt in the first round (24.04-25.04.2012), while a density of 1.6 smolt per 100m^2 gillnet area in the second round (29.05-31.05.2012) (Fig. 12).

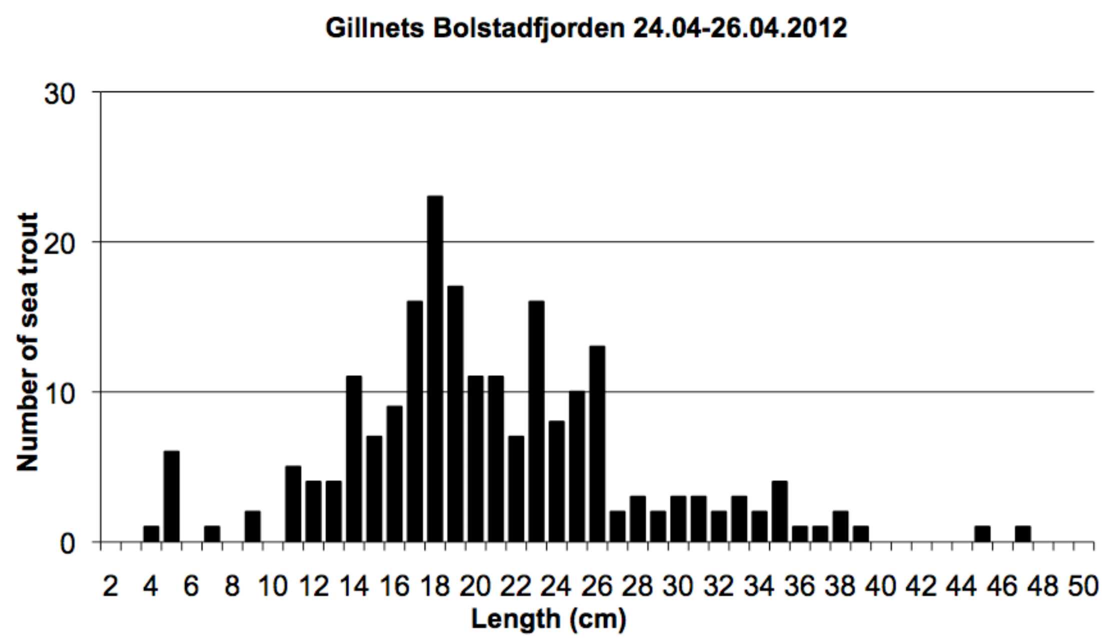

Figure 10 Size distribution of sea trout caught by gillnets in Bolstadfjorden during 24- 26 April.

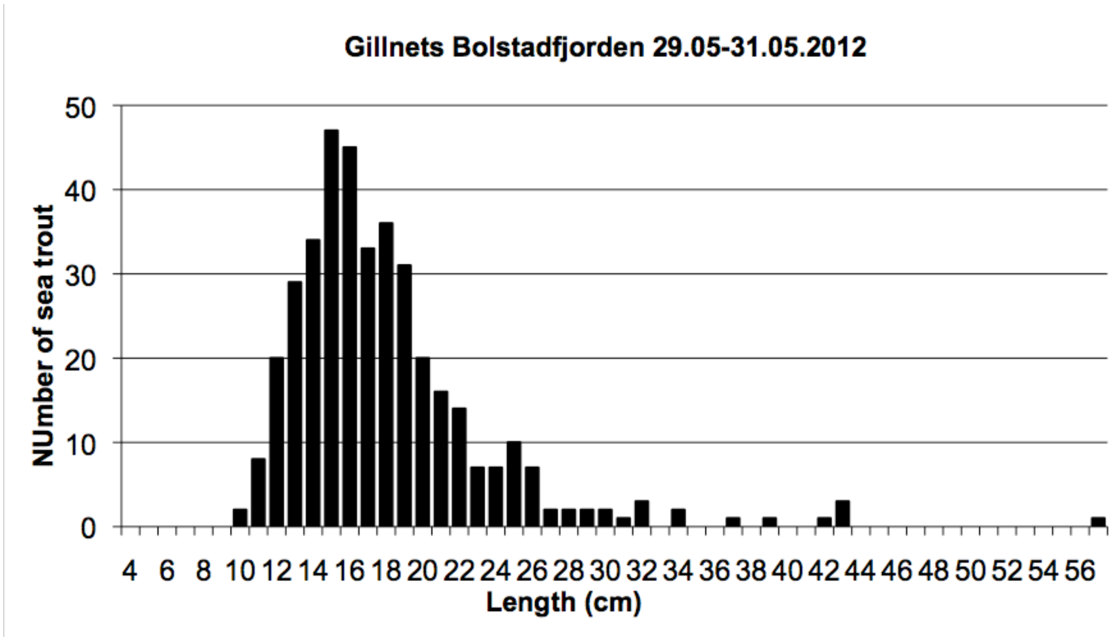

Figure 11 Size distribution of sea trout caught by gillnets in Bolstadfjorden during 29- 31 May.

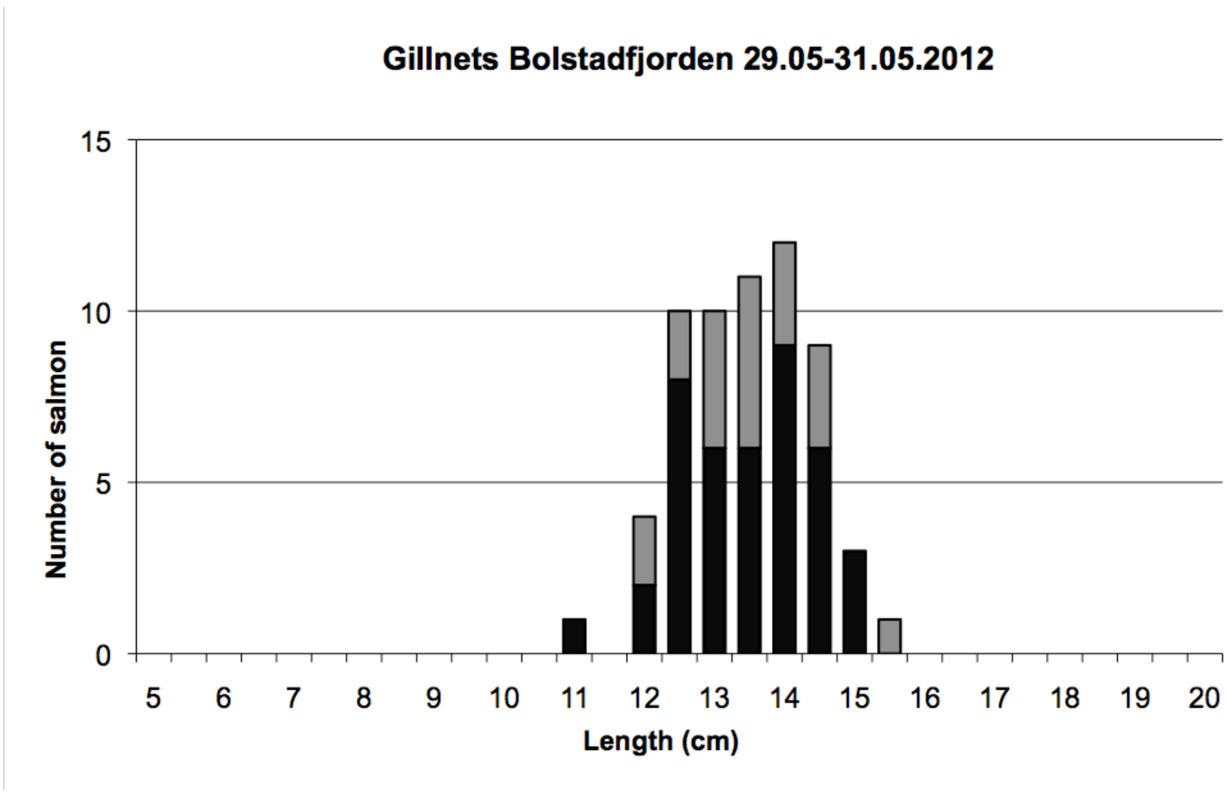

Figure 12 Size distribution of salmon caught by gillnets in Bolstadfjorden during 29-31 May. No salmon were caught in thegillnets between 24-26 April. Black indicates wild, untagged smolts, while grey indicates tagged/cultivated smolt.

Size distribution of sea trout and cod in rod catches

Average length of sea trout caught in the estuaries was 52.7 cm in Arna (sd=2.1, n=3), 53.7 cm at Bolstad (sd=8.1, n=4) and 43.4 cm in Dalevågen (sd=7.6, n=34). Low catches in Arna and Stamnes precluded any formal statistical analysis of differences in size distribution between the three estuaries.

Average length of marine fish caught in the estuaries was 64.5 cm in Arna (sd=1, n=4), 51.8 cm at Stamnes (sd=7.5, n=112) and 47.0 cm at Stanghelle (sd=12.3, n=4). Low catches in Arna and Dale precluded any formal statistical analysis.

Stomach samples

The analysis of stomach content of fish caught by rod fishing, showed that only 1 of 3 trout at Bolstad had salmon smolt in the stomach (avg= 0.67 smolt per stomach, n= 3, range = 54 cm). In Dale and Arna, no salmon smolts were found in any of the stomach samples (Dale n = 32, Arna n = 4).

Of all marine fish only cod at Stamnes had smolt in the stomach. Nine cod caught at Stamnes had eaten smolts (max=3, range=46.5-82 cm). The average smolt per cod stomach were 0.16 (n=81) for all cod examined and 0.23 (n=39) for cod larger than 50 cm (Table 2).

Table 2 Size distribution of cod, and smolt per stomach.

	Cod		Smolt in stomach	
Length (cm)	N	%	Total	Avg.
<30	0	0.00	0	-
31-35	2	2.47	0	0.00
36-40	3	3.70	0	0.00
41-45	12	14.81	0	0.00
46-50	25	30.86	4	0.16
51-55	27	33.33	3	0.11
56-60	9	11.11	1	0.11
61-65	1	1.23	2	2.00
>70	2	2.47	3	1.50
Total	**81**	**100.00**	**13**	**0.16**

The stomach contents of sea trout were mainly large numbers of gammarids, insects (*Trichoptera, Chironomidae, Nematocera, Plecoptera)* in addition to some individuals of three-spined sticklebacks (*Gasterosteus aculeatus)* and trout (*Salmo trutta*). The stomach contents of cod were mainly crustaceans with a large porportion of the fish eating common littoral crab (*Carcinus maenas*, 24 of 86 fish = 38%). Four cod caught inside Bolstadfjorden had large numbers of sticklebacks in their stomachs (*Gasterosteus aculeatus).*

Data from rod-catch statistics of sea trout

Data from rod catch statistics from the Dale, Arna and Vosso river are available online (www.ssb.no) from 1995-2012. Average size of trout in the catch statistics suggested that Arna and Dale had relatively small trout, compared to Vosso (Fig. 13).

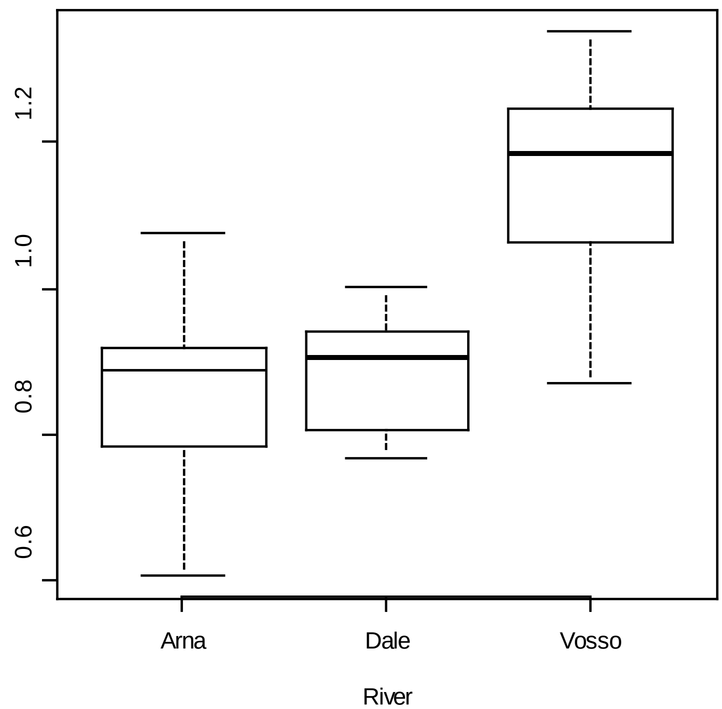

Figure 13 Average weight of trout caught by rod in the rivers of Arna, Dale and Vosso from 1995-2012.

Discussion

While the species composition varied between estuaries in Osterfjorden, cod (*Gadus morhua*) and sea trout (*Salmo trutta*) seemed to be the most important potential predators of smolt in the three estuaries of Vosso, Arna and Dale. Our results indicate that Dale had a relatively large concentration of trout during the smolt run. Comparably, Bolstadfjorden (estuary of Vosso) does not seem to have a high concentration of trout in the size range that could predate on smolt during the smolt run. This is both reflected in the catches during trolling, in the gillnet fishing, and the trap net. For example, during a total of 135 hours of trolling in Bolstadfjorden (including unreported trolling done by IMR) only 3 trout were caught. However, Bolstadfjorden is a much larger estuary than that of Dale and the absolute number of sea trout may therefore be larger in Bolstadfjorden. Furthermore the average size of trout caught in Dale was smaller than the few trout caught in Bolstadfjorden. Average size of trout from catch statistics was also larger in the Vosso River system compared to the Dale.

Inconsistent with our results, rod-catch statistics in the period 1995-2012 suggested that Vosso has had a relatively high number of trout relative to Dale and Arna, and this may indicate that our sampling did not appropriately target sea trout in the estuary of Vosso, or that the trout were not concentrated in the estuary during the sampling period. However, Vosso is a much larger river system than Dale and Arna (River area Dale = ~105 000 m^2 vs Vosso > 500 000 m^2) and we should therefore expect a larger total number of trout in Vosso. Stamnes Handelslag, the local fish depot at Stamnes, received an average of ~3 tons trout per year during the period 1949-1966 (Barlaup et al. 2013), and suggests that the catch of 301 kg in 2012 from fishing in the river is, in a historic perspective, a relatively low abundance of trout. This also reflects the general consensus among sports fishermen that there is currently not a large abundance of trout in the Vosso River system (See also chapter 5 for details).

One of findings in this study was a low numbers of smolts found in stomachs of predators, with the highest average number of smolt per stomach for cod at Stamnes (0.16 smolt/stomach). In comparison Hvidsten and Lund (1988) found an average of 0.98 smolt per cod and 1.68 smolt per saith in the estuary of Orkla, and estimated that predation by cod could account for approximately 20% of the smolt mortality. Previous fishing efforts in Bolstad (unpublished data) have occasionally demonstrated high numbers of smolts in stomachs of sea trout within Bolstadfjorden (n =13, max = 14, mean = 2.1), however, this seems to vary between years and time of sampling.

One bias that could not be corrected for in this study is gear selectivity. Fishing, using rods, traps or gill nets will target certain size classes and will not necessarily represent the actual size range present in the estuaries. In addition rod catches will depend heavily on the motivation of the fish to take the bait or lure, and will most likely target fish that are not satiated by prey. This could be a possible explanation of the low catches in Bolstadfjorden. The original idea of the study design was to get samples of individuals in the estuaries that would predate smolts. Furthermore, by using several gear types it was attempted to obtain a representative sample of the predator population.

One area that we did not sample for trout was the area between Straume and Stamnes, which is the shallow and narrow sill between Bolstadfjorden and the outer fjord. This area contains mostly freshwater and the current and substrate are perfect habitat for trout. Anecdotal information suggests that this area periodically has large aggregations of trout. From our results in 2013 an aggregation of tagged sea trout overlapped with the location where acoustically tagged salmon smolt disappeared, and may suggest an increased predator prey overlap in this narrow and area of the fjord landscape (Chapter 3).

The result from this study directs attention towards marine fish on the shore slope after the sill at Stamnes being an area of predation in the estuary of Vosso. A study by Thorstad et al. (2012b) suggested that 25% of mortality of acoustically tagged smolt could be attributed to predation by marine fish on the shore slope in the river Eira. Similarly Hvidsten and Lund (1988) estimated that cod consumed approximately 20% of smolts released in Orkla. Thus, it seems evident that smolt from the Vosso system can also be targeted by codfish at Stamnes. Observations from snorkeling at Stamnes suggested that a number of cultivated fish had stopped here and were located in the kelp forest along the shore line. These fish would be very susceptible to predation from the aggregations of cod and pollock in this area. Stamnes is most likely the area where smolt first experiences saline water and this behavior may be associated with the smoltification process (Handeland et al., 1996). However, no wild smolt was observed here and it is therefore uncertain whether the observed behavior is an artifact of cultivation.

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Chapter 2

Estuarine migration speed and mortality estimates of Atlantic salmon smolt from the Vosso river based on acoustic transmitters and multiple recaptures in large trap nets.

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Abstract

Migration speed and mortality of cultivated salmon smolt were studied by two methods in the Vosso river system and estuary: (1) Multiple captures of wild and cultivated smolt at four locations using trap-nets during the first 21 km segment of estuarine migration and (2) Surgically implanted acoustic transmitters with an array of acoustic receivers. Mortality estimates suggested that mortality was high during the initial migration through the narrow and long estuary of Bolstadfjorden (4.2 % tag loss × km^{-1}). Highest tag loss was seen from the outer receiver of the estuary to the receivers in the fjord system outside (tag loss 2012 = 52.9 % (9/17) 2013 = 61.9 % (13/21). Only 20 and 12 % of tags were observed outside estuary in 2012 and 2013, respectively. Migration speed estimated from the acoustically tagged fish was significantly higher after fish had left the estuary. A survey using manual tracking after the smolt run in 2013 suggested that mortality was high at the shallow sill separating the estuary from the fjord system outside. Migration speed based on trap nets were lower than from acoustic tags (2012: Trap net Furnes = 1.78 km/day vs acoustic tags = 4.56 km/day, 2013: Trap net Furnes = 0.88 km/day vs acoustic tags = 4.65 km/day). Comparisons of the ratio between wild and cultivated smolts in trap nets suggest that cultivated fish either have a higher mortality or a slower migration through the estuary compared to wild conspecifics. Our results suggest that mortality during estuarine migration is high in the Vosso river, but also that estimates based on cultivated fish, may be overestimated compared to wild fish. We suggest that the high mortality observed in the cultivated fish may be partly explained by a long residence time in the estuary.

Keywords: Salmon, smolt, migration, mortality, recapture estimates, smolt estimates

Introduction

Anadromous migrations of Atlantic salmon smolt from river through estuaries and fjords are generally believed to be associated with high mortality (Dempson et al., 2011; Thorstad et al., 2011a; Thorstad et al., 2011b; Thorstad et al., 2007). Marine survival estimates from cultivated Atlantic salmon smolts released in rivers have proven variable in a variety of systems (Finstad & Jonsson 2001). In the Vosso River, the absence of, or very low numbers of recaptures of cultivated salmon smolts released in the river has raised the concern that conditions in the estuary may cause unnaturally high mortality on migrating wild smolts. As a consequence of the poor recaptures, the cultivated smolts have been towed through the estuary in a perforated, custom made tank and released in the outer fjords up to 100 km from the river mouth. This method has clearly demonstrated that fish released in the outer fjord system have much higher marine survival (3.8 times) than fish released in the river (Barlaup et al., 2013). This pattern of low survival from cultivated fish released in rivers is however not exceptional to the Vosso River (Kallio-Nyberg et al., 2011; Skilbrei et al., 2013).

Mortality estimates for Atlantic salmon smolt based on surgically implanted acoustic transmitters range from 0.6 to 36 % km^{-1} (meidan = 6% km^{-1}) during estuarine migration (Thorstad et al., 2012a). Elevated mortality is often seen in river outlets (Hvidsten and Lund, 1988), which are also areas associated with higher densities of piscivores such a large fish or birds. For example, Thorstad et al. (2012b) estimated that predation from cod (*Gadus morhua*) in the river outlet of the river Eira could amount to at least 25% of the smolt run. In addition to the high likelihood of encountering predators during their migration, smolts face physiological challenges associated with adapting to a marine environment (Strand et al., 2011; Strand and Finstad, 2007). This also increases their susceptibility to predation (Handeland et al., 1996).

As mortality from predation on migrating smolts is likely to be density-independent (or negatively density-dependent), variation in such mortality will directly affect spawning stock variation, and have therefore important management implications. Therefore, correct estimation of mortality during estuarine migration is important as it lays the foundation of how to weight impacts from other mortality factors such as salmon lice (Krkosek et al., 2013) or marine survival (Friedland et al., 1993; Peyronnet et al., 2008). We used two approaches to study the migration and mortality of smolts throughout the estuary of the Vosso river. Our main goals were (1) to assess where in the Vosso system cultivated smolt disappeared during early estuarine migration and to quantify their migration speed through the estuary, (2) compare the migration through the estuary between wild and cultivated fish using a non-invasive method (i.e., multiple recaptures in large trap nets) and (3) estimate the smolt production from the Vosso River based on a two-site mark-recapture experiment.

Material and Methods

Production of cultivated smolts was done in Lake Evanger in a custom made small net-pen. This method allows for production of 1-year old smolt which grows to an average size of ca 12-14 cm before release in mid or late May.

Acoustic tagging of cultivated smolt

A system of acoustic transmitters and receivers widely applied to study the smolt migration and mortality patterns was used (www.vemco.com). V7 tags were surgically implanted into the abdomen of the smolt. Due to concerns with performance issues of fish with the acoustic tags, we selected larger individuals in hopes of limiting the effects of the acoustic tag. The fish were anesthetized with a combination of Benzocaine and MS222 in 2012 and with 2-phenoxyethanl in 2013 before surgery. A small ventral incision was made to place the tag into the body cavity of the fish, and the wound was closed with surgical glue (only suture applied in 2013). Water was drizzled across the gills during surgery. Fish were then released in a holding pen to recover before being released. The study was approved by the National Animal Welfare Committee (FOTS, id 5185). Forty fish were tagged and released in 2012 and 50 fish were tagged and released in 2013. In both years, fish were released together with a large group of cultivated fish (30 000). The size of the tagged cultivated smolts ranged from 16.2 – 17.9 cm (average: 16.8 cm, SD: 0.39) which was larger than the average size of cultivated smolts released. There were no differences in size of tagged fish in 2012 (avg. 16.9) and 2013 (avg. 16.8).

Smolt movement was monitored using acoustic receivers (VEMCO VR2W) placed throughout the inner and outer estuary to follow the release of cultivated smolts from May to July of the study years (Fig. 1 and 2). Due to the frequency of detection of an individual smolt when within range of a receiver (one recording at 90 second intervals), we trimmed each registration at a receiver site to a single occurrence. This facilitated data processing. As a surrogate for mortality, we calculated the detection efficiency of each receiver based on the presence of each smolt through time at each receiver. Mortality was not corrected for by removing individuals that were potentially eaten by predators, as we had no objective method of identifying individuals as eaten.

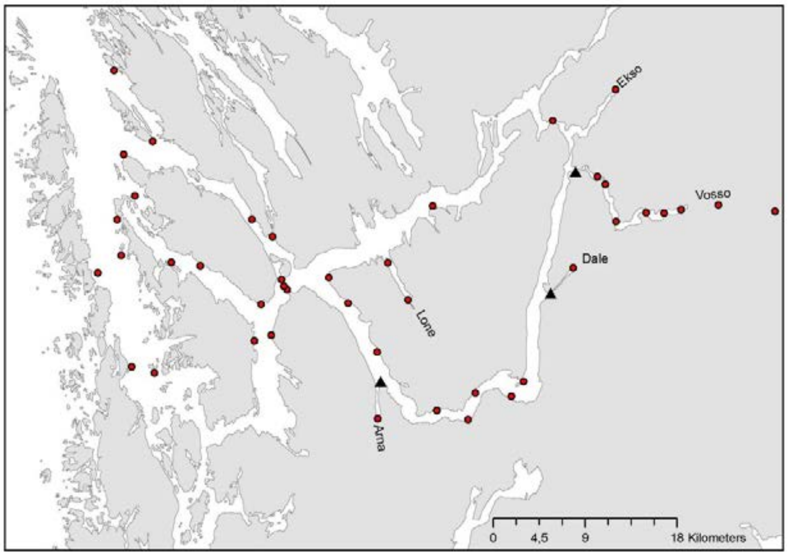

Figure 1 Map of placement of receivers during 1. April to 1. July 2012. Red circles and black triangles indicate receiver locations. Black triangles indicates receiver location defined as the outer part of the estuary.

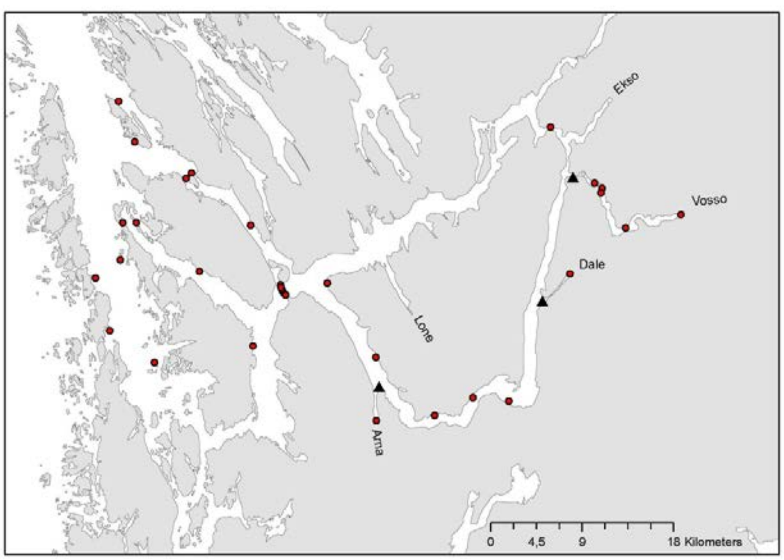

Figure 2 Map of placement of receivers during 1. April to 1. July 2013. Red circles and black triangles indicate receiver locations. Black triangles indicates receiver location defined as the outer part of the estuary.

After the smolt run in 2013 a VR100 detector (manual tracking - Vemco) was used to locate tags still remaining in the estuary. This was repeated three times during a 5-week period to be able to verify whether the tags were moving or laying still on the bottom. All tags registered were found to not move and the corresponding smolts to the tags were defined as deceased.

Multiple captures of wild and cultivated smolt

A network of four large custom made trap nets was placed along the estuary up to 21 km from the release site in Lake Evanger in 2012. The trap nets allowed the fish to be caught unharmed in most cases, which made it easy to identify the cultivated fish and wild fish and release adults unharmed (Barlaup et al., 2013). The downside of catching live fish is the potential predation within the trap chamber. This made it essential to check the trap nets daily. The design of the trap nets was as explained in Barlaup et al. (2013), however, the trap net at Furnes was modified to10 meters deep rather than 5 meter as in the original design. In addition, a smolt screw was installed in the river. However, the smolt screw was not operational during days of high floods, and was therefore not used in the analysis of migration speed and relative numbers of wild versus cultivated fish (see below).

Two large releases of cultivated fish were done at two different dates during the experimental period both in 2012 and 2013. First, three groups of 5000 smolt tagged with Coded Wire Tags (hereafter denoted CWT; Table 1) were released at three locations along the river and estuarine system on the 15th of May. One release was at the outlet of lake Evanger, one at Straume, and another at Stamnes (Fig. 3). A week later, on the 21st of May, a group of 30 000 was released including a group of 5000 CWT marked fish at the outlet of lake Evanger. All released smolts, both with and without CWT-tags, were tagged by clipping of the adipose fin.

Table 1. Release of cultivated smolt in Bolstadfjorden in 2012 and 2013 (same release groups and dates).

Sites	**First release 15th May**	**Second release 21th May**
1 Outlet Lake Evanger	5000 CWT	5000 CWT+ 25000
2 Straume	5000 CWT	
3 Stamnes	5000 CWT	

The experimental setup of these releases was designed to study the effects on marine survival of release site and density. However, the final results from the recaptures will not be available until 2016 when the fish have been at sea for three winters and are available for recapture. Therefore, for the purpose of this report, we focused on the large release of 30 000 smolts.

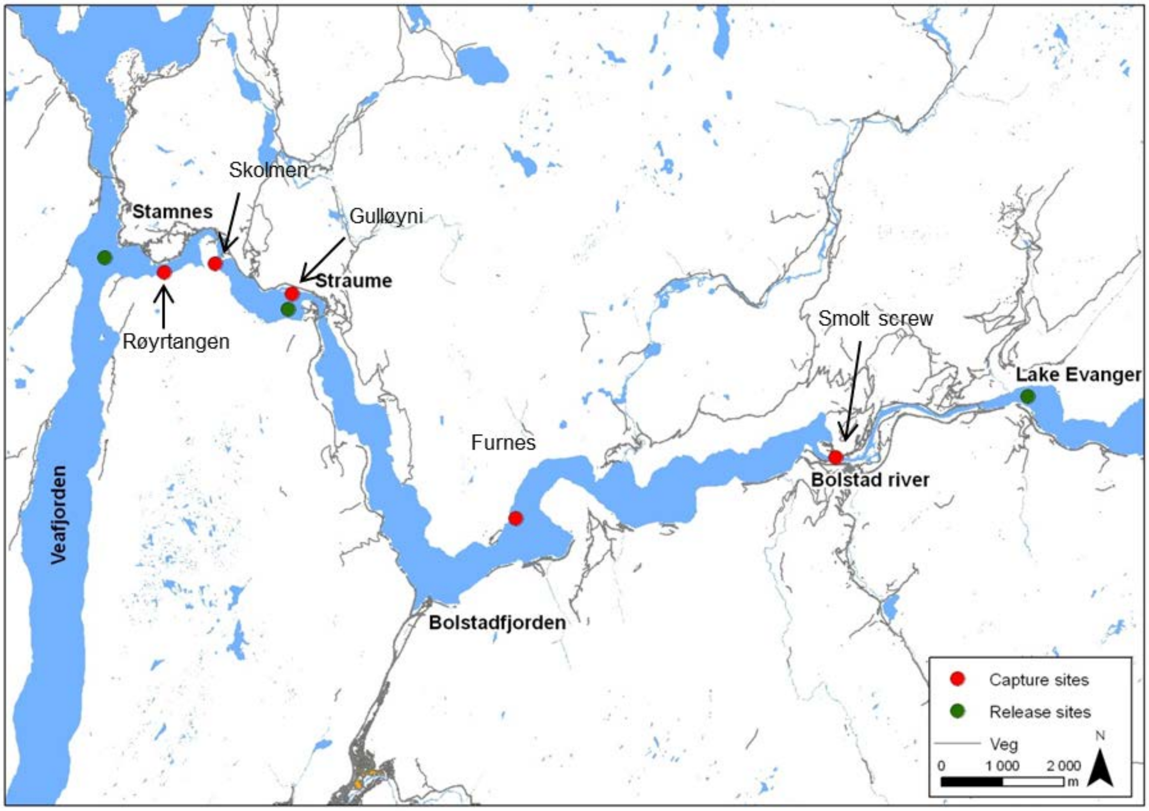

Figure 3 Map of Bolstadfjorden with release sites and capture sites. Trap nets were used in the fjord at Furnes, Gulløyni, Skolmen and Røyrtangen, whereas a smolt screw was used in the Bolstad river.

Data analysis

All analysis was done in R v. 2.15.3.

Potential mortality and migration speed estimates based on acoustically tagged fish

The following equation was used to calculate smolt migration speed between sites based on the last registration from the closest receiver till the first registration on the next receiver:

$$Speed = \frac{d_{ij}}{t_i - t_j}$$

where d_{ij} is the sea distance between receivers$_{ij}$ and t_i is the initial time at receiver$_i$ and t_j was the time at receiver$_j$. Distance was determined using a cost distance analysis in ArcGIS (version 10.1).

Smolts speeds were divided into three groups. Speeds for the first group were based on all smolts that failed to be detected outside Bolstadfjorden (Table 2.A). For all individuals that were detected outside Bolstadfjorden, we calculated the speed within Bolstadfjorden (Table 2.B) and speeds outside Bolstadfjorden (Table 2.C). We used a mixed model to account for the repeated observations for receiver, year, and individual (Pinheiro et al. 2013 – R package). We used a three-way ANOVA to test between the fixed effects of group while controlling for individual length. A Tukey's HSD test was performed to determine significance between the three categories of cultivated smolt migration speeds and significance was determined at $\alpha = 0.05$.

Migration estimates from captures in trap nets

Migration speed was estimated by recaptures of cultivated fish in the four trap nets along the estuarine migration route. Distribution of catches in the trap net was fitted to the inverse Gaussian distribution as suggested by Zabel and Anderson (1997) as follows:

$$g(t) = \frac{L}{2\pi\sigma^2 t^3} exp\left(\frac{-(L-rt)^2}{2\sigma^2 t}\right)$$

were, t is time in days, L is distance from release point to recapture site, r determines the average rate of downstream movement and σ (or sigma) determines the rate of population spreading. The maximum likelihood estimator (MLE) of for the two parameters r and σ (or sigma) is

$$\hat{r} = \frac{L}{\bar{t}}$$

and

$$\hat{\sigma} = L\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{t_i} - \frac{1}{\bar{t}}\right)}$$

were t_i is the capture day of the *i*th individual, t the average travel time of the recaptures and N is the number of recaptured individuals.

Ratio of cultivated versus wild fish.

The ratio of cultivated versus wild fish in the four trap nets was compared between traps by taking the ratio between the two groups during the peak of catches of cultivated fish the first few days after release. Since the variance estimate increased with distance from release point (i.e. σ (or sigma)), the period of comparison was defined as between when 10 and 80% of all the fish in each trap nets had been caught. This was after 5 days at Furnes (in mid-Bolstadfjorden) and 8 days at Røyrtangen (at Stamnes). A contingency table was used to test the ratio between the first trap net at Furnes and the three other trap nets (Gulløyni, Skolmen, Røyrtangen). To correct for multiple tests a Bonferroni corrections was applied to the p-value (p/3= 0.017).

Results

Water discharge

In Figure 4 the water discharge during the two seasons 2012 and 2013 from 1. April to 31. June is shown.

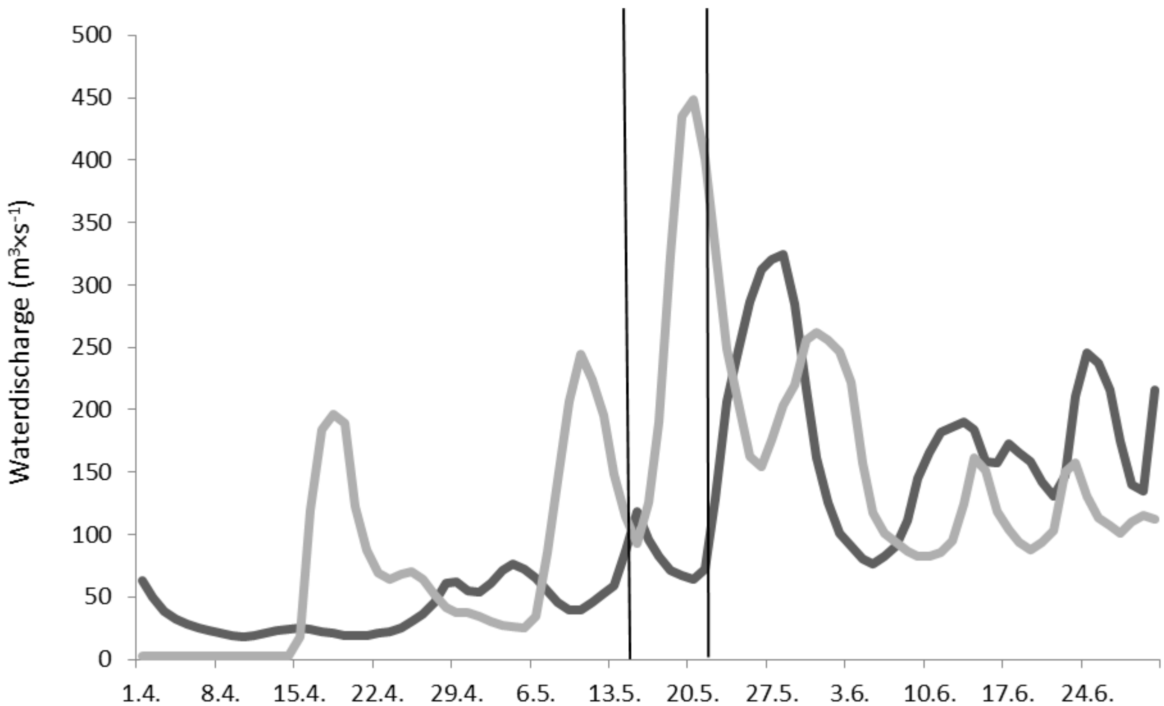

Figure 4 Water discharge in 2012 (dark grey) and in 2013 (light grey). Vertical lines show the dates when the cultivated smolt were released.

Acoustically tagged cultivated smolt

Through Bolstadfjorden, we observed an average of 4.2% mortality × km^{-1} decrease in detection efficiency from (Fig. 5 & 6). 42.5 (17/40) and 40 % (20/50) of the tags were detected at Stamnes (outer most receiver in Bolstadfjorden) in 2012 and 2013. 10% (4/10) and 4% (2/50) of the tags were registered at Nordhordalandsbrua, a pontoon bridge separating inner and outer fjord. The highest tag loss for both years was observed between Stamnes and the receivers in the fjord system outside (tag loss rate 2012 = 52.9 % (9/17) 2013 = 61.9 % (13/21)).

By comparing the speed of cultivated smolts within Bolstadfjorden and outside Boldstadfjorden, we concluded that cultivated smolt speeds significantly increased their speed after leaving the estuary (8.03 km/day vs 17.43 km/day, *z-value* = 4.02, n = 69, p < 0.001; Fig. 7 and Table 2). Furthermore, when we compared the speed of individuals that successfully navigated Bolstadfjorden vs. those that did not, migratory speed was lower but not significantly different (4.71 km/day vs 8.03 km/day, *z-value* = 1.615, n = 69, p = 0.226; Fig. 7 and Table 2). Effect of length on swimming speed was also significant (f-value = 9.17, n = 69, p<0.01). It is also important to note that a significant amount of variation was seen between years for treatment groups A and C (Table 2). This may be attributed to fluctuations in discharge or other physical aspects like temperature, however, we were unable to control for such confounding variables with the current scope of this study.

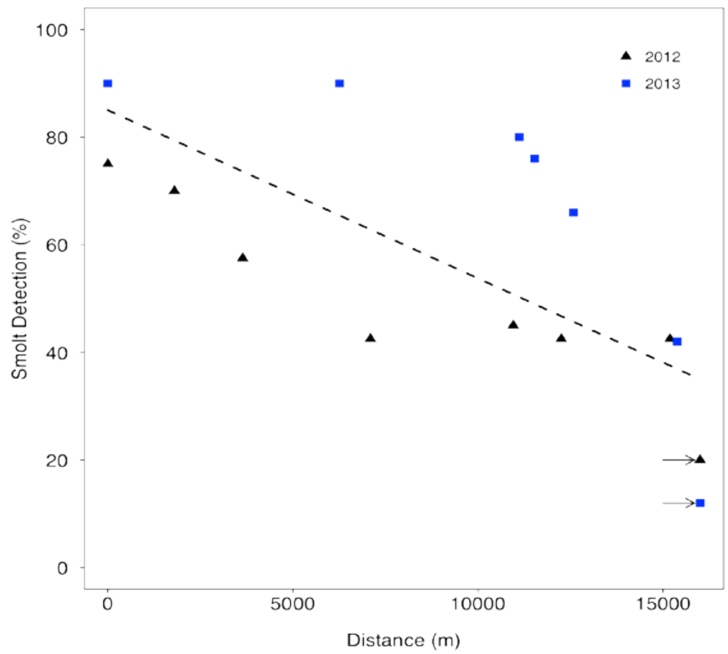

Figure 5 Detection efficiency of cultivated smolts through Bolstadfjorden. Triangles were observations from 2012, and squares were observations from 2013. Arrows indicate the detection efficiency on receivers following Stamnes.Dashed line indicates a mortality rate of 4.2 % mortality × km^{-1}.

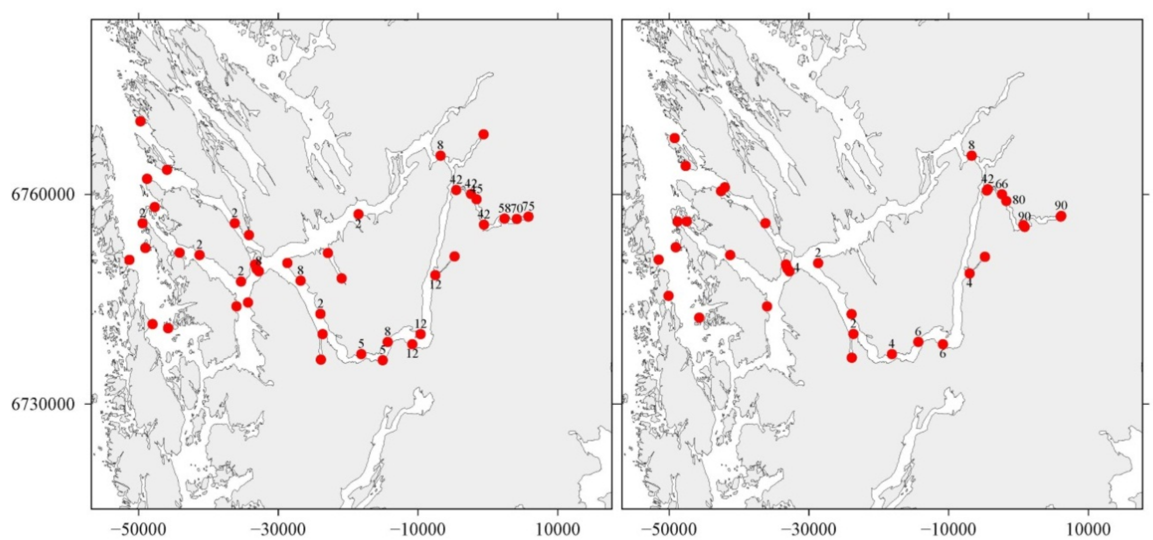

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Figure 6 Detection efficiency of cultivated tagged cultivated smolts from 2012 (left) and 2013 (right). Red circles are receiver locations with percent of tagged fish detected at the receiver location indicated. Number of tagged smolts was 40 and 50 in 2012 and 2013, respectively.

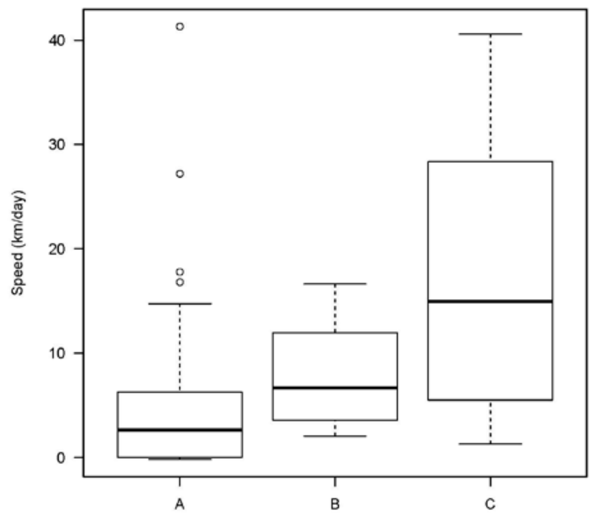

Figure 7 Migration speed of cultivated smolts. “A” represents smolts that were only detected within Bolstadfjorden, B represents migration speeds of smolts within Bolstadfjorden that were also present outside Bolstadfjorden, and C are the speeds of smolts outside Boldstadfjorden. Solid lines indicate the median speed, boxes represent the interquantile range (IQR) where 50% of the observations were observed, whiskers are 1.5 times the IQR, and circles represent outliers.

Table 2 Mean speed (km/day) and standard deviation (in parenthesis) of smolts for individuals only detected in Bolstadfjorden (A), migration speeds of smolts within Bolstadfjorden that were also present outside Bolstadfjorden (B), speeds of smolts outside Boldstadfjorden (C), and all smolts (total) for year and group.

mean (sd)	A	B	C	Total
2012	3.39 (6.32)	7.14 (6.52)	28.99 (8.61)	7.90 (11.29)
2013	5.60 (7.28)	8.79 (4.74)	7.53 (5.83)	6.27 (6.84)
Total	4.71 (6.94)	8.03 (5.45)	17.43 (13.12)	6.95 (8.96)

Results from Manual tracking in 2013 (VR100)

A total of 21 of 50 tags were found in the estuary of Vosso from Bolstad to Stamnes. All individuals were found to be dead since no tags were found to move during a period of five weeks (three rounds of registration). An aggregation of tags (13) was found from Straume to Stamnes with five tags being identified on the shore slope of Stamnes (Fig. 8).

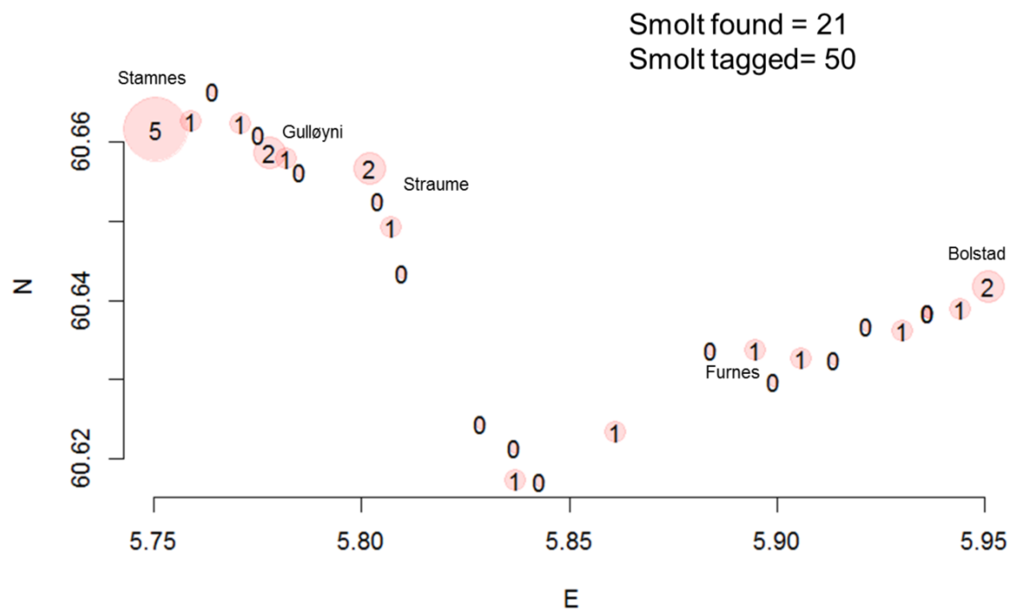

Figure 8 Results from manual tracking of tags after the smoltrun in 2013 from the river outlet (Bolstad) to the outer part of the estuary (Stamnes). All tags was defined as dead. Each circle represents a listening location along the estuary.

Release and multiple recaptures of cultivated smolt

The catches in the trap nets reflected a wave of fish migrating downstream and outwards through the estuary the first day after release of the large group consisting of 30 000 cultivated smolts on May 21st. In 2012 the release was conducted on a date when water discharge increased dramatically (Fig. 4). This probably led to a more synchronous migration of cultivated and wild smolts (Fig. 9). In 2012, catches were highest in Furnes (N= 393) and lowest at Skolmen (N = 121). Catches was similar at Furnes in 2012 (N = 393) and 2013 (N = 323). The estimated migration speed varied from 1.78 km/day at Furnes to 4.30 km/day at Gulløyni in 2012. In 2013 a similar trend of a wave of fish appearing the first few days was observed in the Furnes trap (only one trap in 2013). However, the tail of the distribution was longer and the estimated migration speed was slower (0.88 km/day; Fig. 10 & 11). In 2012 37 % of the smolts were caught later than 4 days after release compared to 64% in 2013. At Røyrtangen (Stamnes) in 2012 62 % was caught later than 4 days after release.

Comparison of detections of acoustically tagged fish and trap net catches

To evaluate whether re-occurring detections of acoustically tagged fish (i.e. individuals that reappeared on a receiver location more than once) was smolt or fish predators with smolts in their stomachs, the distribution in the trapnets and the nearest receiver location at Furnes/Trollkona and Stames/Røyrtangen was compared. At Furnes/Trollkona the distribution of detections was more similar to trap net catches when re-occurring detections were plotted (Fig. 12 A & C) compared to when only first occurrence detections were plotted (Fig. 12 B & D), indicating that the re-occurring detections at Furnes could be smolts. At Stamnes/Røyrtangen the distribution was more similar when re-occurring detections were removed (Fig. 12 E & F), which may indicate that re-occurring detections were predated fish. In general, the migration speed from the acoustically tagged smolts, which were based on only first detections, were higher compared to fish caught in trap nets (2012: Trap net Furnes = 1.78 km/day vs acoustic tags = 4.56 km/day, 2013: Trap net Furnes = 0.88 km/day vs acoustic tags = 4.65 km/day). This indicates either that the tagged fish migrated faster or inherent sampling limitations make it difficult to accurately determine migration speeds. For instance, the resolution with acoustic data is far better when estimating migration speeds because we are able to determine precise time metrics. Whereas, individuals caught in trap nets can remain captured for several hours to a day prior to observation thereby reducing their estimated migration speed. In addition, in trap nets we cannot control for multiple recaptures. Results indicate that a proportion of the fish remains in the Bolstadfjord for a long time before leaving, which may lead to multiple recaptures.

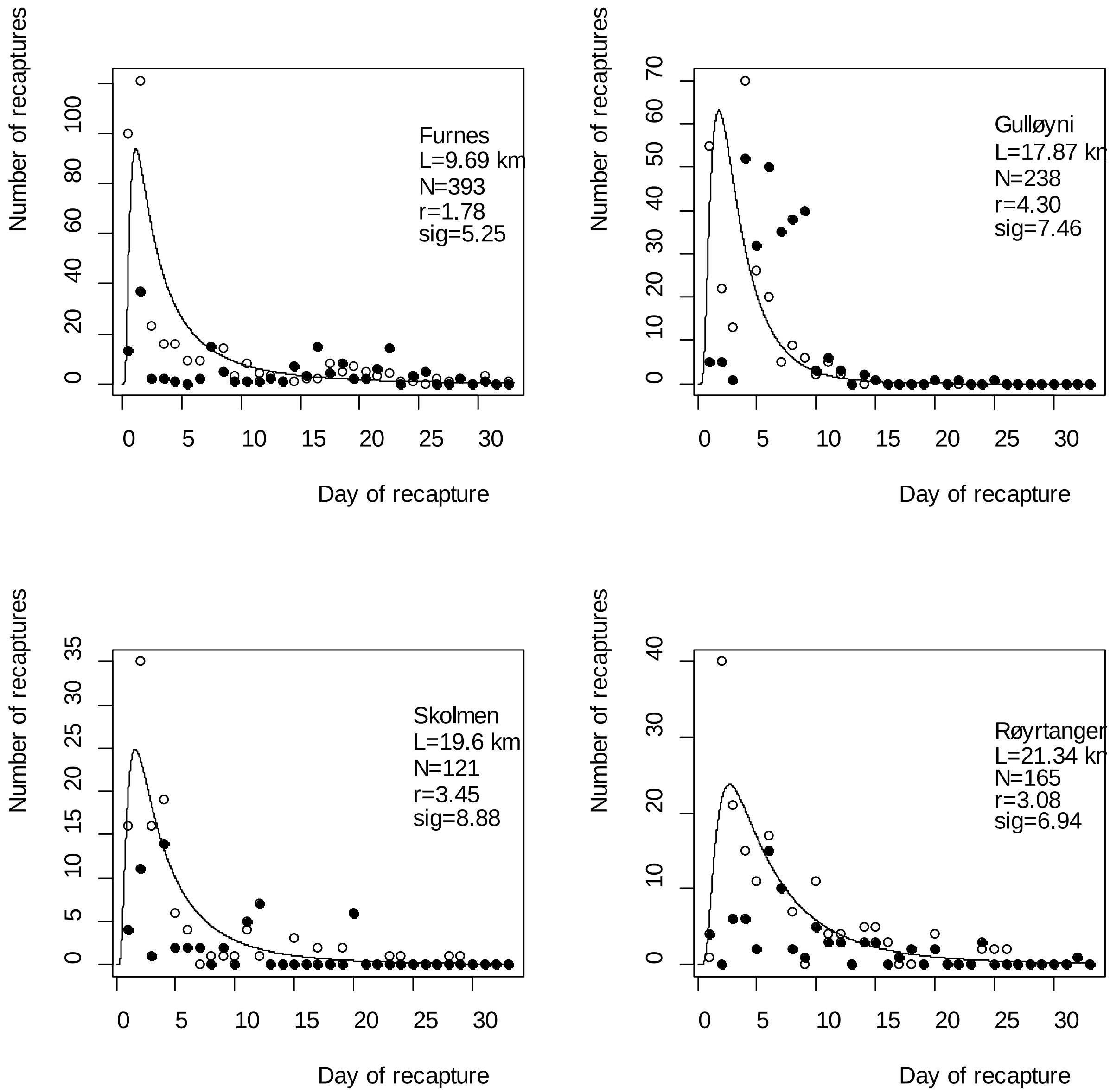

Figure 9 Number of recaptures at days after release for the four trap nets stations in 2012. L indicates length from release site to trap net station, N indicates total number of recaptures, r indicates estimated speed (km/day) and sig indicates σ estimates of the distribution as suggested by Zabel and Anderson (1997). For comparisons both cultivated (open circles) and wild fish (solid circles) are plotted. However, estimates are based solely on cultivated fish. Solid line is the density distribution multiplied by N.

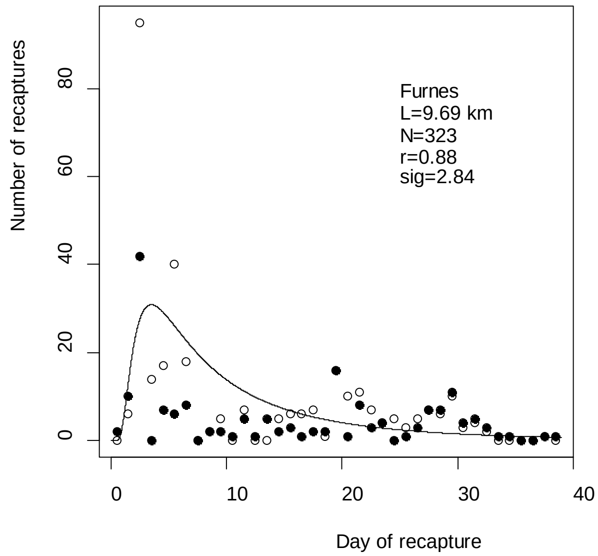

Figure 10 Number of recaptures at days after release for the trapnet station at Furnes in 2013. L indicates length from release site to trapnet station, N indicates total number of recaptures, r indicates estimated speed (km/day) and sig indicates σ estimates of the distribution as suggested by Zabel and Anderson (1997). For comparisons both cultivated (open circles) and wild fish (solid circles) are plotted. However, estimates are based solely on cultivated fish. Solid line is the density distribution multiplied by N.

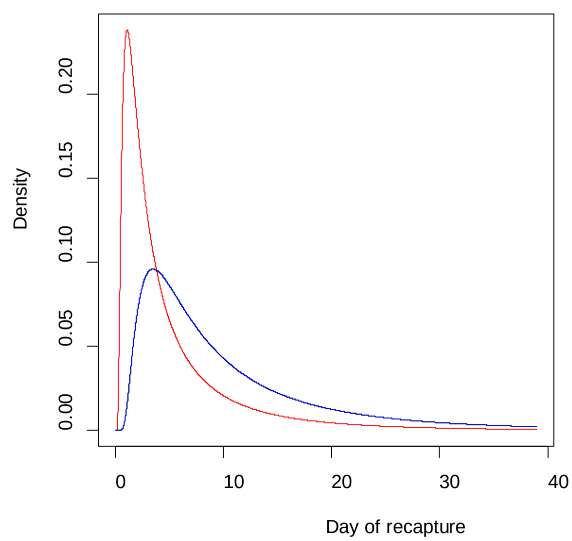

Figure 11 Density distribution of inverse gaussian fits to recaptures at Furnes in 2012 (red) and 2013 (blue) of cultivated fish.

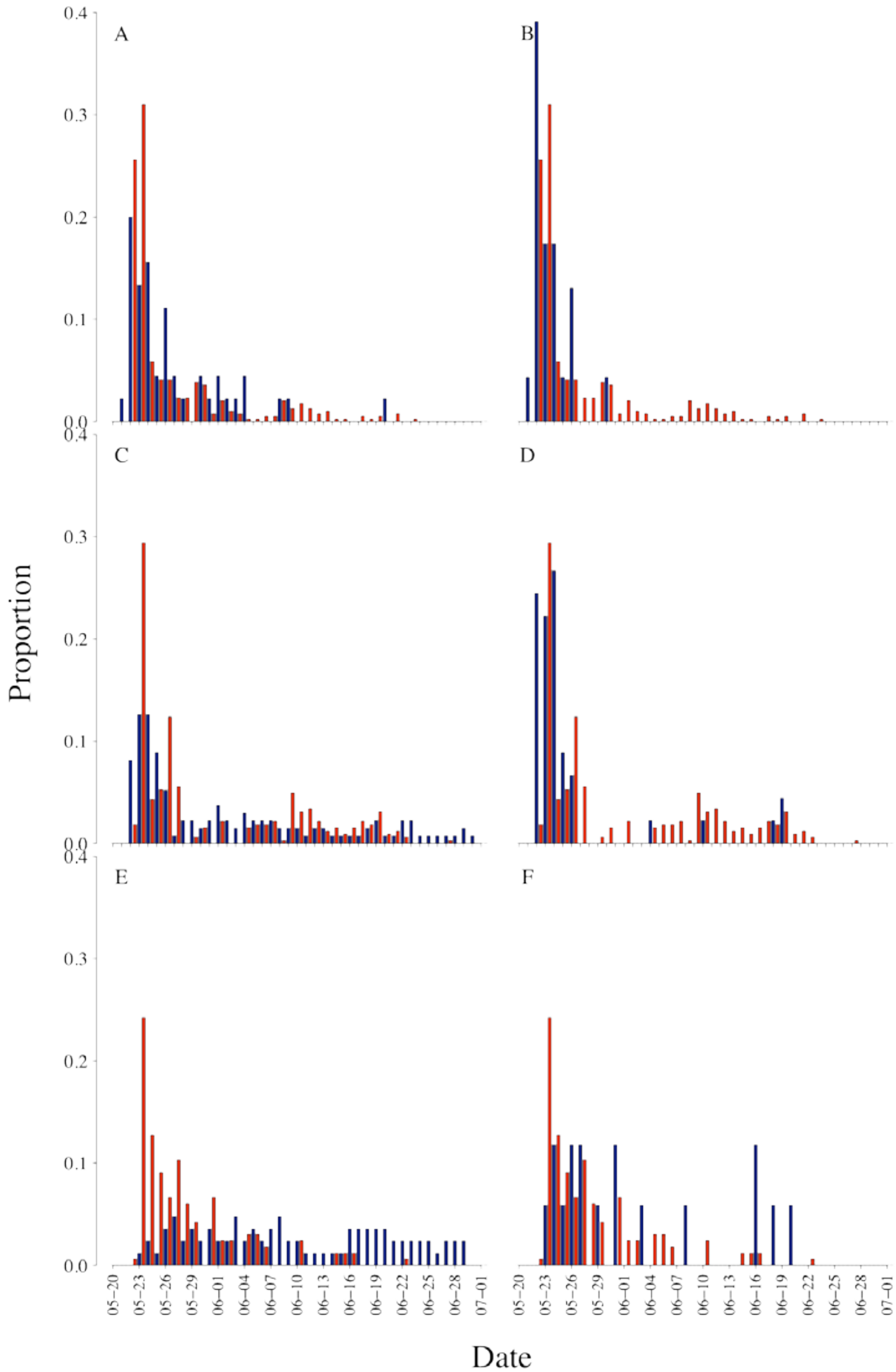

Figure 12 Timing of cultivated smolt migration to Trollkona (A-B 2012; C-D 2013) and Stamnes (E-F 2012) for acoustically tagged (blue bars) and cultivated smolts (red bars) between 20 May and 1 July. Graphs A, C, and E include individuals with multiple recordings and graphs B, D, and F exclude individuals with multiple recordings at each site.

Ratio of wild vs cultivated fish

There were significantly less cultivated versus wild fish in the trap at Gulløyni versus Furnes (χ^2_1= 23.3, p<0.017), Skolmen versus Furnes (χ^2_1= 4.3, p<0.017) and Røyrtangen versus Furnes (χ^2_1= 4.7, p<0.017). The ratio of cultivated fish was highest at Furnes and lowest at Gulløyni (Fig. 13).

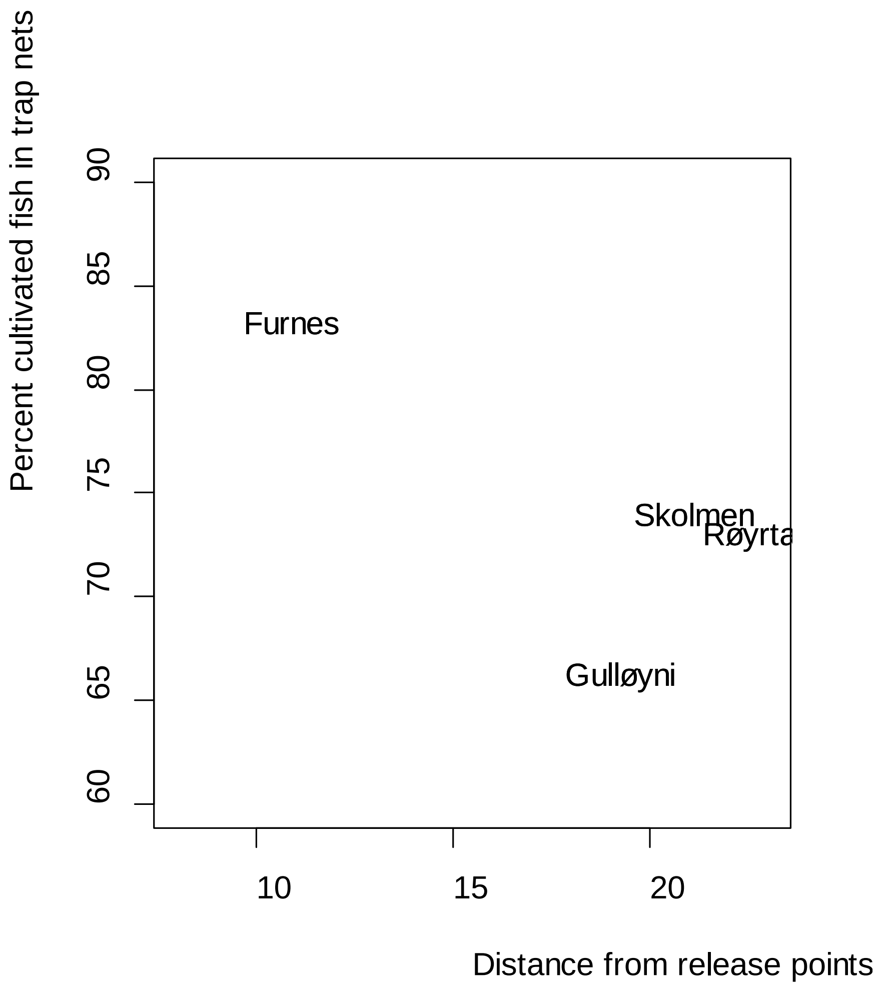

Figure 13 Proportion of cultivated vs.wild smolt recorded in the successive trap nets from Furnes to Stamnes (Røyrtangen).

Population estimates based on two-site mark-recapture experiment.

The results of the Peterson abundance estimate for smolts conducted in 2013 indicated that approximately 38 721 (CI ± 30 626) smolts migrated from the Vosso River. Moreover, we were able to estimate wild smolt abundances (i.e., fish produced in river either from egg planting or natural spawning) at 11 859 (CI ± 11 435) and cultivated smolts at 21 217 (CI ± 20 541).

Discussion

Our data suggests a high mortality of cultivated tagged smolts during the migration through the estuary in both 2012 and 2013. The mortality rate estimated from tag loss (% mortality × km^{-1} = 4.2) is similar to estimates from other studies (Thorstad et al. 2012). However, there seemed to be an elevated tag loss between locations at Stamnes to locations in the Osterfjord (i.e. from the sill separating the inner estuary and the fjord). This was evident both in 2012 and 2013. This could be a function of the low detection efficiency in Osterfjord due to insufficient numbers of receivers across the fjord at all locations. However, when a fish was detected in the Osterfjord it was registered on multiple receivers indicating that we did register most fish outside Stamnes. Also, an array of receivers across Nordhordalandsbroen (a pontoon bridge ~50 km from Stamnes) had sufficient range to detect passing smolts and detected the same smolts as further in. Detections of tags registered as mortalities using manual tracking in 2013 (VR100) also pointed to the sill separating the inner estuary and the Ostefjord as the main area of mortality. More specifically five tags were found on the shore slope at the end of the sill at Stamnes. This is an area with high aggregations of cod, and where stomach samples have confirmed that these cod eat smolt (Chapter 1). Other studies confirm that cod can predate on a large proportion of the smolt during estuarine migration (Hvidsten and Lund, 1988; Thorstad et al., 2012b).

In 2012, an increased tag loss was also observed in the area between the river outlet and the first receiver downstream. This area is not associated with large abundances of marine fish as the low salinity results in suboptimal habitat conditions. Sampling in this area suggests that trout is the primary predator; however no large aggregations of fish have been observed here (see Chapter 1 for details). Even so, it still seems likely that predation from trout is responsible for a proportion of the mortality in this area as acoustically tagged brown trout have been shown to aggregate at the in areas were smolts disappear (see Chapter 3 for details).

In 2012, the ratio of cultivated to wild fish was higher at Furnes compared to the traps located between Straume and Stamnes (Gulløyni, Skolmen, Røyrtangen). These results indicate that wild fish either migrate faster through the estuary or are less targeted by predators during migration. However, these estimates must be treated with caution as times of migration of wild fish are not known.

Estimates of migration speed of cultivated fish from both acoustic tags and trap nets were low compared to other systems.. This could be explained by either (1) predators that eat smolt do not have a directional movement and will be registered as moving slowly between receivers or (2) a large proportion of the smolt remain in the river or estuary for long period after their release. Results from trap net catches suggest that a large proportion of fish did remain in the river and estuary after release without being consumed. Furthermore, during night time snorkeling surveys in Bolstadfjorden, large numbers (> 200) of cultivated smolts were observed along the shore. Similarly, at Stamnes cultivated smolts were observed hidden in the kelp forest. At both locations the cultivated smolts totally dominated and wild smolts were not observed. The observations were done during the first week after the release of the 30 000 smolts at the 21th May in 2012. Results from Chapter 3 indicates that smolt-sized fish on the echograms were not moving directionally during the release of 30 000 cultivated smolt, suggesting a lack of seaward migration of salmon smolt in Bolstadfjorden.

Stamnes is the first location where smolts experience increased salinity and the observed behavior of cultivated smolts could be a physiological trait which allows them to adapt to sea water. For instance, Strand et al. (2011) demonstrated that released groups of cultivated fish would reside longer in the lower part of the river and delay sea entry if the group on average had a low NA+,K+-ATPase activity. Handeland et al. (1996) demonstrated experimentally that there was a relationship between predator avoidance and osmotic stress. This could potentially explain the increased predation at Stamnes.

Studies on released groups of smolts generally conclude that survival is lower in cultivated versus wild conspecifics (Jonsson et al., 1991). For example, Kallio-Nyberg et al. (2011) estimated that for similarly sized wild and cultivated fish the survival of wild fish was 18 times higher than cultivated fish in the Simjoki River. In general, however these studies do not focus on where this difference in mortality takes place. Our study suggests that the difference between the two groups may already be apparent after their initial migration through the estuary. A possible explanation for the difference between the cultivated and wild fish may be their physiological state. While the cultivated fish in the Vosso river are thought to have the correct NA+,K+-ATPase activity, other physiological variables may deviate from the wild fish. For example, Vainikka et al. (2012) demonstrated that the migration behavior in Atlantic salmon smolt was more directional and faster in fish with restricted food rations prior to release.

The wild smolt run estimates based on a two site mark-recapture experiment suggested a low smolt run of wild fish. However, we also underestimated the number of cultivated smolts within the system where we had a known release of 30 000 smolts. This could indicate that we also may have underestimated wild smolt abundances. Furthermore, we had high confidence intervals around our estimates and perhaps with greater trap efficiencies we may have been able to obtain better estimates of abundance. Future work should focus on obtaining more precise abundance estimates in order to identify the yearly variation associated with smolt migrations, allowing appropriate management actions to be taken, based on future more precise estimates.

Increasing the understanding of how individuals cope with environmental challenges relative to their predispositions is especially important when data from maladapted or multiple stressed individuals are used to infer patterns of survival in wild populations. In some cases such mortality estimates can draw attention from other equally important threats when managing fish stocks because they suggests a doom and gloom situation. Efforts must therefore be made not to focus solely on data based on cultivated or handled fish, but also on captures or observations of wild fish when possible.

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Chapter 3

Estuarine habitat use of brown trout (Salmo trutta) and its potential overlap with and predation on Atlantic salmon smolt.

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Abstract

Acoustically tagged sea trout (37.5-84 cm) were tagged with acoustic transmitters and followed during two years to analyze the habitat use and potential predation of salmon smolt in the three estuaries Bolstadfjorden (estuary of Vosso), Dalevågen (estuary of Dale) and Arnavågen (estuary of Arna) during the smolt run of Atlantic salmon. The main goal of the study was to evaluate how large a proportion of the trout caught in the estuary remained during the smolt run and if the habitat use of trout overlapped with the loss of acoustically tagged salmon smolt, inferring acts of predation. In 2012 48.2 % (20 of 39) of the fish tagged in Bolstad remained in the estuary during the smolt run, compared to 9.1 % (1 of 11) and 90% (9 of 10) of the fish in Arna and Dale, respectively. Fish with a lower condition and tagged early in the season migrated further than fish with a higher condition and fish tagged later in the season. There seemed to be a pattern of tag loss in the same area where there was an aggregation of sea trout in both 2012 and 2013.

Key words: Anadromous brown trout, acoustic tags, vemco, habitat use, estuary

Introduction

In the period from 2000 to present there been a joint research effort to identify the causes of the collapse Vosso River salmon, and to discover why the population has failed to recover (Barlaup et al. 2013). One of results from the project is that low returns of spawners are due to by exceptionally high mortality of smolts/post smolts during the early marine migration period. Of a total of 110 000 smolt of hatchery origin released in river the period 2000-2011, only six have been recaptured as returning adults. Whereas some sources of mortality have been identified (Vollset et al. 2014), and other potential causes have been substantiated (see Barlaup et al. 2013), it has proven difficult to identify what the most important sources of mortality are, and where most mortality occurs. Results from acoustically tagged smolt have demonstrated a low survival of cultivated smolt during early marine migration, particularly in the estuary where River Bolstadelva enters the Bolstadfjord (see Chapter 2). Earlier studies using acoustically tagged smolt report that a number of tags appeared to show abnormal movement patterns and have suggested that these smolt had been eaten by a predatory brown trout (pers. comm. J.C. Holst). Smolt predation of trout has also been confirmed by stomach analysis of trout sampled in the estuary during the smolt migration period. Based on these observations, a hypothesis was proposed that the high mortality of out-migrating smolt was caused by brown trout predation in the Bolstadfjord estuary.

Trout are known to be an efficient generalist predator (Knutsen et al., 2004). This, in combination with flexibility in life-history strategy (Jonsson, 1985), potentially makes it an important predator on smolt. The smolt run occurs over a relatively short period of time during May, and may present a localized opportunity for sea trout to capitalize on an abundant and vulnerable prey item. The magnitude of predation rates and the impacts of estuarine predation by trout on salmon smolt are not known.

In this study we acoustically tagged trout that potentially could prey on Atlantic salmon smolt (trout >35 cm) in Bolstadfjorden during the smolt run and followed them for two consecutive years. The main goal of this study was two-fold: firstly, since trout are known to be highly mobile we sought to investigate the habitat use of the trout that were caught in three estuaries (Bolstadfjorden, Dalevågen and Arna) during the smolt runs (i.e. if they would remain in the estuary or migrate to sea). Secondly, to compare the spatial distribution of trout that remained in the estuary with the loss of acoustically tagged smolt, to evaluate whether predation by sea trout could explain this tag loss.

Material and methods

Trout above 35 cm (size range: 37.5-84 cm) were captured and tagged with acoustic transmitters in 5 estuaries: 39 in Vosso (Bolstad), 10 in Dale, 11 in Arna, 2 in Lone and 1 in Ekso (Table 1).

Table 1 List of number of transmitters implanted in trout and at different release sites. Detection efficiency indicates percent of tagged fish detected in the period april-june for 2012 and 2013.

Capture site	V13	VP13	Detection Efficiency 2012 (%)	Detection Efficiency 2013 (%)
Bolstad	**31**	**8**	**95 (n = 37)**	**67 (n = 26)**
Dale	**8**	**2**	**100 (n = 10)**	**40 (n = 4)**
Ekso	**1**	**0**	**100 (n = 1)**	**NA**
Lonevåg	**2**	**0**	**100 (n = 2)**	**NA**
Arna	**9**	**2**	**91 (n = 11)**	**36 (n= 4)**

Catching and handling of fish

Trout were caught either by sport fishing equipment (trolling or flyfishing), by local fishermen. The fishermen were instructed to handle the fish carefully and place them in large keep-nets, were they would stay for a maximum of 2 days before tagging. In Bolstad fish were caught with a large modified trap net at Furnes (see chapter 1 & 2 for details).

Tag specifications

We used coded pingers/transmitters that were surgically implanted into the sea trout (www.vemco.no). These were automatically registered at receivers, anchored with buoys in a grid in Bolstadfjorden (Fig. 1 & 2). Two types of transmitters were used: V13 and VP13 (Table 2). V13-type only transmits an ID when passing a receiver buoy. The VP13 transmitter also registers and transmits depth information. The surgery and treatment of sea-trout was approved by the National Animal Research Authority (ID 4141). In this study the results from the depth sensors are not included.

Table 2 Tag specifications from VEMCO

Tag Family	Diameter	Minimum Size: Length (mm), Weight in Air (g)	Maximum Size: Length (mm), Weight in Air (g)	Power Output (dB)	Sensors: T-Temp P-Pressure (depth)	Battery Life Example (Sensors: None) (Delay: 90 secs)
V13	13 mm	36 mm, 11 g	45 mm, 12.3 g	147-158	None	900 days
V13P	13 mm	36 mm, 11 g	45 mm, 12.3 g	147-158	P	685 days

Surgery

Fish were anesthetized with a combination of MS222 and Benzocaine. The fish were then placed in a stable position on top of a wet cloth. Water was drizzled across the eyes and gills to keep them from drying out. Length and weight were measured while the fish was anesthetized. A small incision was made in the lower part of the body cavity carefully avoiding puncture of any internal organs. The tag was rinsed in alcohol, disinfected water, and an antibacterial solution before insertion through the incision. The wound was closed using suture and a surgical glue. The fish were then allowed to recover in a large bucket of water and released when they behaved naturally. There was no observed mortality from this procedure during the project and all fish displayed natural swimming behaviour after release.

Receivers

A grid of 47 receivers was used to track the fish from the river to the outer fjord (~200 km from the outlet of Vosso). The habitat use of the trout was monitored throughout the year, but for the purpose of this study, we focused on the migration pattern of the trout from 1 April to 1 July in 2012 and 2013 during the smolt run. The receivers were located somewhat differently in the two years. The reason for the change was that some receivers were lost during storms and for other unexplained reasons (presumably theft). Consequently, relocations were necessary to ensure data collection in important areas. Maps of the locations of receivers are shown in Figures 1 and 2

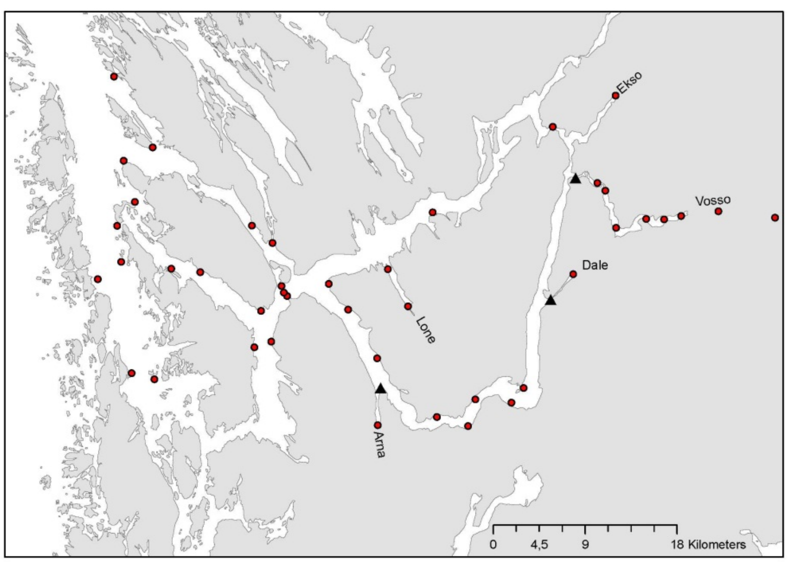

Figure 1 Map of placement of receivers during 1. April to 1. July 2012. Red circles and black triangles indicate receiver locations. Black triangles indicates receiver location defined as the outer part of the estuary.

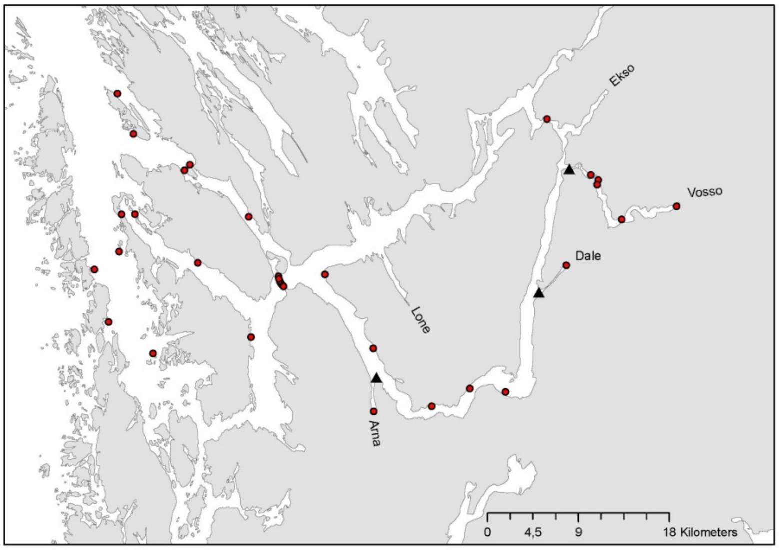

Figure 2 Map of placement of receivers during 1. April to 1. July 2013. Red circles and black triangles indicate receiver locations. Black triangles indicates receiver location defined as the outer part of the estuary.

Data analysis

Results from fish tagged in Lone and Ekso were excluded from the analysis due to low number of fish tagged. Estuarine use was compared between estuaries as the proportion of the tagged individuals registered beyond the outer most receiver in the estuary. Differences between estuaries were tested using a contingency table.

Differences in migration distance from river (i.e., km to furthest receiver with individual registration) were tested using a simple linear model with length, condition and size as explanatory variables.

The distribution of tagged trout during the smolt run was compared with the distribution of tagged smolts that disappeared during both years by plotting them onto a map and visually inspecting it. All analysis was done using R v. 2.15.3.

Results

Differences between trout caught in different estuaries

In 2012 there was a clear difference among populations (i.e., fish tagged in different estuaries) in the proportion of fish that left the estuary during the study period (Table 2).

48.2 % (20 of 39) of the fish tagged in Bolstad never left the estuary. In comparison 9.1 % (1 of 11) and 90% (9 of 10) of the fish in Arna and Dale never left the estuary, respectively. Comparison for 2013 was not possible due to the low number of tag detections in Arna and Dale (Table 1).

Table 2 Results from contingency tables tests of proportion of sea trout leaving the estuary during the April-June.

Comparison	χ-square	*p*-value
Dale/Vosso	4.939209	0.033
Arna/Vosso	6.269784	0.015
Dale/Arna	13.747190	< 0.001

Inspecting the distribution of sea trout throughout the receiver range, it was also evident that there were differences among fish tagged in the three locations. Fish from Vosso and Arna were registered across most of the receivers in both 2013 and 2012 while fish from Dale were only registered on the receivers closest to the river (Fig. 3 and 4).

The distance sea trout migrated was correlated with both the fish condition at tagging and day of the season the tag was placed, but not the length of the trout (ANOVA, R_{adj}=0.32, $p<0.05$). Fish with a lower condition and tagged early in the season (before May) migrated further than fish with a higher condition and fish tagged later in the season (May and June).

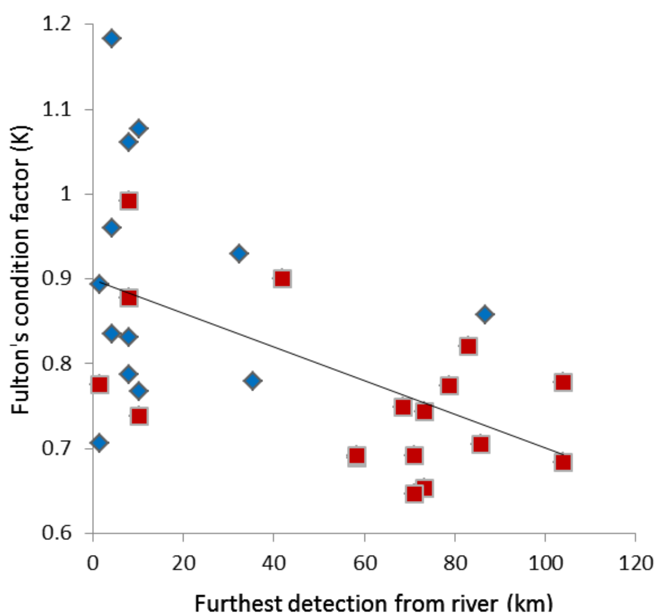

Figure 5 Relationship between Fulton's condition factor (k) and furthest detection from river for trout tagged in Bolstadfjorden. Red indicated fish tagged in April, blue indicates fish tagged in May-June 2012.

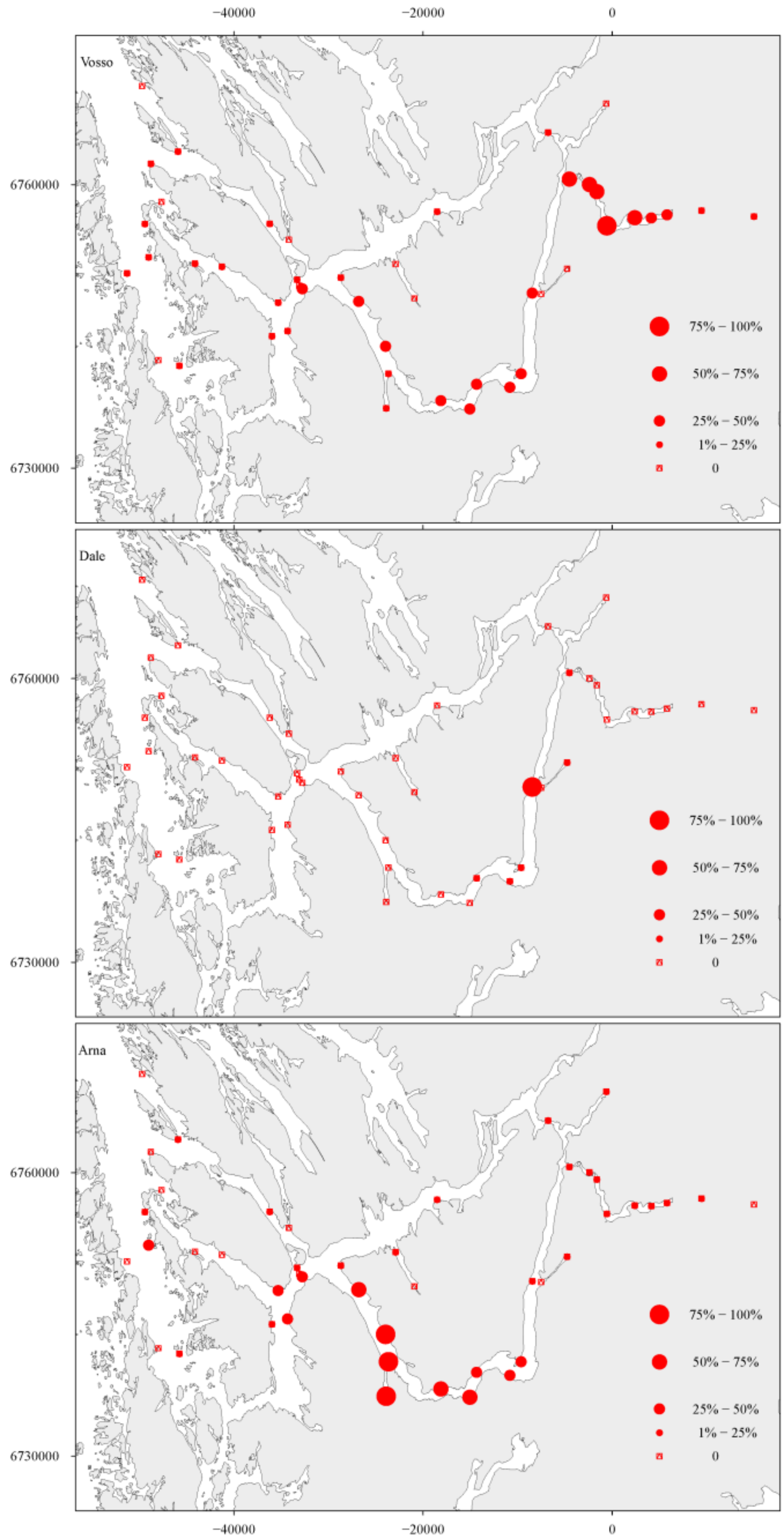

Figure 3 Percent of fish in 2012 registered at the different receiver locations of from Vosso (upper panel), Dale and Arna (lower panel) from 1.April – 1. July.

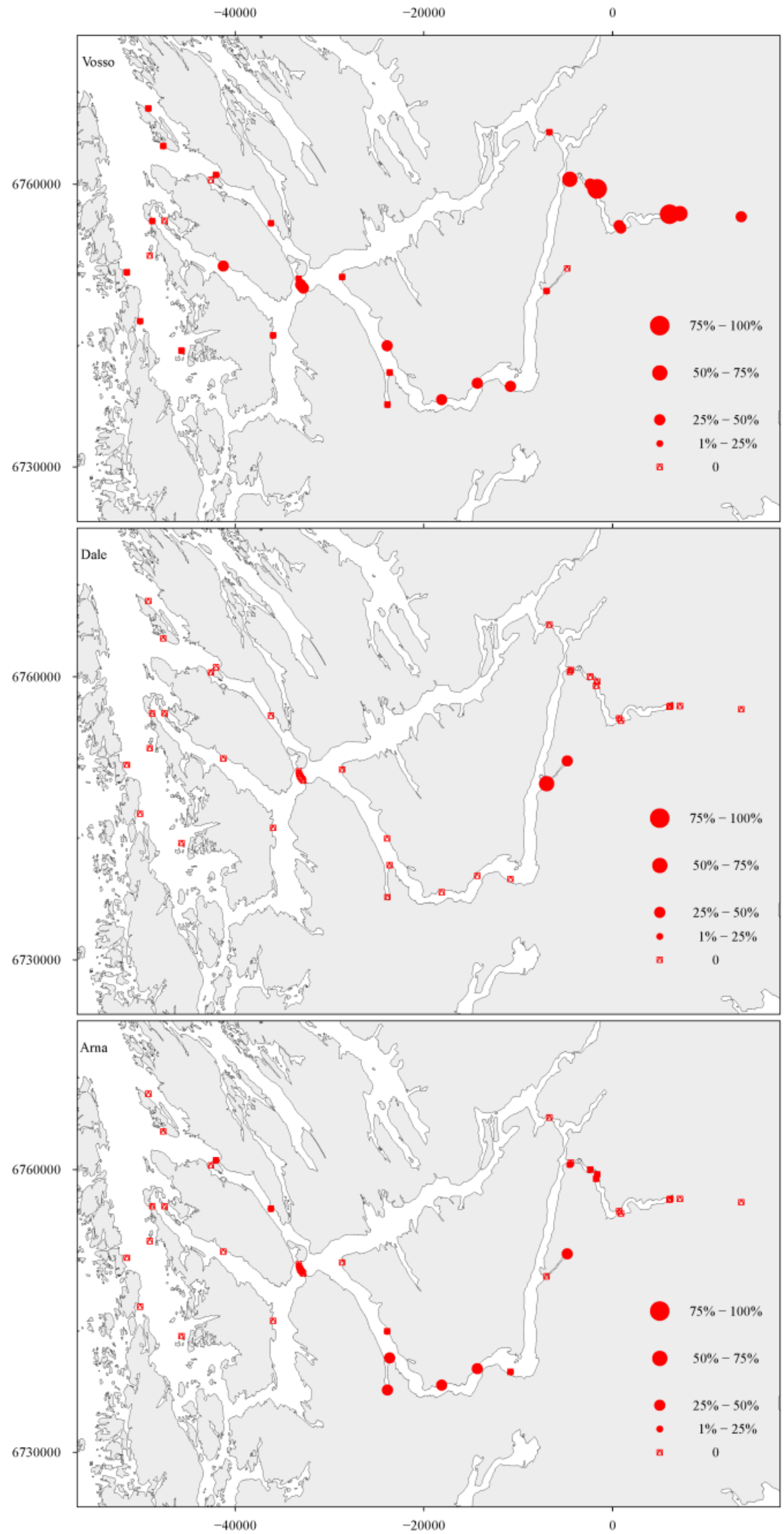

Figure 4 Percent of fish in 2013 registered at the different receiver locations of from Vosso (upper panel), Dale and Arna (lower panel) from 1.April – 1. July.

Consequently a clear difference in condition between fish that remained in Bolstadfjorden and those that left the system was observed (Fig. 6).

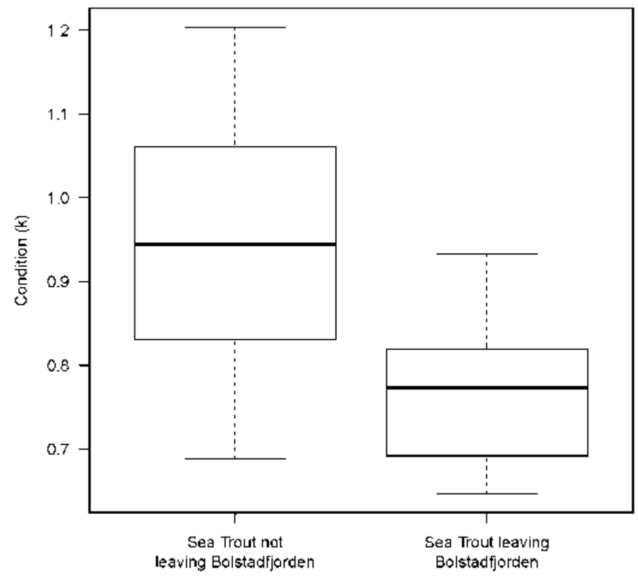

Figure 6 Difference in Fulton's condition factor (k) for sea trout that migrated to the outer estuary and sea trout that stayed inside Bolstadfjorden during the study period. Solid lines indicate the median speed, boxes represent the interquantile range (IQR) where 50% of the observations were observed, whiskers are 1.5 times the IQR, and circles represent outliers.

Comparison of habitat use of trout and tag loss of salmon smolts

Visually inspecting the plot of percent time spent at each receiver in Bolstadfjorden and the registration of tagged salmon smolts, there appears to be a pattern of tag loss in the same area where there was an aggregation of sea trout in both 2012 and 2013 (Fig. 7). In 2012, an aggregation of trout coincided with an estimated mortality rate of 23% (7/30) between the river outlet and 3.8 km downstream. In 2013 a large aggregation around Straume coincided with a mortality rate of 47.5% (19/40) between Straume and Stamnes. However, the largest loss of smolt does not appear to occur in these areas, but rather from Stamnes to the next receivers in both years (mortality rate in 2012 = 52.9 (9/17) 2013 = 61.9 % (13/21)).

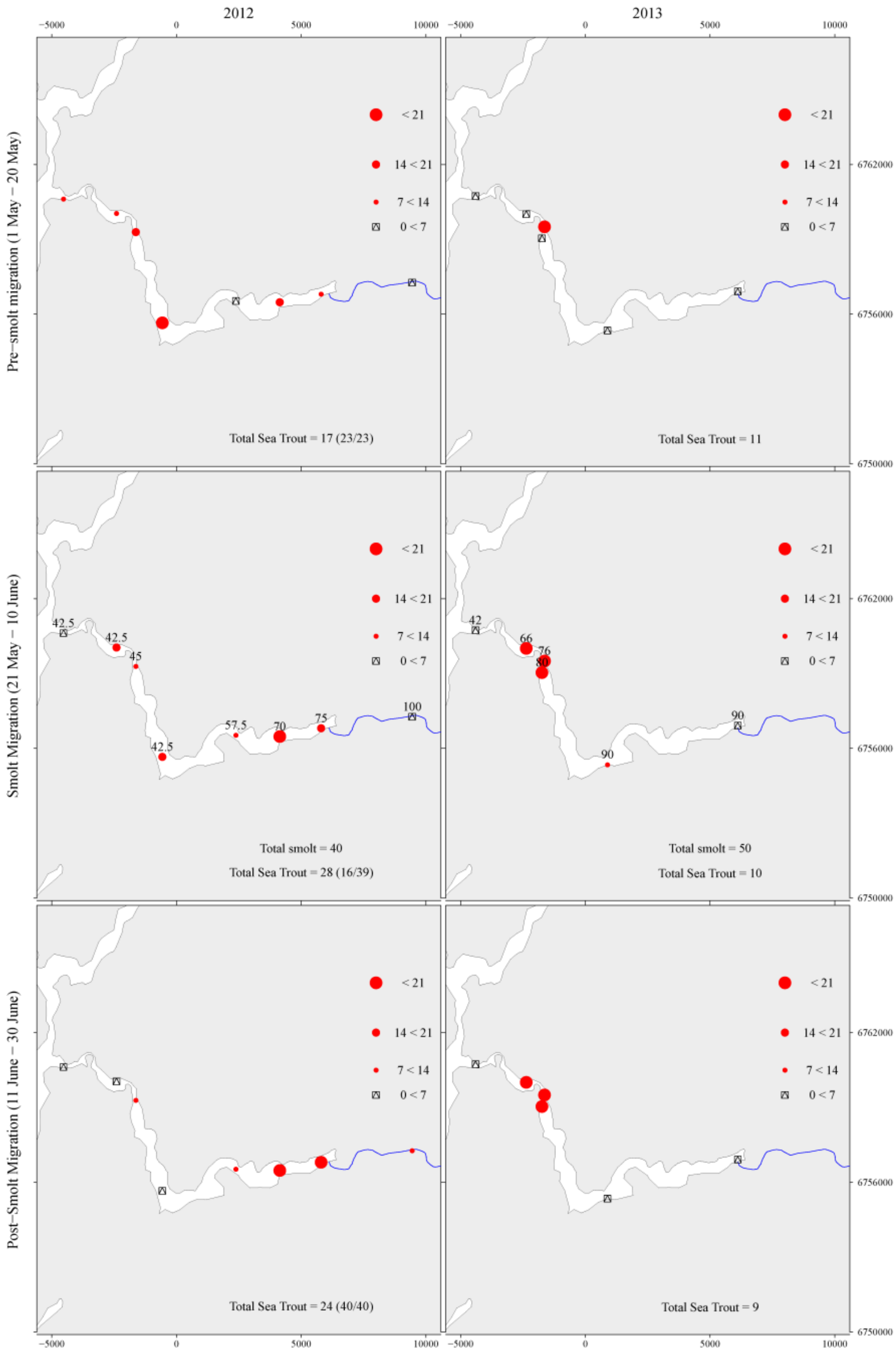

Figure 7 Percent of trout at each receiver location in 2012 (left panel) and 2013 (right panel), for the period before (upper panel) during and after (lower panel) the smolt run. Plots during the smoltrun has also indicated percent smolt registered at each receiver (from chapter 2).

Discussion

This study indicates that there was a loss of acoustically tagged salmon smolt in the areas of the Bolstad estuary with highest aggregations of trout. However the area of tag loss and overlap between predators and prey was different between the two years. This may be due to for example hydromorphological or behavioral differences between the release groups. Our results suggest that predator prey hotspots between trout and salmon smolt may be dynamic and will be strongly dependent on both predator and prey behavior.

Effects of condition and time of tagging

There was a significant relationship between condition of the trout and the distance migrated from the river. Motivation to migrate far is most likely related to the trade-off between energy gain and migration cost (Jonsson and Jonsson, 1993; Jonsson and Jonsson, 2011). The assumption being that there are more potential prey items available if the sea trout migrates further. We also find a relationship between condition and time of capture, indicating that the condition of fish increases as the season progresses. Notes from the field data indicates that the individuals caught later in the season were returning from their marine migration as most of the individuals had infections of sea-lice. This was not the case for the individuals caught earlier in the season. Consequently, the fish that were tagged throughout the season in Bolstad were most likely a combination of sea trout migrating seawards, sea trout returning from sea, and potentially non migrating residents. Jonsson (1981) reported results from the tagging of 1282 trout parr and smolt in the Vosso river system. Veteran migrants, i.e. more than 2 years of age, was reported recaptured up to 100 km from the river. These results are corroborated in the present study which shows that a proportion of the trout migrates to the outer fjordsystem, most likely to forage.

Comparisons between estuaries

Trout caught in the different estuaries had a different likelihood of remaining in the estuary after release. In Dale 9 of 10 fish never left the estuary, compared to 20 of 39 in Bolstad and 1 of 11 in Arna. This could be a consequence of size since the average size of fish tagged in Dale was somewhat smaller (avg: 43.1 cm) than fish tagged in Vosso (avg.:52.7 cm) and Arna (avg.: 55.1cm). However, migration distance was not correlated with size for the fish tagged in Vosso. Another potential explanation is that the trout population in Dale river is less migratory. However, with a relatively low number of tagged individuals in Dale it is difficult to draw any firm conclusions. The migratory pattern of the tagged fish in Dale is corroborated by an estimate of a high catch-per-unit-effort in this estuary (Chapter 1). Stomach analysis of trout caught here indicates a high abundance of gammarids. Stanghelle and Dalevågen is one of the few shallow areas in the fjordsystem which are mainly dominated by deep fjord sections. This may indicate that the shallow estuary of Dalevågen and Stanghelle is an important feeding area for sea trout during spring.

The mortality rate through Bolstadfjorden (~4% / km) does not seem to deviate from mortality patterns from studies in other estuaries. For example, Thorstad et al. (2012a) reported a median estuarine mortality rate of 6 % mortality × km $^{-1}$ from a number of studies on Atlantic salmon smolt. Furthermore, the area of highest mortality, from Stamnes and to receivers in the fjord outside, did not correspond to the area were sea trout aggregated. In total 48.2 % (20 of 39) of the fish tagged remained in Bolstadfjorden throughout the smolt run in 2012.

In conclusion, the results from the tagging experiment demonstrate that approximately 48 % of the brown trout that were tagged in the Bolstadfjorden estuary before and during the smolt-run also migrated out of the estuary to the fjord system outside. Together with the low catches of predatory brown trout per unit effort during trolling in the estuary during the smoltrun (see Chapter 1), this does not suggest that the aggregation of predatory brown trout during the salmon smoltrun in Bolstadfjorden is high. However, the fish that did remain aggregated in areas which coincided with elevated tag loss of acoustically tagged fish. However, it is not possible in this study to tease apart whether the salmon smolt disappeared here because of aggregations of predatory trout, or if trout aggregated towards areas were they would encounter cultivated released fish. Results from Chapter 2 indicate a very slow migration of cultivated smolts through the Bolstadfjord. Therefor we suggest that the high mortality of cultivated smolts in Bolstadfjorden may be explained by an interaction of maladaptive behaviour and predation.

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Chapter 4

Acoustic investigations on smolt migration dynamics in the Bolstadfjord

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Abstract

Acoustic investigations using echo sounder and sonar were used studying the migration of salmon smolt through the Bolstadfjord during May-June 2012. Large aggregations of smolt were observed at Bolstad Bay connected to the release of 30.000 smolt at Vassenden,suggesting a retention effect in this area. Another possible retention area was inside the powerline at Dalseidevågen, both with possible effects to the residence time and survival of smolts migrating through the Bolstadfjord. A much lower flux of smolt schools were observed at Straume than compared to at Trollkona. This indicates either a significant loss of smolts between the two positions, in line with observations of a large mortality of acoustically tagged smolts in the Bolstadfjord, or that the smolts have a long residence time in the Bolstadfjord as suggested in chapter 2. The second alternative implies a prolonged exposure for the smolts to the Bolstadfjord predator regime and a possible mismatch of late smolts with the main northern feeding migration wave of European smolts in the Norwegian Sea. The acoustic studies cannot reveal the causes of the indicated disappearance of smolts but predation is suggested as one possible cause.

Keywords: Predation, smolt, migration, Vosso river, acoustics

Introduction

Results from several independent investigations suggest that Bolstadfjorden, the estuary of the Vosso River, is an area of high mortality for seaward migrating salmon smolt. These investigations suggest that 1) return rates increase when smolt are released at positions further along the seaward migration from ‘in river’ to ‘the outer skerries’ (Vosso stock enhancement programme), 2) unexpected low catches of smolt are observed outside the Bolstadfjord in the Veafjord compared to catch rates in other comparable fjordic systems (Unpublished data Institute of Marine Research, IMR) and 3) high potential mortality rates in the Bolstadfjord of acoustically tagged smolt released in the river (Chapter 2, unpublished results from an acoustic tagging experiment in 2003).

Here we describe the echosounder and sonar investigations carried out from April to June 2012 to further study the migration patterns of smolt in the Bolstadfjord by 1) following the smolt through the fjord using acoustic methods, 2) measuring the flux of smolt at two different positions in the fjord and examining differences in smolt flux rate at those positions, 3) trying to detect predator fishes in the system and 4) studying possible predator interactions between smolt and predators as indicated by the acoustic observations.

Material and methods

Acoustic equipment

The acoustic work was carried out using an 18 feet Hansvik vessel fitted with a 50 HP, 4 stroke, Yamaha outboard motor. The vessel was fitted with an electric 12 W system with a 240 Ah battery capacity. Simrad EK60 echo sounder system was applied with two separate 200 kHz transducers connected to the same General Purpose Transceiver (GPT). The GPT was set to multiplex, i.e. continuously alternate sound pulse transmission between the two transducers. The opening angle of the transducers was 7 degrees according to manufacturer’s specifications and with only weak side lobes. This corresponds to a beam width of about 6 m at 50 m range. The two transducers were rigged on a hoistable aluminum pole in the front of the vessel so that the echo sounder depth could be adjusted (Fig. 1).

Figure 1 Vessel with rigging of the transducers with pole in lifted position, here rigged with one transducer pointing downward and one pointing to port (standard setting during application). In operation the pole would be lowered so that its angle with the water was 90 degrees. Arrows indicate transmission directions of transducers.

During the investigations, the transducer was fixed at 70 cm depth. To minimize transducer vibrations the pole was stabilized by an adjustable support mounted through the bow of the vessel and with two ropes running from the pole at transducer depth and attached on either side of the vessel at about the middle of the vessel. Both transducers were mounted on the pole such that it was possible to either use one transducer pointing vertically and the other horizontally perpendicular to the survey direction towards port side, or to point both horizontally perpendicular to survey direction towards starboard and port side, respectively (fig. 1). During stationary recording only one transducer pointing towards the port side was applied. On fixed stations the bow was facing towards Bolstad with the port transducer facing the fjord as a sonar. Acoustic data were recorded up to a range of 200 meters in sonar position.

Acoustic data collection

Acoustic work was carried out for 15 days from April 19th to June 21st 2012 (Fig. 2).

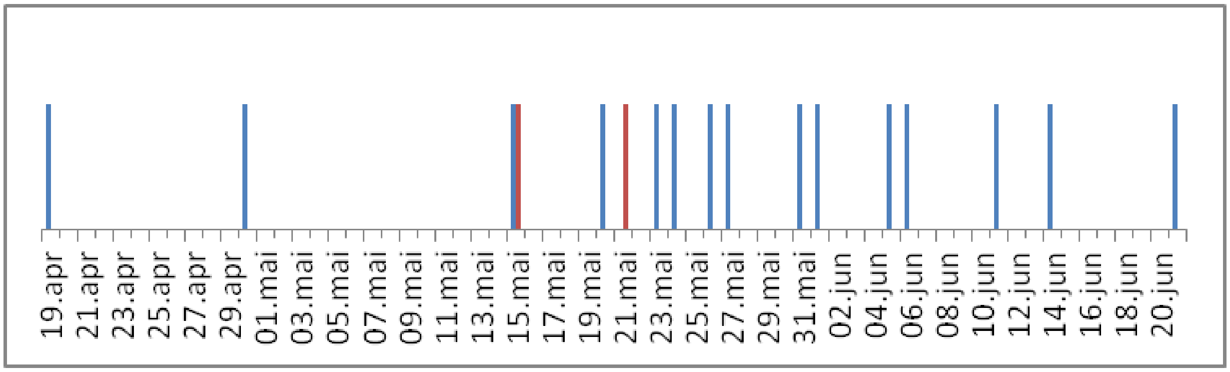


Figure 2 Dates of acoustic surveys in the Bolstadfjord, blue bars, and smolt release at Vassenden, red bars.

The effort was allocated so that some investigations prior to the main smolt run could be used as reference situations (19th and 30th April), the main investigation was carried out around the main smolt release at 21 May (see chapter 2), and the final investigation covered the period when the smolt run was known to have ceased (around June 20th). To document the migration of the large release of cultivated fishes through the Bolstadfjord, we increased our sampling effort in Vassenden. One transect was also conducted outside the Bolstadfjord past Stamnes and into the Veafjord to capture smolt migration outside Bolstadfjord.

As these were preliminary and investigative acoustic investigations in this area, three different approaches were tried and evaluated providing alternative ways to map the migration of smolts through the system. They included: 1) a Zig-zag transect (Fig. 3), 2) a mid-fjord line transect with two transducers pointing horizontally to each side of the vessel (Fig. 4), and 3) a diel cycle station at two fixed positions (Fig. 5).

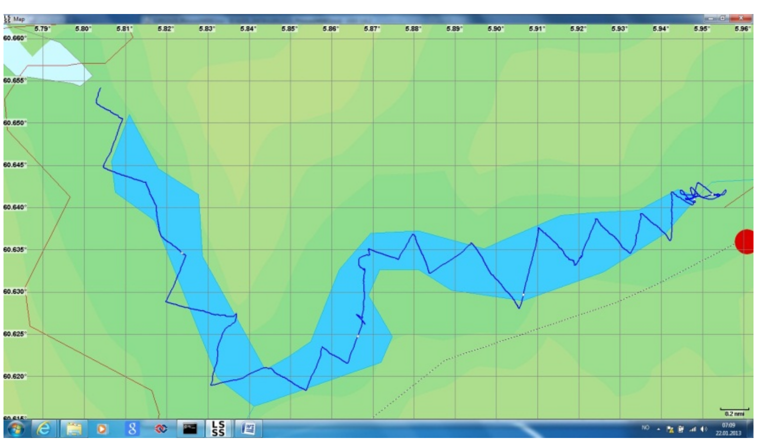


Figure 3 Example of zig-zag transect. These surveys were run with one transducer pointing vertically and one horizontally to the port side.

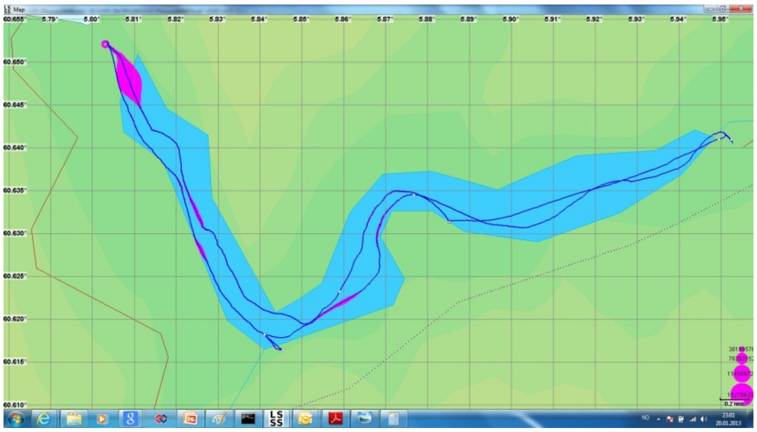


Figure 4 Example of mid fjord line transect. These transects were carried out with two transducers pointing horizontally to each side of the vessel.

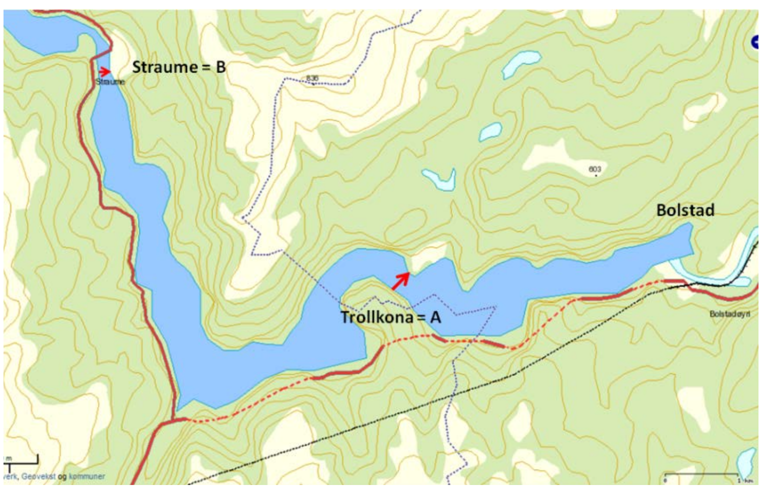


Figure 5 Positions for the diel cycle stations for smolt flux measurements at Trollkona (A) and Staume (B). Red arrows indicate transmission directions of the echo sounders in fixed positions and distance to nearest land. At Trollkona the distance is approximately 200 m, at Straume 100 m.

Data sets and selction of data sets for analyses

All acoustic data logged in raw format were imported into the software Large Scale Survey System (LSSS). Among a range of features, the software allows for display of the acoustic data as echograms at the desired vertical and temporal resolution.

Given the large amount of acoustic data collected, a strict prioritization had to be done to choose which dataset to concentrate on for analysis within the available resources. The echosounder data were, in general, not regarded to give relevant data due to the scaring effect of the vessel and relatively few observations of smolt at the standard survey speed of 10 knots. A lower surveys speed would have been one solution to this problem but due to the size of the sampling area and the time limitation, this was not a feasible solution. Some examples of smolt schools are shown from the Bolstad Bay to demonstrate the effect of vessel speed on the smolt school behavior (Fig. 10).

The large-scale surveys (zig-zag and linear) gave a large amount of data on smolt school distributions throughout the Bolstadfjord during the period of study. Because of the large amounts of data, it was decided to focus on the diel cycle sonar stations at Trollkona and Straume. These data were used to quantify smolt flux that passed by these two positions. We selected batches of 30 minutes of recorded data within a range of 5-55 m from the transducer and counted the schools, or aggregations of fish. A total of 2683 minutes were recorded at the fixed positions, corresponding to 44.7 hours. (Table. 1). The recordings were spread over the period 21/5 to 14/6 at Trollkona and Straume.

Table 1. Overview of location and time of acoustic data logging at fixed positions. 'A' denotes location at Trollkona, 'B' at Straume.

Location	Date	Time start	Time end	Duration (min)
A	21.05	15.06	16.01	55
A	21.05	16.18	17.01	43
B	21.05	19.20	19.58	38
B	22.05	02.06	02.34	28
B	23.05	13.18	13.50	32
A	23.05	14.58	15.32	34
A	23.-24.05	14.59	08.55	895
B	24.05	12.17	13.17	60
B	26.05	11.58	12.44	46
B	30.05	11.09	11.50	41
A	30.05	12.50	13.18	28
B	31.05	10.14	10.52	38
B	31.05-01.06	13.27	06.44	1037
A	01.06	12.54	13.18	24
A	06.06	09.31	12.00	149
B	11.06	09.49	10.18	29
A	11.06	11.09	11.51	42
B	14.06	09.54	10.17	23
A	14.06	11.06	11.47	41

Interpreting acoustic results from the Bolstadfjord

In the initial acoustic investigations of a region, it takes time to learn to know the main acoustic components present. Normally, acoustic data is combined with trawl catches to verify the species and size distribution of the observed traces. Unfortunately such fishing was not carried out in this project and the verification of the observed traces would have to be documented indirectly based on the analyst's experience.

Target strength measurements of smolt

In order to estimate the acoustic Target Strength (TS, dB re 1m^2) of smolt in the size range expected to be observed during the investigations, 20 smolt of size 10-15 cm were released into a 9 m deep net pen and recorded with one of the 200 kHz transducers which was used during the investigations. Recordings from a section of the recordings of high quality and out of the acoustic near field were chosen and analyzed (Fig. 7).

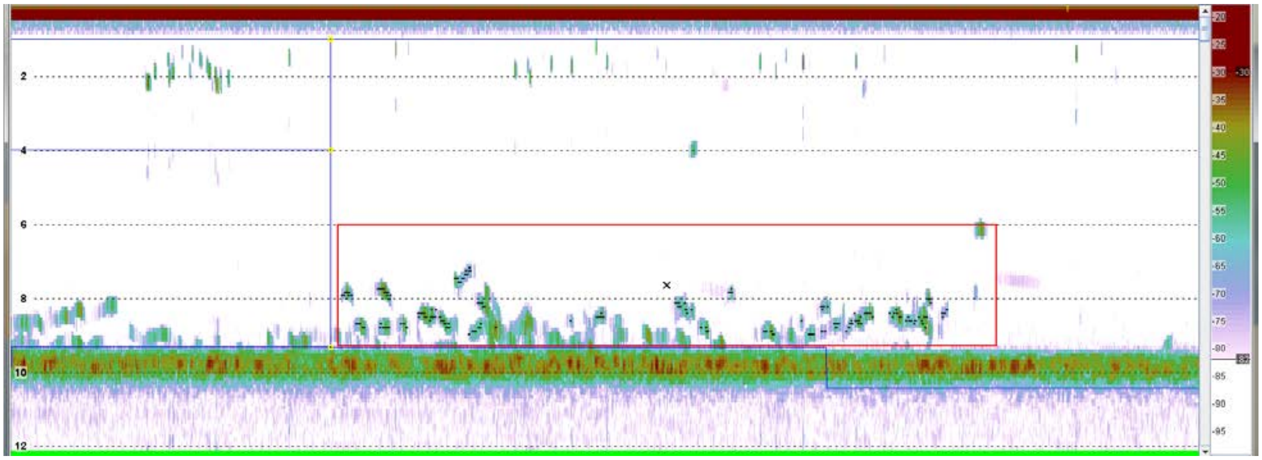


Figure 7 Echogram showing recordings of smolt in a net pen with the bottom of the net pen as a thick line at 9-10 m range. The red box marks the selected area of recordings used for the analyses. The small black dots within the red box mark single echo detections of smolt target.

From the recordings, the average target strength of smolt in the size range expected in our study was 44.97 dB (Fig. 8).

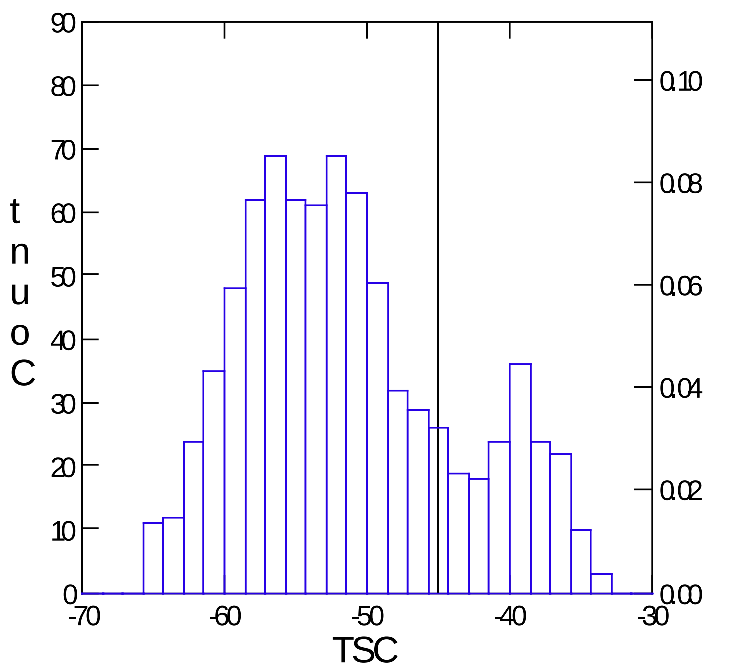


Figure 8 Distribution of single echo detection target strength values from the selected echogram section with smolt. The target strength is compensated for target position in the acoustic beam (TSC; dB re $1m^2$) and both count (left y-axis) and proportion per bar (right y-axis) of a given bar interval is provided. The dotted vertical line marks the cut-off point and values above this point were used to calculate average target strength.

Data quality check and test analysis using the Sonar 5 software

Professor Helge Balk, University of Oslo, kindly carried out a quality test of the data and a test analysis of a representative data sample from a diel station using the Sonar5 software. Balk is the developer of the Sonar 5 software and has extensive experience in analyzing such data. The file analyzed and the echograms produced for this report does not correspond exactly but the approximate data file analyzed is shown in Figure 9.

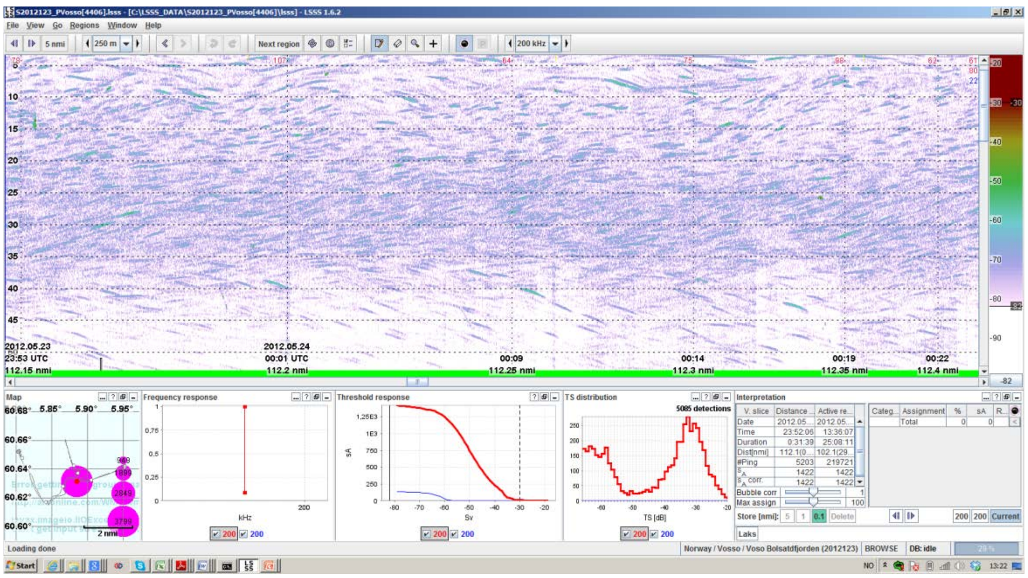


Figure 9 Example of echogram with7-8 smolt school, greener aggregations, at Trollkona on May 24th 2012, 0505-0537 hours. Most single traces are debris or air bubbles.

For a horizontally aligned beam close to surface, the most common problem is the influence from the surface. The beam is wider than the nominal 3 dB beam and tends to pick up echos from the surface even if the beam was trimmed down until most of the noise seems to have disappeared. Another problem is the bending of the beam caused by the vertical sound velocity profile related mainly to temperature. An Sv test was carried out in order to check the data quality. The test shows avoidance of spherical spreading but is influenced by targets. With no targets in the beam, the Sv test should show a flat horizontal line. Figure 10 shows a Sv test for 100 pings from the recorded file.

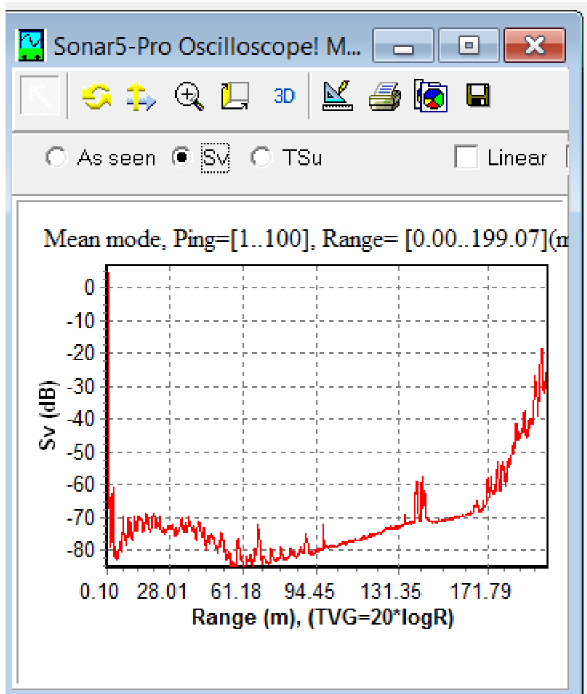


Figure 10 Sv-test in Sonar 5, based on an average of 100 pings.

We see that the Sv divides the data into three regions, 0-61 m, 61-171 m and 171-200 m. For the first region we see that Sv increases with ~10 dB during the first 28 meter and then drops to a minimum at 61 meter. This may be caused by targets in the water or by influence from the surface. In the echogram (Fig. 9) we saw lots of very long smooth and parallel trace lines. These targets seemed not to come from any swimming targets, but rather from waves or drifting material. After 61 meters we see a steady increase in Sv, indicating avoidance of spherical spreading. This is probably due to channelling effects caused by the beam hitting surface. Only data within the range of 55 m were used in the analyses.

Single echo detections were done using the Sonar5-Pros Crossfilter method (CFD) and tracked with the Crossfilter tracker (CFT). This provided 192 tracks from the data sample. Most tracks followed the trend of targets slowly drifting in the same direction. These were weak targets with their strengths far below what is expected for smolt. A few tracks were seen with dedicated movement different from the trend. These are active swimmers likely to be fish (Fig. 11). Only these tracks were selected and used in the further analysis.

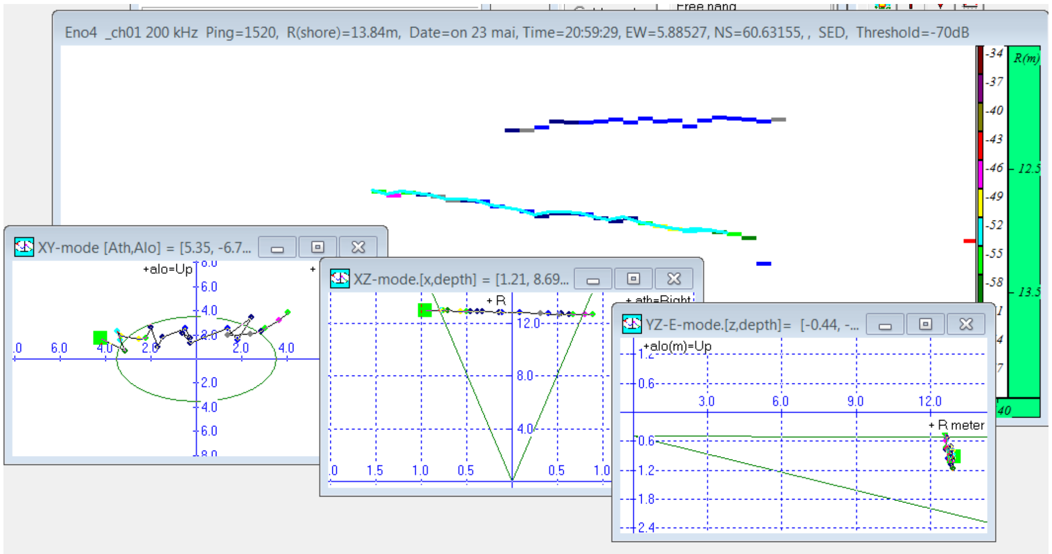


Figure 11 Example of tracked targets and their positions. The shown targets moved in a different horizontal direction than surrounding targets in the water.

Important acoustic components in the Bolstadfjord

This section gives a brief overview of the main acoustic components observed in the Bolstadfjord mainly for informing the reader on terminology and as a reference for later works in the area. These components were:

- Smolt, single fish and schools, salmon and sea trout (**SM,** Fig 12 & 13).
- Vosso River water in Bolstad Bay (**RW,** Fig 12 & 13).
- Bottom (**BO**, Fig. 12).
- Transitional layer between fresh and saltwater (**TL**, Fig. 13).
- Smolt schools scared by vessel (Fig. 14).
- Larger fishes, probably predator fishes/sea trout (**LF,** Fig.15).
- Deep schools, possibly daytime schools of sticklebacks (**DS,** Fig. 16).

Bold letters behind component is code used in figures.

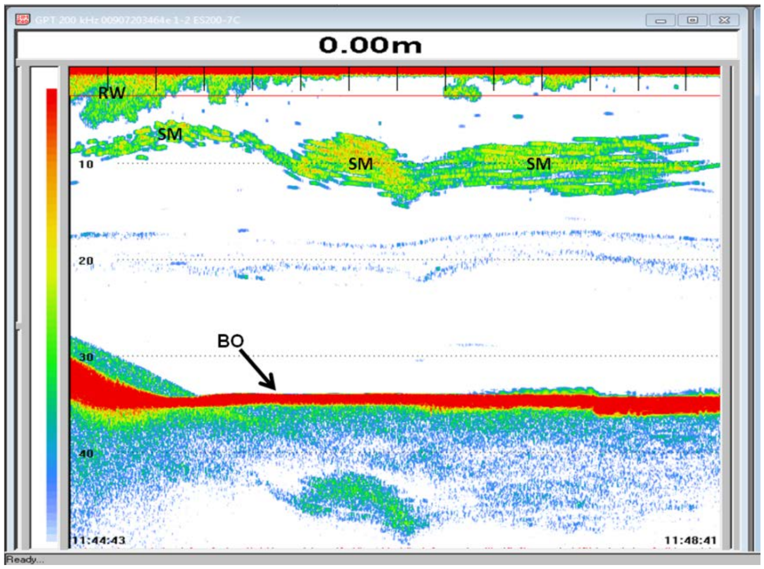


Figure 12 Echosounder. smolt school and Vosso River water in Bolstad Bay. In schools single fishes can be distinguished, river water is diffuse. Red line is bottom.

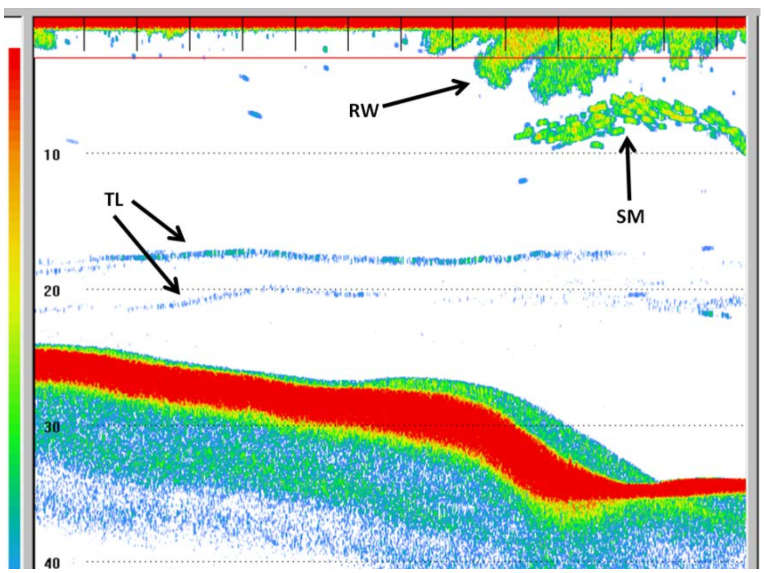


Figure 13 Echosounder. Smolt school under river water indicating the probable mechanism of how smolt schools migrate out of Bostad Bay. The blue shadow is the transitional layer between upper lighter freshwater and lower heavier saltwater.

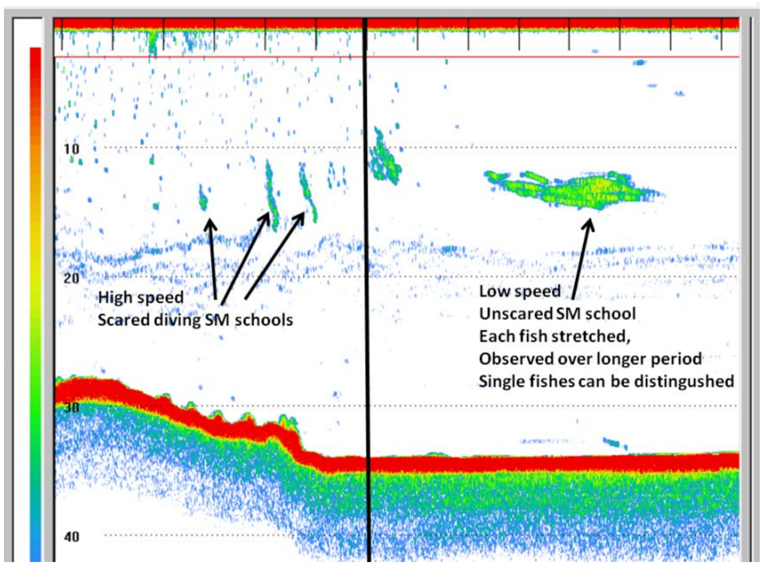


Figure 14 Example of scaring effect of vessel on the echosounder trace. The left part vessel is moving at about 5 knots, three smolt schools can be observed diving. Right part vessel is at low speed and school remains unaffected by vessel.

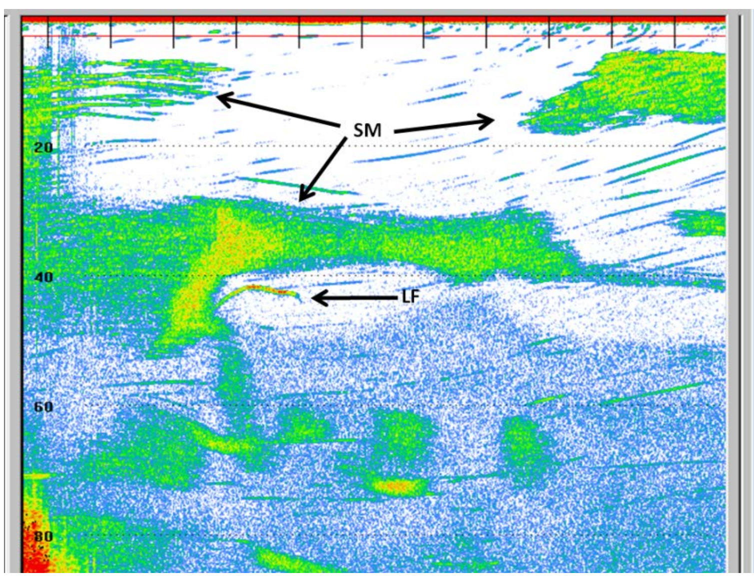


Figure 14 Sonar picture. Smolt schools and one probable predator fish surrounded by smolt. The red color in the signal indicate a large fish.

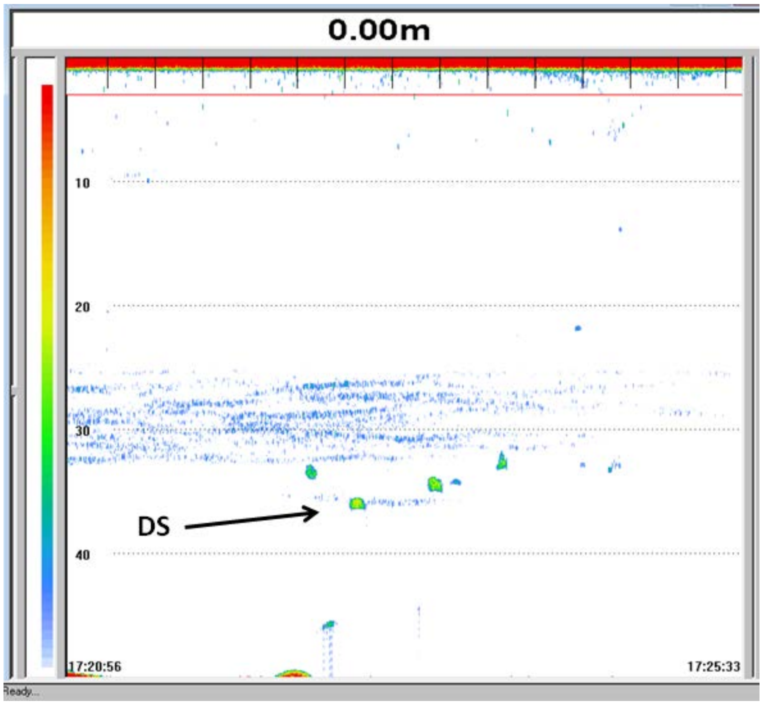


Figure 15 Presumed deep stickleback schools in daytime. Such schools were observed throughout the Bolstadfjord between approx 30 and 60 meters depth in daytime. At night abundant numbers of disaggregated sticklebacks were observed swimming close to the surface by divers in the project (Bjørn Barlaup, pers comm.).

Results

Retention areas in the Bolstadfjord

The acoustic investigations revealed two smolt retention areas in the Bolstadfjord where particularly high densities of smolt were observed. The first area was the Bolstad Bay where smolts accumulated after the 30 000 smolt release at Vassenden. The second area of particularly high smolt densities was the Dalseide Bay with a higher occurrence of schools than in other areas of Bolstadfjorden apart from Bolstad Bay.

Bolstad Bay

A large mount of smolts were observed inside the river water on the Bolstad Bay (Fig. 16). The river water passes the bay towards land on the opposite side. This may create a natural trap inside the current of the river water. It seems reasonable that this trap is more efficient at high water levels as the river water will form a deeper wedge down towards the bottom. This wedge of river water was easily observed on the echogram due to its high content of air.

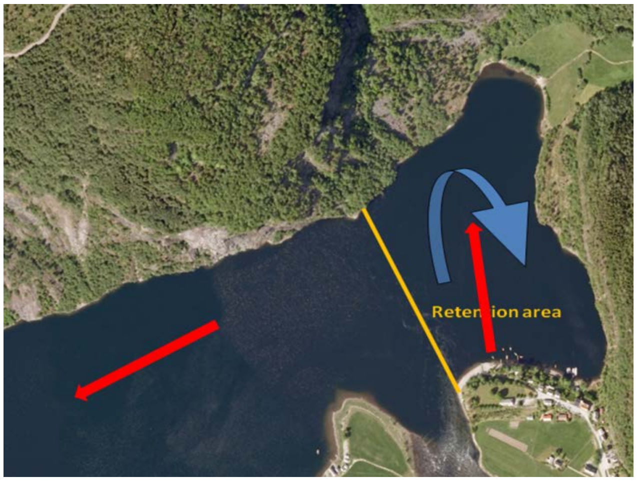
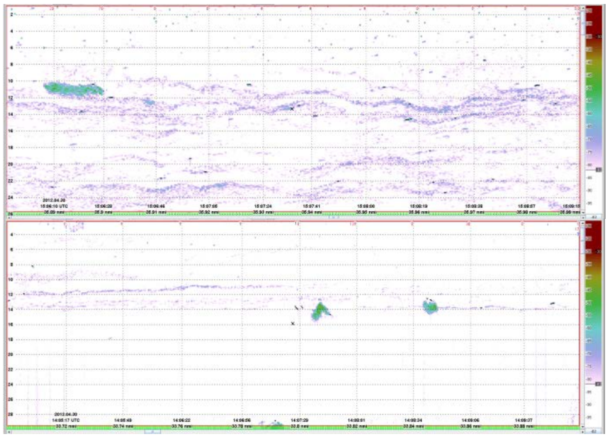


Figure 16 Approximate area considered as retention area at Bolstad Bay. At high river water levels the retention effect is probably larger due to a deeper freshwater current cutting along the yellow line. Red arrows indicate approximate transects in figure 13, inside and outside retention area.

As can be seen from Figures 17 and 18 there was a large accumulation of smolts on Bolstad Bay in particular on the 23rd and 24th May in connection with the release of 30 000 smolt at Vassenden (21th May). The ratio in Sa value between the two areas ranged from 0.1 in the days after the release then decreasing to above 1 around May 31st. The available data did not allow us to estimate the retention effect of Bolstad Bay in terms of mean retention time per fish or distribution on run level.



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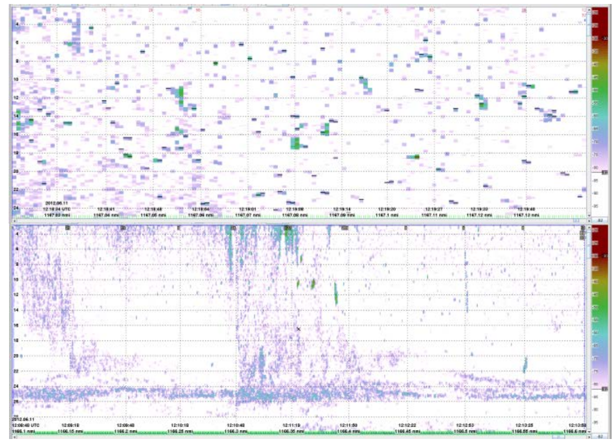

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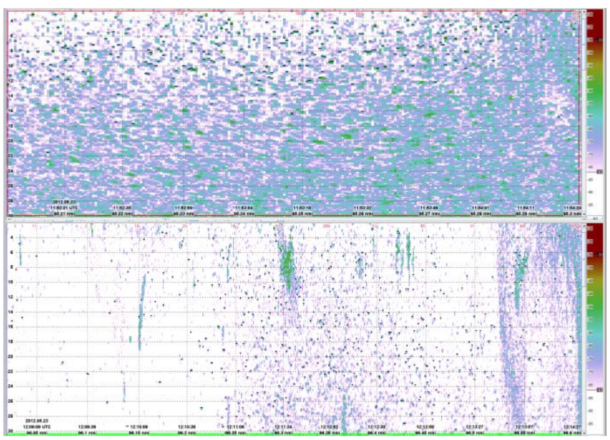

23.05

Figure 17 Echogram examples of the water column from 0-30 m inside the retention area (left) and outside the retention area (right) prior to (upper) durig (middle) and after (lower) the main smolt run. Approximate transect lines are indicated as red arrows in figure 16.

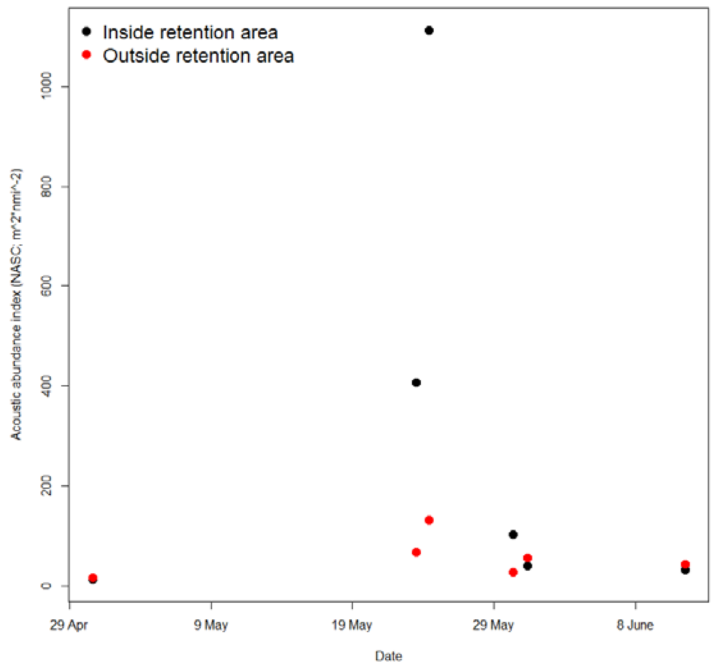

Figure 18 Acoustic abundance index (Nautical Acoustic Scattering Coefficient; NASC m^2/nmi^2) inside and outside retention area prior to, during and after the main smolt run.

Track analysis

The track analysis was carried out during the first two full diel cycle stations; the first at location A (Trollkona) from the 23 to the 24 May (2012) lasting for approximately 15 hours. Altogether 29 tracks could be isolated from the echogram during the period. In order to be as certain as possible that the selected tracks were smolt, tracks were only selected from echogram regions where single echo detections occurred close to echo aggregations with target strength and appearance characteristic for smolt (Fig. 19).

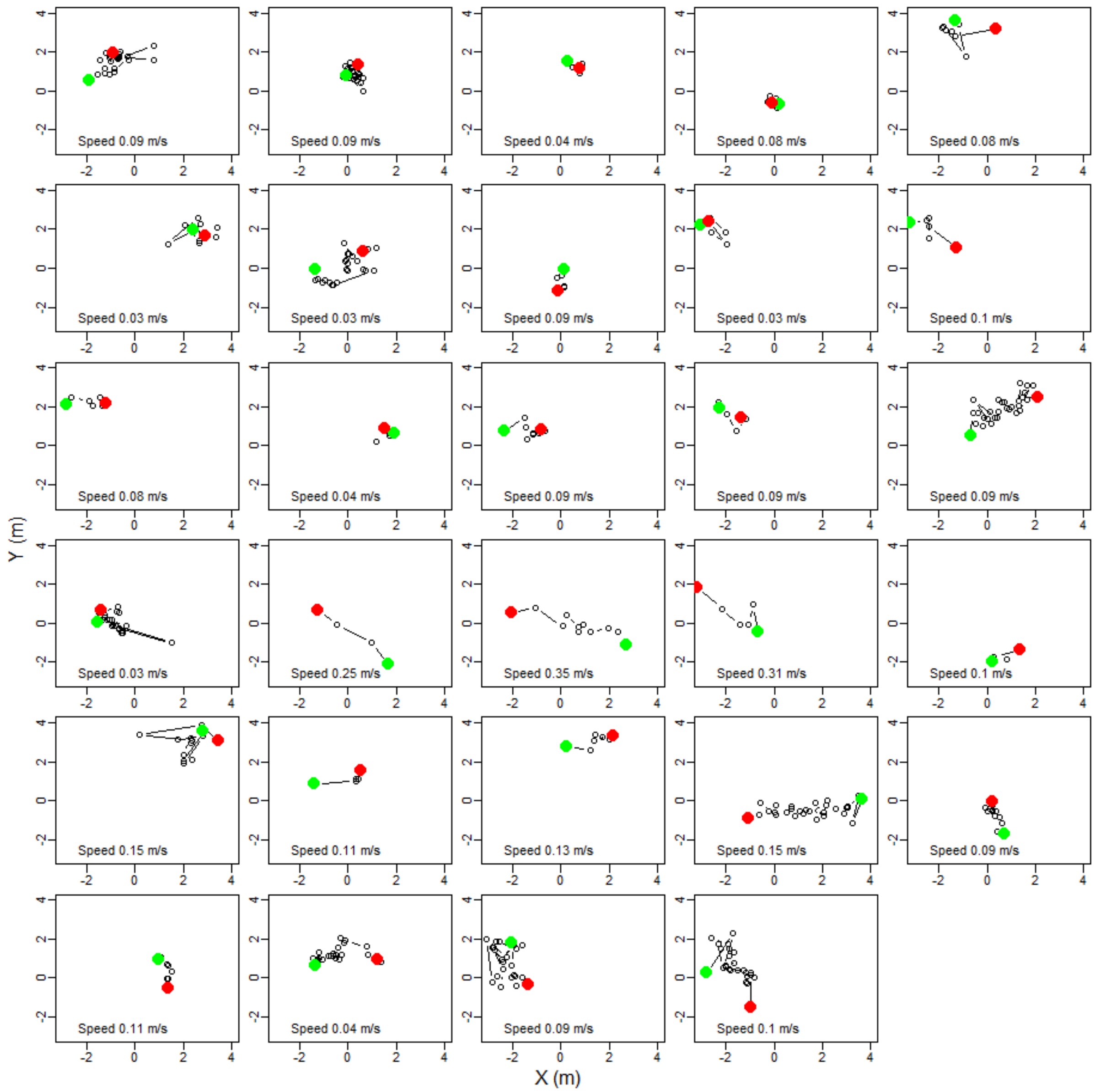

Figure 19 Single echo detections from smolt echogram tracks at diel cycle station A on the 23-24 May at Trollkona. In each panel detections from a single fish passing through the split beam is plotted. The X-direction is perpendicular to the echo sounder beam with direction river outlet to the right and fjord outlet to the left. The Y-direction corresponds to depth. Green dot marks the first detection and red dot the last. Speed is given as net value from first to last detection in three dimensions (dimension along the beam not shown).

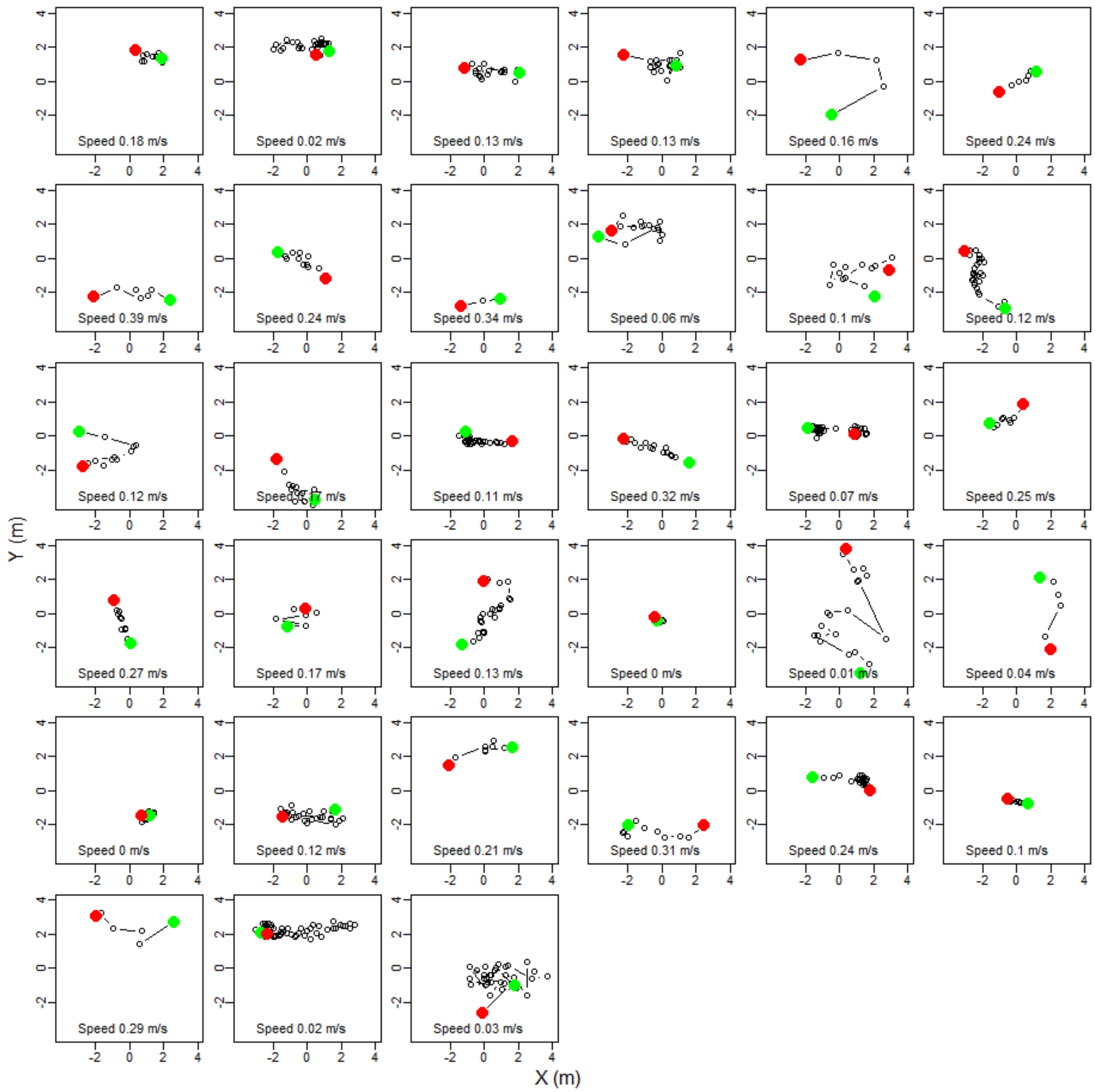

Figure 20 Single echo detections from smolt echogram tracks at diel cycle station B on the 31 May-1 june at Straume. In each panel detections from a single fish passing through the split beam is plotted. The X-direction is perpendicular to the echo sounder beam with direction river outlet to the right and fjord outlet to the left. The Y-direction corresponds to depth. Green dot marks the first detection and red dot the last. Speed is given as net value from first to last detection in three dimensions (dimension along the beam not shown).

Although a net swimming direction out of the fjord system was expected, this was not clearly seen from the tracks. Net average swimming speed was 0.11 (±0.08 SD) m/sec corresponding to approximately 1 body length per second for fish of length 10-12 cm.

The second diel cycle station at location B (Straume) had a duration of a little over 17 hours and altogether 33 tracks were isolated. Net migration speed was higher than Trollkona (Student's t-test , $p<0.05$) and averaged 0.15 (±0.11 SD) m/sec (Fig. 20). Like for location A, the swimming not directional towards the ocean. Notably, the tracks at location B (Straume) were mostly observed as single tracks whereas the majority of the tracks at location A (Trollkona) were parts of larger assemblies or aggregations of acoustic backscatter indicating schools or groups of fish.

Numbers of smolt schools at Trollkona and Straume

Very few schools were observed at Straume as compared to Trollkona (Fig. 21). This situation was observed throughout the studied period.

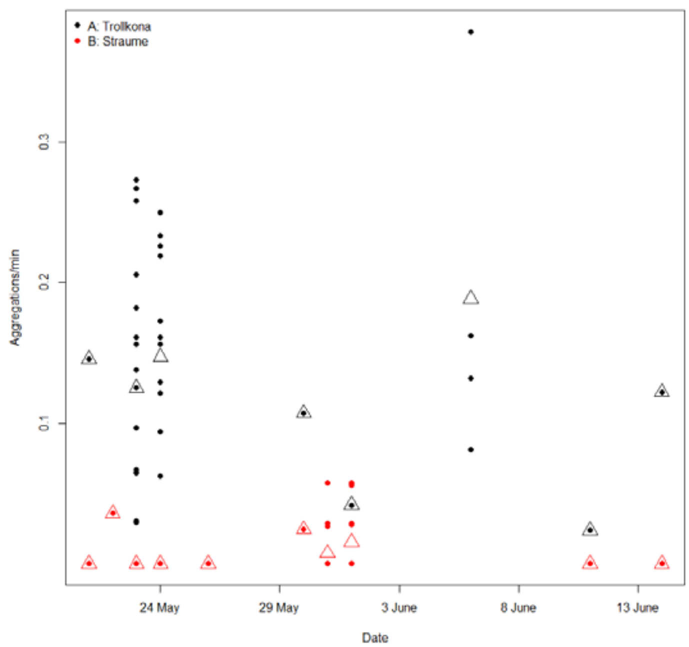

Figure 21 Observed frequency of aggregations/schools during all acoustic fixed stations at Trollkona (black) and Straume (red), ref table 1. The points denote half-hour values and triangles averages per day of observation.

Diurnal rhythm in school observations

There was a tendency for lower number of schools during the darkest hours around midnight (Fig. 22). The darkest hours were defined from sunset to sunrise in Bergen on June 1st 2012 which was 22:51 to 04:24. The frequency of aggregations was significantly lower during night-time than daytime (Wilcoxon rank sum test, $p<0.01$).

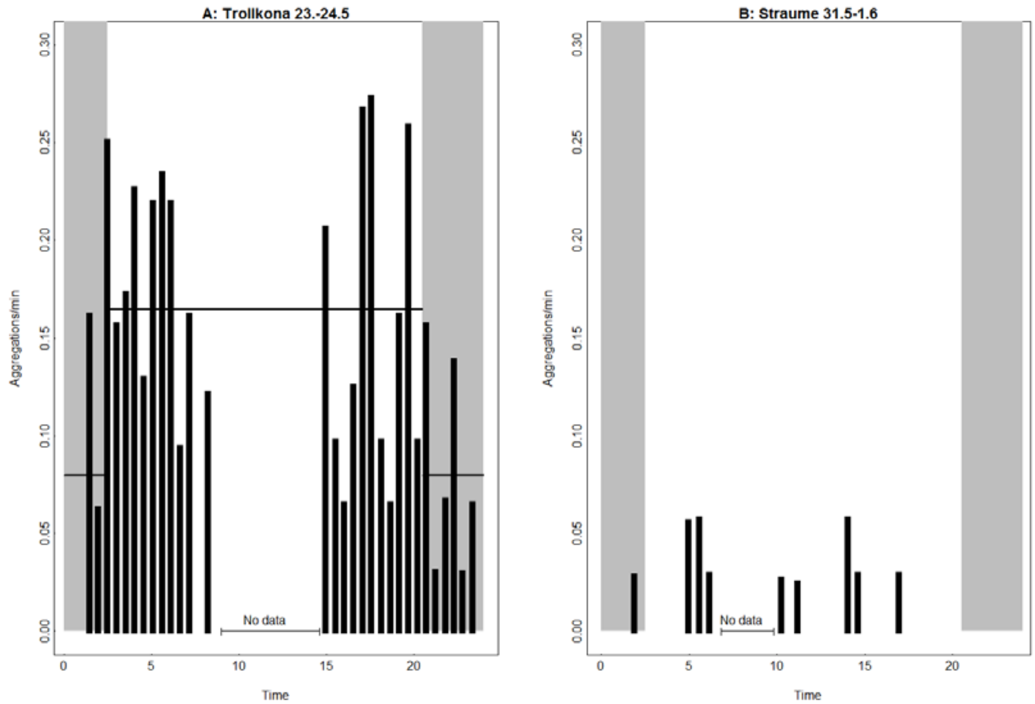

Figure 22 Observed hourly frequency of events during the diel cycle acoustic fixed stations at Trollkona 23/5 (left) and Straume 31/5 (right). Horizontal lines mark average number of aggregations for day and night, respectively. Gray background marks night-time.

Discussion

Verification of schools in the acoustic data

To scrutinize acoustic data verification of the observed acoustic traces is a prerequisite. In this study, a target strength experiment was carried out but there was not a focused fishing for the main acoustic target (salmon smolts). On the other hand, the very large run of smolts, connected with the release of 30 000 smolts at Vassenden, gives a precise description of single fish at Bolstad Bay and of schools in the Bolstadfjord which were both numerous in the days after the releases. The smolt wave through the system was also documented by the trap net catches which were very similar to the results from with the acoustic observations of schools. Therefore, we are confident of the observations made here.

Larger fishes

Several larger fishes were observed interacting with the smolts but no quantitative analysis was performed. From various test fishing it is known that larger fishes in the Bolstadfjord during the studied period are sea trout and consequently potential predators on the smolts. Furthermore, in 2010 smolt predation by sea trout was also observed on several instances within the Bolstadfjord (J C Holst, pers comm., Chapter 5). Occasionally, adult salmon may also pass through the area but these would be maturing fish and not potential predators on the smolts. In addition, cod has also been caught in deeper waters below the halocline.

Retention effect of Bolstad Bay

As the field investigations progressed higher densities of smolts in two particular areas were noted, indicating potential smolt retentions areas. Such retention areas can in theory stretch the migration wave of smolts out in time, and thus make the smolts more vulnerable to predation due to a prolonged residence time in the Bolstadfjord. Alternatively the behavior can be an adaptation to aggregate in to larger schools before they migrate together. The area inside the Vosso River water in Bolstad Bay may be a retention area. A high aggregation of fish was observed in this area compared to the area downstream after the 21st May release at Vassenden.

The possible retention area at Dalseidevågen may have a comparable effect on the smolt run through the Bolstadfjord. One potential hypothesis for why we saw an aggregation of smolt here may be the magnetic field set up by a 300 kW powerline which transverses across the fjord may affect the navigational sensors of smolts leading to confusion and mis-navigation. This can in theory explain some of the long residence time of smolts in the Bolstadfjord. However, we were unable to evaluate this and further investigation is need to determine if magnetic fields from power lines can influence fish movement.

Flux at Trollkona and Straume

The flux of schools was higher at Trollkona than at Straume throughout the studied period. The water volume screened was the same at both positions but the fjord width is about double at Trollkona (200 meters) as compared to Straume (100-120 meters), indicating that the differences of observed schools between the two positions may be smaller than presented here. The observations of migrating schools from both shores at Trollkona, not presented in the report, indicate that the smolts use the entire width of the fjord and therefore estimates were underestimated. The more narrow passage at Straume combined with fewer observed schools indicate that either: A) there was a large loss of smolts between these two positions or B) that the smolts have a long residence time in Bolstadfjorden, after Trollkona, or both. In the 2003 acoustic tagging experiment 11 out of 26 smolts that passed Trollkona were observed at Straume, a mortality at 58% between the two positions (unpublished data J C Holst). On the other hand results from chapter 2 indicate that smolts do have a long residence time in Bolstadfjorden. There are several implications of this latter possibility, one being a prolonged exposure of the smolts to the

Bolstadfjord predator regime leading to higher mortality, another that the smolts from Bolstadfjord will not amalgamate optimally with the main northern smolt migration wave out at sea, resulting in late arrival at the summer feeding areas at sea and lowered survival due to lost marine summer growth.

If the smolt schools have a lower depth distribution at Straume than at Trollkona this could bias our results. There is no data indicating that this was the case, but we cannot evaluate this based on the available analysis. Smolts are generally known to migrate in the upper part of the water column, but is possible that a more narrow passage would force the fishes deeper due to an unknown reason. However, we find this unlikely in light of previous studies on migrating smolts.

Dirunal rhytm in predator incidences

There seems to be a diurnal rhythm in the total number of schools. Schools in general occurred in lower numbers during the dark hours and schools with deviating behavior in very low numbers. This diurnal rhythm is also typical of predator activity and it therefore seems reasonable to link schooling behavior to predator interaction.

Summary

The acoustic studies suggest either or both a significant loss of smolts and a strong retention effect between Trollkona and Straume. The pattern is consistent throughout the duration of the study. The acoustic study cannot reveal the cause of disappearance or delayed migration of smolts and further investigations into this phenomena is suggested.

Chapter 5

Characteristics of the sprat and sea trout stocks in Osterfjorden from 1960 to present

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Abstract

After mean catches of about 10.000 tons per year during the period 1901 to 1973 the sprats catches in Norwegian fjords showed a decrease during the period 1974-2013 and are at present very small, with a mean catch of 1100 tons during the period 2007-2013. A parallel trend ending with a total stop in the sprat fishery around 1990 has been observed in the Osterfjord system, the fjord system outside Vosso river. Various independent datasets like catch statistics, observations made by locals on changes in feeding habits of predator fishes away from sprats, lack of sprats in acoustic and trawl surveys and lack of sprats in predator stomachs samples collected during scientific surveys, indicate that the sprats stock in the Osterfjord system at present are low compared to before 1985. The disappearance of a major fish food source is anticipated to have had major effects on both the individual growth potential, to the stock productivity and to the total stock size of the Vosso sea trout stock. Data from the 1950's and 60's indicate that catches of sea trout originating from mainly the Vosso river system in some years was close to 10 tons annually. However, for 2012 and 2013, only 301 and 123 kg were caught and in 2014 a total ban will be introduced on the Vosso sea trout stock. Sea trout is known to prey on sprat, and we suggest that the decrease of this prey item may have shifted the predation by sea trout to alternate food sources such as salmon and sea trout smolt during the smolt migration from Vosso.

Keywords: Sprat stock, Osterfjord system, stock collapse

Introduction

One part of the predator hypothesis (see further details in extended summary) suggests that the Vosso sea trout stock lost its major food component, sprats during the period 1985-1990 and as a consequence switched its feeding focus from sprats to smolts during the smolt run. This section describes numerous qualitative and quantitative data documenting the development of the Osterfjord sprat stock and Vosso sea trout stock during the period 1960 to 2013. The main quantitative data on sprats and trout are fishery statistics on the Norwegian coast and in the Osterfjord system in particular. A second set of quantitative data is observations of sprat in trawl catches made by IMR in this system in 1998, 1999, 2000 and 2012. The qualitative data are interviews made with professional fishermen and locals in the area. We also include a consultancy report on the development in the sprat fishery in the Osterfjord during 1960-2012 in Norwegian made by Magnus Tangen which is an appendix to the report.

Material and methods

The various quantitative and qualitative datasets and can be classified into these main groups: Fishery statistics, interviews with local fishermen, scientific acoustic and trawl surveys, and stomach analysis of predator fishes.

Fishery statistics

Data on sprat catches were obtained from the Fisheries Directorate and Sildesalgslaget (The pelagic fish sales organization of Norway). Due to changes in statistical areas after 1985 it was not possible to discriminate the Osterfjord area as a separate area and catch observations in the area after this had to come from interviews with local fishermen.

Interviews with local fishermen

Qualitative data on the fisheries were obtained from interviews with skippers/logbooks on sprat fishing vessels that used to fish in the area before 1990. Observations of stomach contents of sea trout prior to the collapse in the sprats stock was obtained from sitting net fishermen in the Stamnes area.

Scientific trawl acoustic and trawl surveys

Data on sprat in the Osterfjord were obtained from an acoustic-trawl survey in 1991 by the Institute of Marine Research, Bergen, (IMR). The Institute of Marine Research Bergen carried related trawl surveys for salmon smolts during 1998, 1999 and 2000 in the Osterfjord system. In addition, a trawl survey was done in May 2011 also for smolts. The trawl used in all surveys was the specially designed Salmon Trawl fitted with the Fish-Lift live catching device (Holst and MacDonald, 2001). The Salmon Trawl was hauled skimming the surface and sampling from the very surface and down to about 7 meters. The trawl was towed at 3 knots typically for 3 hours before hauling.

Stomach analysis of wild predator fishes

Stomachs for wild fishes were obtained from the trawl surveys and also from dedicated net and trolling fisheries for predator fishes. These stomachs were all worked up for fish content but not for other food items.

Indications of stock development of the Vosso sea trout stock

Data on the development on the fisheries for the Vosso sea trout stock 1949-2014 was used to trace trends in the stock condition of the Vosso sea trout stock and taken from sources like statistics of trout delivered to Stamnes Handelslag (Barlaup et al., 2008) and catch statistics collected by Fylkesmannen, the County Governor of Hordaland. While it is recognized that other factors may influence catch statistics, we believe that the catch data here represent the relative condition of the stock.

Results

Long term development of sprat fisheries on the Norwegian coast and in western Norwegian fjords.

The catch of sprat in Norwegian fjords has varied considerably from year to year, probably as a consequence of the short life cycle of sprat combined with variable recruitment, and yearly varying production potential in the fjords. The variation is very clear in the catch statistics seen in Figure 1.

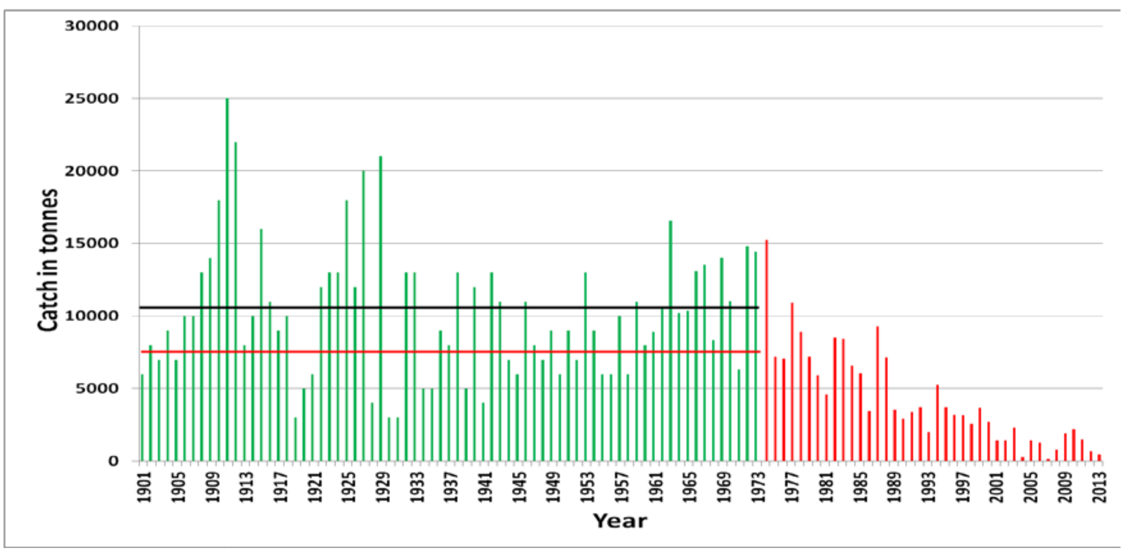

Figure 1 Fisheries statistics of sprats from Norwegian fjords 1901-2013. Green bars 1901-1973 includes all Norwegian fjord catch while red bars 1974-2013 is western Norwegian fjords only. For the period 1974-2013 on average 73% of the sprats were fished in western Norwegian fjords. The black line indicates the mean catch in Norwegian fjords during the period 1901-1973 at about 10.250 tons. The red line indicates the estimated mean yearly catch in western Norwegian fjords 1901-1973 at about 7500 tons when the total catch is reduced by 73%.

Up till about 1970-1973 for all Norwegian fjords catches averaged approximately 10 000 tons per year. Between 1985 and 1990, the sprat catches started to decline to a low level of around 1 100 tons from 2007 to 2013. This period includes catches of 161 tons in 2007 and 467 tons in 2013. The catch in these two years represent 2.2% and 6% , respectively, of the estimated yearly mean catch in western Norwegian fjords from the period 1901-1973. Despite orders for 2200 tons for canning in 2013, the fishermen were only able to catch 467 tons in western Norwegian fjords and the remaining tons had to be taken from North Sea sprats, which has a less desirable quality for canning.

Catches for the Osterfjorden system also indicated strong yearly variation ranging from no reported sprat catches (1980) to approximately 250 tons (1982, Fig. 2). However, after 1987 Osterfjord sprat catches were no longer considered a separate stock area and catch statistics were therefore unavailable for long-term analysis.

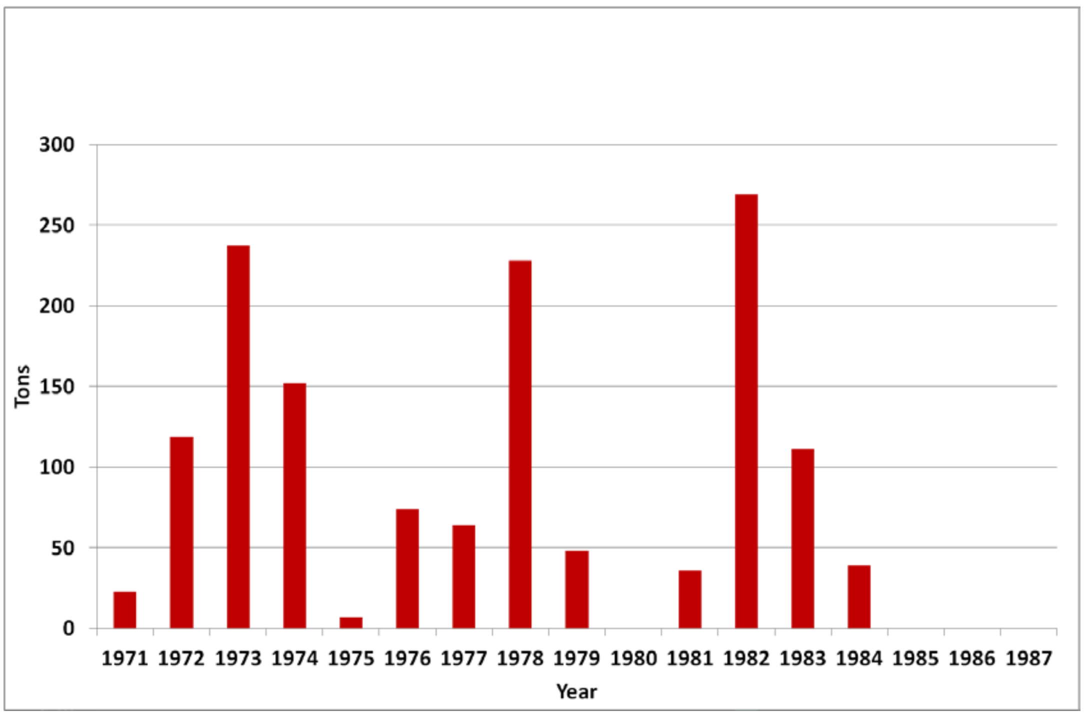

Figure 2. Catch statistics from the Osterfjordsystem 1971-1987 After 1987 statistical areas were pooled and Osterfjorden could not be discriminated in the statistics. Catches in the Osterjorden were low after 1985 according to the local fishermen.

Development of the fisheries in the Osterfjord system (from appendix 1)

The Osterfjord system was a good but never a large sprat fjord according to the fishermen (Tangen, 2012). It was a fjord they "went to when they didn't know of other places to go" and it was "good in windy weather conditions due to its sheltered nature". In general the feeding conditions for the sprat appeared to be good here as the sprat had high fat content in all years while in other fjords the fisheries could be closed due to a low fat percentage some years and seasons. Most likely due to good growth conditions in Osterfjorden it happened that they could fish 9 cm 0-group sprats with canning quality in the autumn.

According to the local fishermen interviewed, very few catches were taken after 1985 and those taken were dominated by fish at 14-17 cm, three years and older mainly. Earlier, the catches were dominated by younger fish but mainly above 9 cm which was the minimum size required for canning. Such sprats could be either 0-group in the autumn under favorable summer growth conditions or 1 years old. Furthermore, 14-17 cm fish were too large for ordinary canning and they were mainly used for "ansjos", spiced, salted and canned sprats. The observation that mostly larger sprat were caught in the latest years of the fishing indicates that there was a recruitment failure in the system. Although 0-group sprats were observed, they did not result in productive fishing for 1 year–olds the following year which suggests a very high mortality rate from 0 to 1 group.

Observations made by local fishermen

A local inhabitant, Ola Kvamme, from Stamnes, who used to fish at the "laksegilje", sitting net, at Røyrviktangen, opposite Stamnes, and has been working on the Vosso project hiring out his vessel for towing salmon smolt to sea, said that "in earlier days the pollock and saithe stomachs in the Veafjord area were 'always' filled with sprat. This is no longer the case and the saithe and pollock are now mainly feeding on krill and deep water fishes". Ola Kvamme also says that they started fishing the set net from the 20th of May and the sea trout started appearing around mid summer, "jonsok". Due to the allowed mesh size they would catch sea trout down to about 1 kilo when the net was new, but after the net aged and mesh stretched due to jellyfish filling the net and hard currents in the area, they would catch fish mainly from 1.5 kilo and upwards. They would have schools at up to about 100 sea trout entering the net, but would then only catch approximately 20 sea trout in a set due to the size selectivity of the meshes, letting the smaller fishes out. Sea trout were at times observed to have round bellies were filled with sprat but other times there were few or no sprat in the stomachs.

Kvamme also reports that the sprat fishermen used to anchor their "mærer", sprat storing net bags, at the Kvamsbukten in the northeastern part of Veafjorden, just downside his farm at Kvamme due to the sheltered nature of this bay. Sometimes he would row along alongside the bags in the evening with a light and would observe sea trout in the bags amongst the sprat, obviously caught as bycatch. The sprat had been caught during the so called "lysfiske", or light fishing, where boats fitted with strong lights were used to attract the sprat before the purse seine was set around the light vessel just before break of dawn.

This type of sea trout bycatch in the sprat fishing areas has been controversial for years on the Norwegian coast and a ban has been put on light fishing for sprat in several areas due to bycatch of salmon and sea trout.

Kvamme said they would sell most of their catch of sea trout to "Stamnes Handelslag", the local grocery store at Stamnes, who shipped it off to Bergen. The yearly sales statistics for Stamnes Handelslag shows shipping of up to about 5.5 tons per year (Fig. 3) during the period 1949-1966.

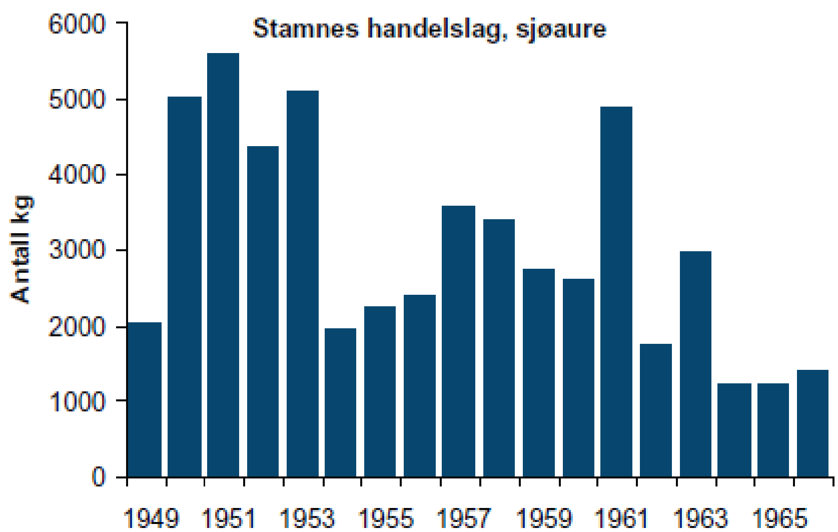

Figure 3. Kilos of sea trout shipped through Stamnes Handelslag during the period 1949-1966. These catches were mainly done by sitting nets in the area around Stamnes, inner parts of the Osterfjord system. (Figure from Barlaup et al, 2008).

Kvamme also reported they would sell sea trout locally to private buyers. It seems reasonable this was also done by other fishermen indicating that the statistics from Stamnes Handelslag are underestimates of the real catches by those fishermen delivering to this buyer. Stamnes Handelslag was only one of many, but maybe the largest buyer of salmon in the area (Barlaup et al, 2008). However, Barlaup et al. (2008) only mentioned the selling of salmon to Stamnes Handelslag but it seems reasonable that this was also the case for sea trout.

Scientific trawl and trawl acoustic surveys

Various surveys have been conducted by The Institute of Marine Research in Bergen throughout the Osterfjroden system. The last acoustic-trawl survey in the Osterfjorden system in summer 1991 with Svein Iversen as the survey leader (Survey report, IMR) indicated that no sprat was observed acoustically in this survey. However, a trawl survey haul outside Stamnes had catches of juvenile sprat. Also during the years 1998, 1999 and

2000, IMR trawled for smolt in the Osterfjord system as part of sea lice infestation studies on seaward migrating smolt. In these surveys, sprat were not taken in the surface-skimming Salmon Trawl despite substantial trawling effort. This is in contrast to the Nordfjord and Sognefjord which were trawled the same years using the same gear with occasional large catches of sprat. Finally, another trawl effort was done in 2011 with the RV "Fangst" that made a total of 13 trawl hauls at various positions in the Osterfjord system (Fig. 4).

Figure 4 Trawled distances and catches during the 2011 scientific trawl survey. Not all 13 hauls plotted but the missing ones overlap with those plotted. Catch of sea trout (sjøørret) and salmon smolt noted by area.

All hauls were approximately 3 hours in duration covering about 10 nautical miles. One single sprat was caught in these hauls, whereas 116 sea trout were caught.

Table 1. Number of hauls by trawled distance and total number of sea trout caught during late April – early June 2011.

Distance	Nr of hauls	Sea trout caught
Stamnes-Stanghelle	3	30
Kvisti Bro-Hamre	4	29
Lonevåg-Nordhordlandsboren	5	33
Herdlefjorden	1	27

Stomach samples of wild fish

During trawling efforts by the RV "Fangst", sprat were not present in any of these sea trout (n = 116) stomachs while 6 smolt were found in stomachs of sea trout caught outside the Lone river (Fig. 4).

During an investigation on whether aggregations of saithe around fish pens prey on smolt in 2010, stomachs from a total of 687 fishes were caught using nets (Fig. 5, Table 2). The main food item found were pellets from the farms but also the natural food items such as mychophids and krill. A few saithe had eaten mycthophids and one saithe had eaten a cod-like fish, however, no fish had eaten sprats. The 9 sea trout in the outer and mid area had eaten 4 salmon smolt.

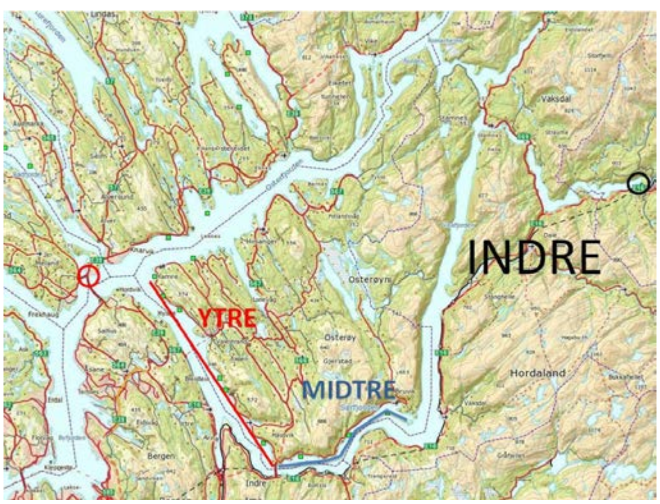

Figure 5. Areas for net trial fishing in 2010. "Ytre" means outer, "midtre" means mid and "Indre" means inner as referred to in table 2.

Table 2. Fish stomachs examined by areas in figure 5. Note that catches in the inner part is by trolling.

	Outer area, net	Mid area, net	Inner area, trolling	By species
Ling	3	5		8
Pollock	2	38		40
Spiny dogfish	3			3
Rainbow trout	24	5		29
Saithe	494	51		545
Cod	3	35		38
Horse mackerel		6		6
Tusk		1		1
Whiting		1		1
Sea trout	4	5	7	16
Sum by area	533	147	7	
Total				687

Development in the Vosso river sea trout fishery

The Vosso river sea trout fishery has shown a negative trend in recent years with catches dropping from approximately 550 individuals caught in 2005 to less than 100 individuals being caught in 1013 (Fig. 6). In 2013, reported criticism on the Vosso sea trout fishery from local fishermen tell it "was not worth going fishing".

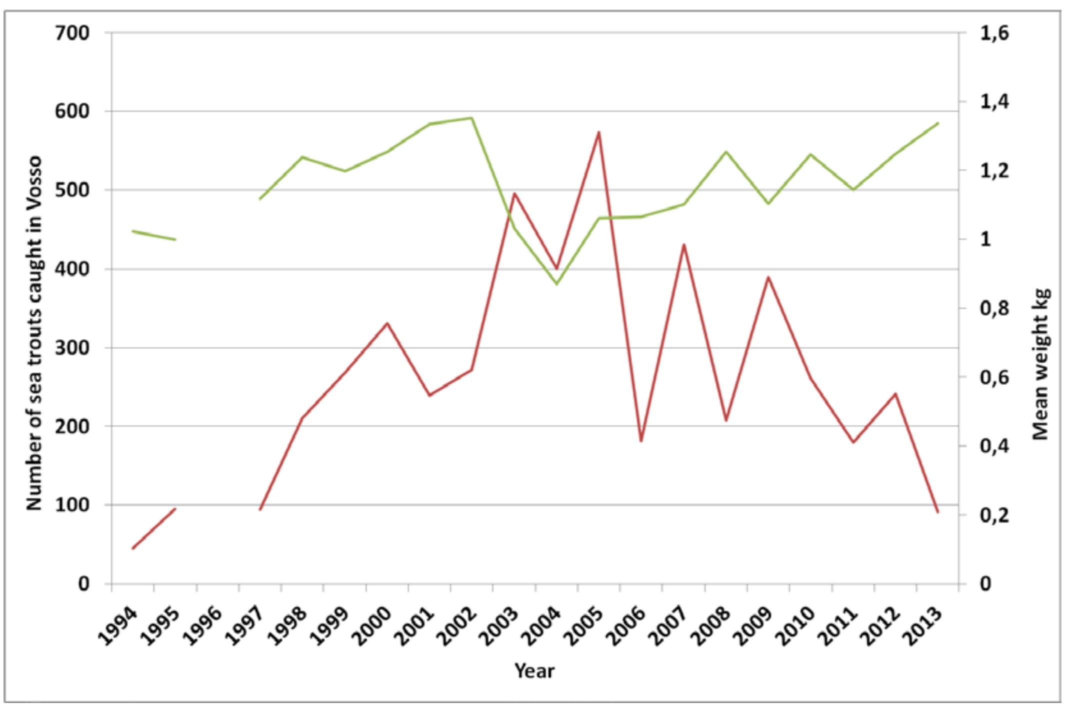

Figure 6. Development in catch in numbers and mean weight of sea trout taken in the Vosso river above Evanger lake 1994-2013. Red curve, catch in numbers. Green curve, mean weight.

The fishery for sea trout has only been allowed upstream at Evangervannet in later years. Based on advice from the river owners, the local fishing association "Fylkesmannen", and the County Governor of Hordaland, is was suggested to close the area above Evangervannet in 2014 (http://www.fylkesmannen.no/Hordaland/Miljo-og-klima/Fiskeforvaltning/Hoyring-av-fisketider-laks-og-sjoaure-2014/) which means all sea trout fishing in the Vosso will be closed indefinitely in 2014.

Discussion

All available direct data series including statistics of directed fisheries, observations made by the fishermen, sprat presence in stomachs of marine fishes and trawl surveys, indicate a collapse in the Osterfjorden sprats stock sometimes around 1985-1990. The spratsstock in the Osterfjorden gave mean catches of 100 tons during the later fishing period 1971-1984, with a maximum catch at 269 tons in 1982. The sprat stock was obviously a variable resource from year to year which corresponds with a large variation in the total Norwegian catches and the catches in western Norwegian fjords (Fig. 1). It seems reasonable to explain the large variations in the sprats stocks by a combination of the species being short lived, having a large recruitment potential given high fecundity, and living in a variable environment in the fjords.

Based only on the statistics of Stamnes Handelslag up to 5500 kilos of sea trout was fished in one season in this area with much of this sea trout originating from Vosso. In addition, there were substantial amounts of sea trout delivered to other buyers around Osterøy and sea trout were also sold to private buyers along with personal use by the fishermen. Furthermore, the sea trout was fished in the river. To sum it up, it seems fair to claim that the Vosso sea trout stock could have a sustained fishery up to 10 tons yearly. With a suggested harvest level at 50-80%,, this corresponds to a potential sea trout stock at about 13 to 20 tons. In 2013 about 100 sea trout at a total weight of 123 kilos was fished in the river from this stock and all sea fisheries have long since been closed. Currently, the stock is at very low levels as compared to its historic potential, and as of 2014, there will be a total ban on sea trout fishing in the Vosso system.

Fisheries for sprats were variable but generally good in the Osterfjord system prior to the stock collapse estimated to have taken place sometimes between 1985 to 1990. Sprat were also frequently found in sea trout stomachs in fishes caught in the sitting nets at Stamnes. Based on the presented data it seems fair to claim that the Vosso sea trout stock lost a major fish food source with the collapse of the Osterfjorden sprat stock sometime between 1985 and 1990. As demonstrated by the catch statistics, a significant part of the stock consisted of fish weighing 1 kilo and larger. After the sprat stock collapse, alternative fish food sources for the sea trout could include juvenile herring, 0-group of other fishes, deepwater fishes, and large plankton like krill and Themisto. The stomach samples available for sea trout from the in the Osterfjord trawl survey in April-June 2011 now suggest fish constitute a negligible fraction of the food with only 6 smolt being identified in sea trout stomach samples. However, smolt predation by sea trout has been observed within the Bolstadfjord system (2010 & 2011: 13 trout with average 2.1 smolt per stomach were evaluated, 2012 3 trout with average 0.67 smolt per stomach (chapter 1)).

Salmon smolt may be a short term easily accessible prey item that sea trout (and other predators) can capitalize on. The presence of sprat in the system could have been a prey refuge for the smolt that is now seemingly at a lower level than before.

We hypothesize that the collapse of the Osterfjorden sprat stock could have affected the productivity of the Vosso sea trout stock. This sea trout stock was known for its size with reports of individuals above 10 kilos. Today the Osterfjorden system is known for having few fish except for mackerel, which is abundant (J.C. Holst pers. Comm.). From the description from the fishermen the main sprat fisheries took place inside the Nordhordland bridge (Tangen 2011, Appendix 1). This would mean that these inner areas should have been important feeding areas for sea trout.

Our observations are mainly correlative and in some cases qualitative. We cannot therefore rule out that the observed parallel trend in the two stocks is driven by an independent outer factor. However, we suggest that there is a top-down trophic link between sprat and trout which has affected the trout population in Vosso. Similarly, the parallel collapse of salmon in the Vosso system can also be explained by other factors. However, we propose that predation of trout on smolt may also be an important link in this ecosystem.

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Brislingfiske og forekomster av brisling i Osterfjorden 1960 – 2012

Magnus Tangen

1.1 Generelle trekk ved brislingfiske på Vestlandet

Fra de gode brislingårene på Vestlandet på 1960-tallet, ble det et ustabilt og nedadgående fiske på 1970-tallet. Nedgangen fortsatt på 1980-tallet, og man fikk enda et tilbakeslag i 1990.

Allerede i 1976 protesterte Hordaland Brisling- og Småsildfiskarlag mot «rovfiske» i Nordsjøen. På årsmøtet krevde de at myndighetene tok grep for å redde det vesle som var igjen av brisling i Nordsjøen. Fiskerne så tydelig en sammenheng mellom fiske-presset på havbrisling og mengden brisling som var å finne i fjordene. Brislingfiskere som opplevde dette på 1960-tallet (J.H.Nøstbakken, Harry Edvardsen mf.) forteller at store mengder brisling først opptrådte i ytre kyststrøk. Derfra gikk den innover og ble gjerne jaget av makrell og størje. En annen fisker (Sigmund Ekerhovd) forteller at brisling som overvintret i fjordene, trakk ut til fjordenes ytre del eller helt ut til kysten senvinters og om våren for å gyte langs kysten. I løpet av sommeren fikk fjordene derfor innsig av overvintret brisling og yngel fra gyting både fra denne og fra havbrisling. Det store utbredelsesområdet for brisling (fra ytre kyststrøk og innover i fjordene) ble observert - og gjenspeilte seg i fangstene - helt opp til 1970-tallet.

1.2 Endring av fangstområder for brisling i Hordaland

Den store brislingflåten (med dels små fartøy og liten redskap) hadde et stort fangstområde i Hordaland på 1960-tallet. Ut fra områder og fangster nevnt i årsmelding fra Sild- og Brisling-salgslaget for 1962 nevnes: Onarheimsfjorden, Høylandsundet, Matrefjorden, Skåneviksfjorden, Romsa, Ålfjord, Hardangerfjorden (Storsund, Ølve, Hatlestrand, Varaldsøy, Strandebarm, Øystese, Alsaker, Ålvik), Bjørnefjorden (Tysnes, Strandvik, Fusa, Os, Samnangerfjorden), Osterfjorden, Masfjorden, Åkrefjorden, Lundegren, Husnes, Bondesund, Eidfjord, Fjelberg, Bjoa, Strandvik, Nordtveit og Malkenes.

Selv om områder og fjorder kunne være stengt for fiske på grunn av for lavt fettinnhold, småfallenhet eller innblanding av mussa, viser fangstene på 1960-tallet at brisling opptrådte og ble fisket fra den ytterste fjordmunning og langt inn i de fleste fjorder.

Fjordene fikk årlig innsig av yngel, antakelig både fra kystbrisling og senere fra havbrisling (som ofte gyter litt senere på våren). Mange fiskere mente at overfiske av brisling i Nordsjøen var avgjørende for det stadig svakere fisket i fjordene på slutten av 1970 tallet og utover 1980-tallet. Også forskere (Sund og Bjerkan) hadde hevdet at en opprettholdelse av de rike brislingforekomstene ved kysten og i fjordene var helt avhengig av rekruttering fra havbrisling.

En synkende bestand, og overkapasitet i flåten, førte til et større press på kystbrislingen. Utover 1980-tallet opplevde man derfor et frafall av flere tidligere gode fangstområder for kystbrisling både i Rogaland og Hordaland. I Børøyfjorden (en sidearm av Bømlafjorden) ble siste fangst gjort i 1983 (jfr. J.H.Nøstbakken). På midten av 1980-tallet opplevde man et tilsvarende fravær av brisling i Osterfjorden. Fenomenet ble også merkbart i Masfjorden, Fensfjorden og Bjørnefjorden.

Det kan virke som om de lokale bestandene ble utsatt for et så sterkt fiske-press – samtidig som tilførsel av Nordsjø-brisling var svekket - at forekomstene ikke var store nok til å betegnes som fiskbare. (På den annen side kan man hevde at disse brisling-ansamlingene var så kort-levde og flyktige at de bør sees på som varierende fragmenter av kystbrisling-bestanden). Frafallet av de lokale forekomstene kan ha ført til at man også mistet flere lokale gyteområder – og da også lokal gytevandring mellom indre og ytre kyststrøk. Ømfintligheten overfor overfiske kan også sees i sammenheng med brislingens korte livssyklus der ett år gammel fisk utgjør hovedtyngden av bestanden, og derfor også av fangstene.

Et annet moment som man bør ha med seg i perioden frem til nyere tid er oppbyggingen av NVG-sild-bestanden. Flere brislingfiskerne forteller at det var (og fortsatt er) en sammenheng mellom sild og brisling i fjordarmene. **Silda beitet ned brislingyngel**, og dermed kan lokale bestander av sild være en medvirkende årsak til at brislingyngel ikke viser igjen i en brislingforekomst det påfølgende året. I 1983 fikk man omsider en strek årsklasse av NVG-sild, men dette kai ikke settes i direkte sammenheng med fravær av brislingforekomster på 1980-tallet. Ei heller kan nedgangen i brislingfisket på 1990-tallet forklares med larvedrift fra de sterke NVG-sildeårsklassene fra 1991 og 1992 ettersom også disse kom fra gytefelt nord for Stadt. Det som imidlertid kan være en medvirkende årsak til at komponenter av kystbrisling holdes nede på 2000-tallet, er høyt beitepress på yngel fra NVG-sild som inntar kystområder på gytevandring til feltene sør for Stadt samt etablering av lokale vårgytende sildestammer etter larvedrift fra sør.

I større fjordsystem (som i Hardangerfjorden) kan de lokale bestandene ha vært såpass store – og hatt et såpass stort utbredelsesområde - at de har overlevd det høye fiske-presset; og overlevd så lenge at flåtekapasiteten ble mer tilpasset brislingens evne til reproduksjon. Man kan også regne med at de større lokale forekomstene – eller fangstene - også har vært hjulpet av en fortsatt,(men svakere) rekruttering av hav-brisling. Mye tyder på at tidligere gyteområder langs kysten ikke brukes. Fiskerne ser da nå også brisling i fjordene gjennom hele året mens man for 40 år siden kunne oppleve at den trakk helt ut mot ytre kyststrøk etter overvintring. Fiskernes observasjoner tyder på at de siste 30 årenes fiske på kyst- og fjordbrisling i all hovedsak beskatter lokale bestander som er av en viss størrelse samt tilfeldige ansamlinger fra larvedrift fra havbrisling.

1.3 Forslag til forklaring på nedgang i fiske

Det er ingen unison eller beviselig forklaring på den dramatiske nedgangen i fiske og bestanden fra midten av 1970-tallet og spesielt etter 1990. Ulike teorier er blitt nevnt av fiskere, og disse kan også sees i sammenheng med hverandre.
–Nedfisking av havbrisling som gjennom gyting rekrutterte til kystbrisling.
–Overkapasitet i flåten førte til nedfisking av mindre og lokale forekomster.
–Endringer grunnet regulering av vannføring fra vassdrag som tilstøter fjordene
–Forurensing fra industri, landbruk og boligområder til vassdrag og dermed fjorder.
–Mindre åte i fjordene.
–Nedbeiting av yngel av makrell og NVG-sild

2.0 Brislingfiske ved kysten i ulike perioder

Brislingforekomstene i Osterfjorden kan ikke sees kun i et lokalt perspektiv. Osterfjorden deler skjebne med mange andre områder i Hordaland, og derfor blir det nødvendig å se på trekk ved den generelle delen av det norske brislingfisket.

2.1 Brisling og brislingfiske før de store endringene (frem til 1970)

Kystbrisling overvintret i ulike fjorder langs hele Vestlandet. Tidlig på våren vandret brislingen ut av fjordene på gyte- og næringsvandring. I ytre del av fjordsystem samlet store mengder brisling seg for å gyte. Samtidig gav årstiden brislingen mye næring i form av plankton-oppblomstring. Etter gyting beitet brislingen seg innover kysten. Stimene var mange. Åteforhold, strømforhold og tilstedeværelse av predatorer har medvirket til å splitte, jage og bestemme kursen for brislingen.

Mens mange arter har et fast vandringsmønster som gjentar seg, synes ikke dette å være tilfelle for kystbrislingen. Den har nødvendigvis ikke noe latent instinkt (som hos enkelte andre arter) til å vende tilbake til oppvekstområdet. Brisling fra en bestemt fjord, kan således ha endt opp i en helt annen fjord (eller fjordarm) etter gyting. Dette kan forklare de store lokale svingningene fra år til år, og også være et svar på hvorfor fiskerne ikke klarte å se sammenheng mellom forventet fiske ut fra observasjoner og det som faktisk ble resultatet. De lokale komponentene hadde derfor ikke nødvendigvis noen lokal tilhørighet, men kan mer oppfattes som naturlig spredning av en større regional komponent.

Observasjoner tyder på at de større ansamlingene av brisling søkte ut av fjordene eller like utenfor kysten for å gyte. Strømforholdene etter gyting førte larvene utover eller inn til ulike deler av kysten, og etter hvert som larvene ble svømmedyktig har de fulgt land innover kysten; helt inn til de innerste fjordarmer. Samtidig ble bestanden supplert med larvedrift fra hav-brisling. Ulik dato for gyting (samt at brislingen er en porsjonsgyter) og årlige variasjoner i strøm- og temperaturforhold, førte yngel inn til en rekke kyst- og fjordområder – og med ulik styrke fra år til år. Hvor mye yngel som overlevde må sees i sammenheng med forholdene under gyting, tilgangen på næring og nedbeiting fra predatorer. Også her er det grunn til at lokale og årlige variasjoner har spilt en rolle. Oppfattelsen av mengden brisling og nedgang i bestanden, vil da omfatte det som blir overskuddet etter naturlig dødelighet.

Rekrutteringen fra lokale komponenter av bestanden kan også ha vært periodevis av minimal betydning. Nævdals (1968) analyser konkluderte med at brisling i norske farvann bestod av en enkelt bestand som ble rekruttert fra Skagerrak-Kattegat og/eller Nordsjøen. Nævdal nevner også rekruttering fra mindre lokale komponenter som gyter i fjordene.

Selv om mye i naturen er stabilt og gjentakende – og gir opphav til begrep som «gode brislingfjorder», og «gode områder for brislingfiske», har brislingfisket alltid vært preget av uforutsigbarhet og dels store lokale og årlige variasjoner. Variasjoner i strømforhold, saltinnhold i havet, temperatur, beiteforhold og naturlig dødelighet, kan være deler av forklaringen.

2.2 Trekk ved brislingen og brislingfiske etter 1970

Brislingsynene i ytre del av kystområdene er borte. Fiskere ser liten bevegelse av de lokale bestandene gjennom året. Voksen fisk trekker fremdeles utover fjordene om vinteren og på vårparten, men den trenger ikke vandre langt for å finne gode nok (eller store nok) områder med næring til vårbeite og gyting. Noen mener at kystbrislingen nå også gyter inne i fjordene, og at larvene driver ut mot fjordmunningen der de som svømmedyktige setter kursen inn igjen i fjorden. Andre observasjoner tyder på at brisling kan samle seg i utkanten av større fjordsystem (som ytterst i Hardangerfjorden) der hovedtyngden av gytingen i Sunnhordland synes å foregå. Nærheten til de samme fjordsystemene som den overvintret i, fører da brislingen tilbake til sitt oppvekstområde (fjorden) etter gyting. De regionale komponentene av bestanden blir dermed mer stedbundne, foretar kortere vandringer og gir derfor også et mer forutsigbart fiske.

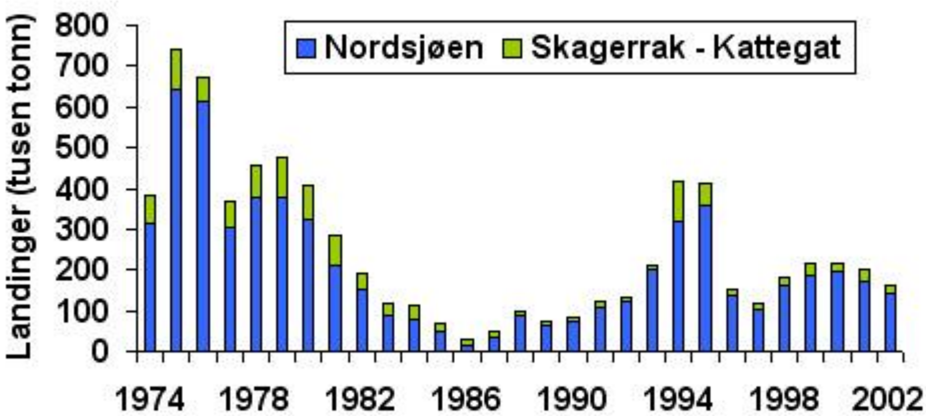
Gyting i fjordene og like utenfor de store fjordsystemene fører larver og yngel i stor grad inn til de samme fjordsystemene. Antallet yngel og nærhet til et stort fjordsystem, gir dårlig grobunn for å etablere andre lokale komponenter og deretter fiske i andre fjorder og fjordsystem. Den tidligere bonusen i form av yngel fra havbrisling synes heller ikke å være stor nok til å bidra i så måte. Tidligere «brislingfjorder» får fremdeles innsig av noe yngel, men den naturlige dødeligheten synes å være for høy til at brislingen klarer å etablere seg – og overvintre – i store nok mengder til å være fiskbare. Rekruttering til slike fjorder hviler kanskje utelukkende på yngel fra havbrisling. Kompleksiteten omkring rekruttering fra brisling i Nordsjøen øker også når gyteperioden for brisling i europeiske farvann starter så tidlig som i desember eller så sent som i juli. Avslutning av gyteperioden skjer da mellom april og november (Jfr. Report of the sprat biology workshop;1986). Endringene i det norske fisket (og fangstene) på 1970-tallet er ikke unike. Forskere konstaterte store endringer i gyteområder og utbredelsesområde av yngel i Nordsjøen i løpet av 1970-tallet. Enkelte områder i vestre del av Nordsjøen opplevde totalt fravær av yngel i de siste årene på 1970-tallet.

Rapporten fra 1986 forteller at det i området rundt Orknøyene ikke ble funnet larver i 1979, eller i de påfølgende årene.

Selv om endringer i fartøy, fangstkapasitet og forskernes metodikk i Nordsjøen var i endring, konkluderte nevnte arbeidsgruppe for brisling i 1986 med at «there appears to have been a major decrease in the spawning population sometime between 1977 and 1979» og, om toktene at «these surveys also indicate a major and sudden decrease in the abundance of spawners between 1977 and 1980». Forskerne ser dette delvis i sammenheng med økt fiske-press utover 1970. De økte fangstene av brisling på 1970-tallet sees i sammenheng med at lokale, sesongbaserte og kystnære fiskerier i Nordsjø-bassenget ble supplert av et nytt og ekspansivt havfiske på begynnelsen av 1970-tallet. På grunn av økende innsats og økt effektivitet klarte man å opprettholde et høyt uttak av brisling i flere år etter at man så de første tegn på en bestand i sterk tilbakegang.

At også totalkvantumet av oppfisket kystbrisling holdt seg oppe på store deler av 1970-tallet, skyldes i stor grad et nytt og nesten eventyrlig brislingfiske nord for Stadt. Samtidig effektiviseres også fisket for kystbrisling.

Fra tidlig 1980-tallet viste undersøkelser at brislingbestanden var i fortsatt fall og at hovedtyngden av havbrislingen var å finne i den sørlige og sørøstlige delen av Nordsjøen. Arbeidsgruppen så nedgangen i bestanden i Nordsjøen i sammenheng med nedgangen i de lokale forekomstene i fjordene på Sør-Vestlandet på 1970-tallet.



Figur 1

3.0 Brislingfiske i Osterfjorden

Osterfjorden var lenge en god og sikker fjord for brislingfiske, selv om det ikke var her de helt store fangstene ble tatt. I Hordaland var Osterfjorden gjerne den fjorden man søkte til når man ikke visste hvor man skulle lete etter brisling. Dette kom dels av at Osterfjorden ligger lunt til og at fangsting derfor ikke er så vær-avhengig. Samtidig var området rundt Vikanes (i fjordens nordøstre del) et område man gjerne kunne oppleve et par dager sammenhengende med gode fangster.

Også lengre inne i fjorden ble det tatt fangster; både på østsiden og på den sørøstre siden av fjorden. Fiskere nevner følgende områder der det ble kastet etter brisling: Midtsundet, området mot Heimvik, Romarheimsfjorden (mellom Vikanes og Mostraumen), Gammersvik, Eidslandet, Stamnes, Veå (utenfor Stamnes) og ved Vaksdal.

Enkelte år ble det oså fangstet i den lange fjordarmen inn mot Mo som utgjør fjordsystemets nordligste ende. Innenfor Mostraumen syntes det å være et eget basseng der yngel vokste opp og overvintret. Hvorvidt det ble fiske i dette området var altså helt avhengig av tilsig av yngel året før.

Her inne var tilførselen av ferskvann til overflatevannet et problem under lås-setting ettersom ferskvannet kunne ta knekken på brisling som stod i lås.

I den sørvestre delen av Osterfjorden var det helst sild det ble kastet på.

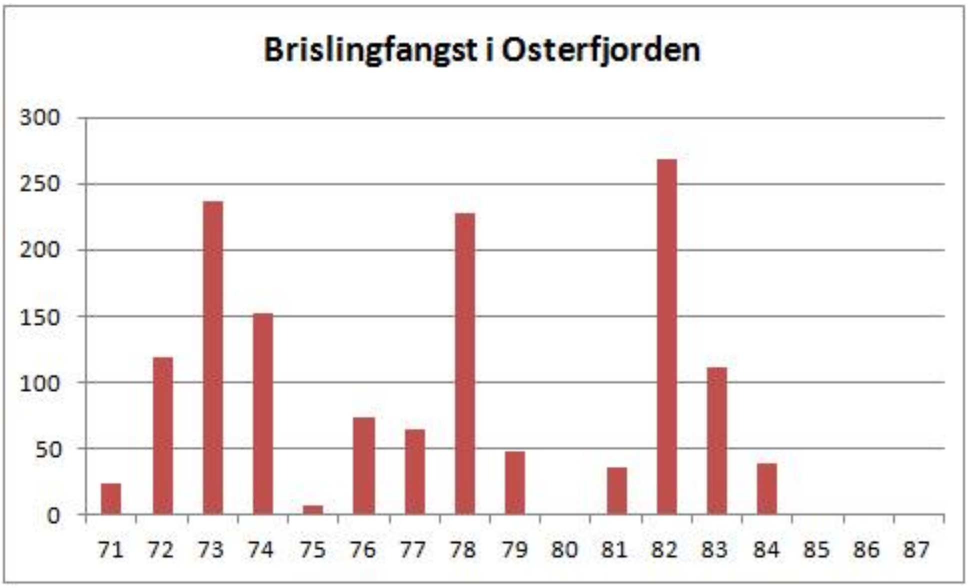
Når det gjaldt brislingfisket, var ingen ting sikkert – ei heller i Osterfjorden. Variasjonene var store fra år til år, også i år som totalt viste seg å gi gode totalkvantum. I 1959 ble det tatt ca 23.300 skjepper brisling i Osterfjorden og i 1963 bare omlag 15.800 skjepper. Det kan nevnes at 1963 likevel var et meget godt år totalt sett for Hordaland med 451.712 skjepper mot eksempelvis 54.988 skjepper i 1958. Variasjonene i brislingfiske var altså enorme, både lokalt og regionalt. Man må her ta hensyn til at dårlige åteforhold kunne gi så lav fettprosent at fisket ble stanset i områder og gjerne i store deler av sesongen. Erfarne brislingfiskere kan ikke minnes at Osterfjorden ble stengt for fiske. Her var brislingen alltid av god kvalitet. Åpning og stenging av områder vil også påvirke fiskeristatistikken på en slik måte at den ikke nødvendigvis viser hvor det er mest brisling, men heller hvor det er funnet og fisket brisling av god nok kvalitet.

I perioden da det ble fisket brisling i Osterfjorden observerte fiskerne to særtrekk ved fjordsystemet. Det ene var den store mengden med svartåte (beskrevet som små sneglehus) i tillegg til raudåte. Svartåta har muligens en del å si for det andre særtrekket som omhandler brislingens raske vekst i fjorden. Om høsten kunne man drive fiske på 0-gruppe-brisling. Særs gode oppvekstvilkår for brislingen førte til at veksten kunne kvalifisere til hermetikk-størrelse (ca. 9 cm) allerede på høsten. Fiske på 0-gruppe var likevel ikke noen stor del av det totale fiske i Osterfjorden.

Fiskerne opplevde også de store mengder med yngel som inntok fjorden. Enkelte år kunne det være «ei plage» når not-maskene ble tettet igjen av enorme mengder yngel under fiske på voksen brisling. Yngel fulgte ofte land på sin vandring, og da gjerne på sørsiden av fjorden. Yngel-toktene til HI på høsten ble derfor en indikator som fiskerne kunne multiplisere på bakgrunn av at yngel-tellingen ikke kunne foretas der yngel-tettheten var størst – altså helt oppunder land. Selv om både fiskere og forskere kunne ha store håp ut fra yngeltokt og egne observasjoner, var det ingen garanti for godt fiske i samme fjord neste år. Selv de mest erfarne brislingfiskerne avsluttet sitt yrkesliv uten å ha svar på brislingens uforutsigbarhet. Yngel-tokt og observasjoner stemte gjerne med det totale bildet året etter, men man kunne ikke spå hvor (altså; i hvilken fjord) fangstene ville bli tatt.

Nedgangen i fisket sør for Stad var markant i fangststatistikken fra 1970 med et lite oppsving i 1973. Allerede på 1970-tallet synes Osterfjorden å bli et ustabilt fangstfelt, og deler denne skjebnen med andre fjordområder i Midt-Hordaland. Osterfjorden er sjelden nevnt i årsrapporter eller i HI's «Fisken og Havet». Fra midten av 1970-tallet reiste fiskerne sør for Stad dels nordover (Årsmelding fra NSSL 1975) etter en meget dårlig sesong i 1975. I 1980 ble ingen brisling fisket i Osterfjorden.

I 1983 ble det tatt 1773 skjepper i Osterfjorden distrikt. Olav Åsvang som da hadde brisling-sjarken «Lyngnes» kjørte rundt hele Osterøy i 1983. Han fant brisling både ved Vikanes og ved Gammarsvik. Selv kastet han ikke, men han vet at andre tok fangst i fjorden. Han mener også at det ble gjort et lite landnotsteng, men dette ble nødvendigvis ikke meldt inn. I 1984 og 1985 var det ikke fiske i Osterfjorden (noe som nevnes spesielt i årsmeldingene fra Norges Sildesalgslag). Likevel viser fiskeristatistikken (se figur 2) et lite kvantum brisling i 1984.



Figur 2. Fiskeristatistikken viser store årlige svingninger etter 1970. Grafen viser brisling fra tre områder som tilhører Osterfjord-systemet; Vaksdal, Modalen og Osterøy.

3.1 Brisling i Osterfjorden etter 1985

Selv om Osterfjordens tid som en sikker brisling-fjord forlengst var slutt, var det fremdeles to fartøy fra Flatøy («Solberg Junior» og «Solundøy») som søkte etter brisling i fjordsystemet. Mellom 1985 og 1990 ble det tatt enkelte fangster i fjorden. Dette forteller Kurt Solberg som da fisket brisling i Osterfjorden med egen båt («Solberg Junior») som han anskaffet i 1985. Det var da helst stor brisling, gjerne i størrelse 14 – 17 cm. (altså minst 3 år gammel). Denne ble fisket på høsten og gikk til ansjos (og for det meste levert til Davanger på Askøy). Det som var igjen av brisling i Osterfjorden frem mot 1990-tallet var altså dominert av eldre fisk.

Angående fangsting i Osterfjorden fra 1984 til 1994 gir kildene (statistikk, årsmeldinger og muntlige kilder) ulike data. Små kvanta, sammenslåinger av områder og levering til ansjos kan ha gjort at Osterfjorden noen ganger ble utelatt fra enkelte kilder.

Utviklingen av fisket var naturlig i den forstand at flåten som opererte i Osterfjorden da var redusert til to mindre - og lokalt tilhørende - fartøy som hadde kort vei til en fjord som inviterte til et usikkert og begrenset fiskeri. Det var heller ikke noe forsøksfiske etter brisling i Osterfjorden i denne perioden.

Norges Sildesalgslags database – som går tilbake til 1995 – viser ingen fangster i Osterfjorden mellom 1995 og 2012

3.2 Yngel i Osterfjorden i nyere tid

I områdene ved Vikanes og ved Arna har det vært observert brislingyngel fra omkring 2005 og enkelte år deretter. Den er observert jaget opp i fjæresteinene av predatorer, og den er funnet i magesekker på hvitfisk i området. Også mengder av død yngel i fjæresteinene ved Vikanes er sett ved en anledning. Observatøren mente at yngel hadde blitt skremt/jaget opp i taren – men andre årsaker til slik yngel-død kan ikke utelukkes.

Til tross for at yngel har vært synlig tilstede, er det ikke tatt brisling-fangster i Osterfjorden på 2000-tallet. Tilsiget av yngel er uansett ikke stort nok til å gi fiskbare mengder av voksen brisling, ei heller danne grunnlag for en lokal bestand av fiskbar størrelse.

Bedre - og mer detaljerte data - angående yngelforekomster bør finnes i toktrapporter fra HI.

Til tross for flere årlige observasjoner av noe yngel, er det ikke funnet fiskbare forekomster sent på høsten eller det kommende året. Det må her legges til at dagens brislingfiske i stor grad styres av oppkjøpere som dirigere fiskeflåten. Ei heller er det letefartøy i fjorden. Man kan derfor ikke utelukke at det har vært fiskbare forekomster i Osterfjorden og i andre tidligere «brislingfjorder». Det er grunn til å tro at de små mengdene yngel som overlever sommeren og høsten, ikke klarer å bidra med yngel til neste årsklasse. En tidligere brislingfisker – Kurt Solberg – fra Flatøy har i mange år tatt turen inn i fjorden for å se etter livstegn fra brisling. Han har ikke registrert hverken brisling eller fugl.

Den største naturlige trusselen mot disse små sammenkomstene av brisling og brislingyngl er kanskje makrellen. I nyere tid har deler den store makrellbestanden årlig inntatt kysten og fjordene på jakt etter mat. Brislingfiskere merker dette meget godt ettersom pir og makrell sprer brislingstimene på dagtid i de store fjordsystemene. Stimene med makrell trenger mye næring, og beiting på små «brisling-dotter» i mindre fjordsystem og fjordarmer kan effektivt avlyse overvintring av brisling. I Osterfjorden er det naturlig at makrellen også beiter på yngel og småfisk av andre lokale arter og bestander. Fiskere mener at et sterkt beitepress fra makrellen startet på slutten av 1980-tallet.

3.3 Andre arter og predatorer i Osterfjorden.

Selv om voksen brisling ikke er å finne i mengder i Osterfjorden, har predatorene fått andre muligheter. Opplysningene nedenfor bygger kun på muntlige kilder som har drevet (eller driver) fiske eller fritidsfiske i Osterfjorden.

Fra slutten av 1980-tallet har det vært observert flere typer sild i fjorden. De siste 10 årene har både høstgytende og vårgytende sild opptrådt regelmessig. En fisker forteller om to typer vårgytere i nyere tid, der den ene typen (en slank type) kan tilhøre en lokal bestand som har oppstått etter larvedrift fra gytefeltene fra Karmøy og nordover, og en feitere type som antakelig er innsig fra NVG-sild på gytevandring. Silda i fjorden viser seg helst i småfiske med garn, men det er også gjort kast på småsild. .

Andre særtrekk ved faunaen i Osterfjorden er at det ikke tas hummer i fjordsystemet og at stor torsk er en sjeldenhet. Likevel er torsk den mest interessante arten for fritidsfiske. Det meldes om et årlig innsig av småtorsk. Både på pilk og med ruser tas det en del småtorsk på våren og sommeren. Størrelsen er som regel fra 1-2,5 kg, og nesten aldri over 3 kg. Denne torsken er ikke å finne om vinteren selv om fritidsfiskere da også forsøker større dybder. Oppfatningen er at den unge torsken trekker inn i fjordsystemet om våren, men det er uvisst hva som lokker den. Om det kan ha en sammenheng med observasjon av brisling-larver er uvisst. En fritidsfisker som hadde sett på mageinnholdet til noen av torskene, forteller at småkrabbe dominerte.

Det vil naturlig nok også være sei, lyr, lange, brosme, sjøfugl og andre typiske predatorer i fjorden. I sjøen er det likevel de pelagiske artene (sild og makrell) som er dominerende. Generelt har det vært – og er det - lite hvitfisk i fjorden. Brislingfiskerne forteller at de gjennom alle år hadde med seg matfisk på brisling-turer til Osterfjorden. Lite hvitfisk gav også «renere» brislingfangster (uten innblanding av andre arter).

De siste 10 årene har det også blitt mye taskekrabbe i fjorden (noe som fiskerne dels irriterer seg over). I enkelte områder er det også svært mange kråkeboller.

Osterfjorden har også vært en meget god fjord for ålefiske – da dette var lovlig.

Innsig og tilstedeværelse av makrell om sommeren og høsten, merkes også i Osterfjorden. Makrellen går rundt hele Osterøy, og størrelsen oppgis som liten, men likevel større enn pir. En viss innblanding av større makrell er også observert.

Vinterstid er det lite å få for fritidsfiskere. Små-lange nevnes, men torsken er helt fraværende.

4.0 Sammendrag

«Osterfjorden var aldri noen stor brislingfjord», forteller en eldre brislingfisker. For små båter - og i dårlig vær - var den likevel et godt og sikkert alternativ for brislingfiskerne, spesielt frem til slutten av 1960- tallet. De ujevne forekomstene (fangstene) på 1970-tallet, gjorde at fiskerne nedprioriterte Midhordland som fangstområde. Man fant «urørte» brislingforekomster i nord (Trondheimsfjorden, Namsen mf.), og prioriterte de store fjordsystemene (Hardangerfjorden og Sognefjorden). Fangster ble likevel tatt i Osterfjorden utover 1970-tallet, men de dårlige og svarte åren kom oftere.

Et lite lyspunkt kom tidlig på 1980-tallet. Etter den tid ble det enkelte år bare tatt noen få fangster av gammel fisk på slutten av 1980-tallet. Yngel er observert, men dette har ikke resultert i kommersielt fiskbare forekomster. Våre dagers brislingfiske tilsier ikke at det blir gjort forsøksfiske i slike fjorder, og man kan derfor heller ikke utelukke at det i enkelte år kan være små forekomster (eller det som på 1960-tallet hadde vært verdt å kaste på) av brisling i fjordsystemet. De tre største naturlige predatorer for brisling-larver og yngel (og annet yngel) de siste 10-20 årene, synes å være makrell, sild og torsk. Fiskerne er samstemte når de peker på et økende innsig av makrell fra slutten av 1980-tallet, og at dette har vært den viktigste faktoren som hindrer etablering av brisling-forekomstene i Osterfjorden og flere andre fjorder. Fiskerne er også enige om at innsig av lokale komponenter av NVG-sild i en fjord, også vil beite ned brisling-yngel. To store pelagiske bestander kan derfor være hovedårsak til at en annen pelagisk art ikke klarer å reise seg.

uni Miljø
Laboratorium for ferskvannsøkologi og innlandsfiske (LFI)

Ferskvannsøkologi - laksefisk - bunndyr

LFI ble opprettet i 1969, og er nå en seksjon ved Uni Miljø, en avdeling i Uni Research AS, et forskningsselskap eid av universitetet i Bergen og stiftelsen Universitetsforskning Bergen. LFI Uni Miljø tar oppdrag som omfatter forskning, overvåking, tiltak og utredninger innen ferskvannsøkologi. Vi har spesiell kompetanse på laksefisk (laks, sjøaure, innlandsaure) og bunndyr, og på hvilke miljøbetingelser som skal være til stede for at disse artene skal ha livskraftige bestander. Sentrale tema er:

- Bestandsregulerende faktorer
- Gytebiologi hos laksefisk
- Biologisk mangfold basert på bunndyrsamfunn i ferskvann
- Effekter av vassdragsreguleringer
- Forsuring og kalking
- Biotopjusteringer
- Effekter av klimaendringer

Oppdragsgivere er offentlig forvaltning (direktorater, fylkesmenn), kraftselskap, forskningsråd og andre.

Våre internettsider finnes på www.miljo.uni.no