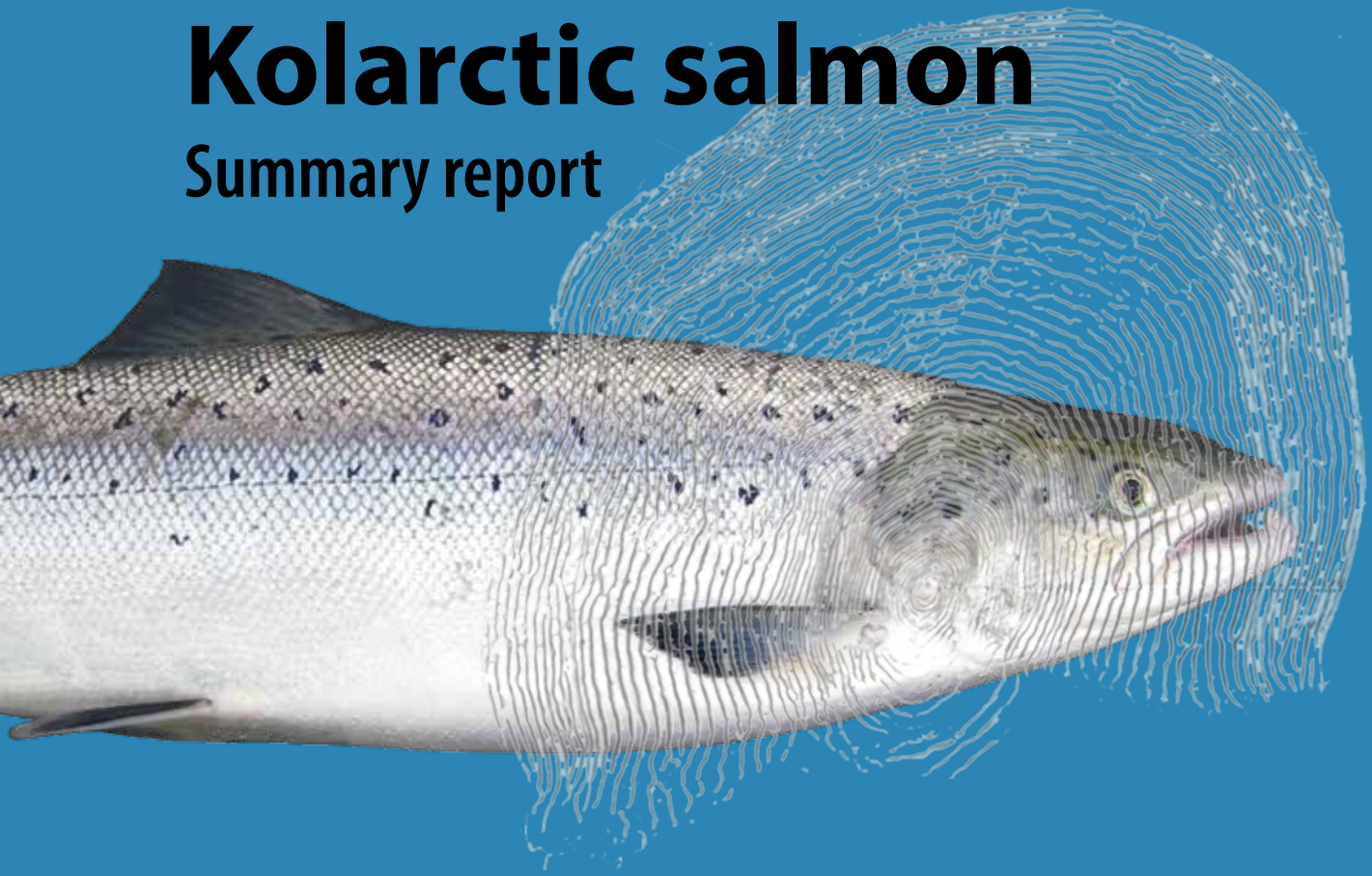
Kolarctic salmon

Summary report



"Merging modern science with traditional knowledge to improve the future management of the Atlantic salmon in the Barents region"

Office of the Finnmark County Governor
Department of Environmental Affairs
Report 1-2017

Kolarctic salmon

Summary report

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Eero Niemelä

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KOLARCTIC SALMON SUMMARY REPORT
REPORT 1-2017
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Preface

The border areas between Norway, Russia and Finland have unique natural qualities and natural resources. The Atlantic salmon is a symbol of healthy and vital ecosystems and is of significant economic and cultural importance, both through commercial and recreational fishing.

The *Kolarctic salmon* project was a unique venture between scientists, managers and commercial fishermen from Northern Norway, Finland, Northwest Russia and the White Sea area, aiming at providing a better knowledge-base for salmon management in the individual countries.

Through the joint effort, we managed to establish a unique sampling program along the North-Norwegian coast and in Russian Barents and White Sea areas, generating the most comprehensive biological sample collection, and ecological and genetic data sets for Atlantic salmon until now.

Overall, the project results provide opportunities for developing a knowledge-based and adaptive salmon management. We hope our efforts will contribute towards maintaining a future sustainable exploitation of the northernmost Atlantic salmon populations in Europe.

- **We found the salmon's home-river**
  We created a unique genetic map of the northern salmon stocks, with comprehensive information on the salmon rivers and the different salmon stocks in the area, including their genetic diversity. This allowed us to identify the river and region of origin of each individual salmon caught at sea with high probability.

- **We mapped the salmon's migration patterns**
  We developed a stock-specific migratory model to describe inference of spatial and temporal migratory patterns for chosen salmon stocks in the Barents region. The results demonstrated that catches from outer coastal regions have a higher stock diversity and a lower percentage of local stocks than catches in the inner fjord regions.

- **We identified the salmon stocks exploited in Northern Norway**
  We gathered information and examined the stock composition of the mixed-stock fisheries catches in Northern Norway.

- **We estimated the amount of farmed salmon in Norwegian coastal fishery**
  We found that escaped farmed salmon occurred in the coastal fishery catches of Northern Norway throughout the summer from early May to the end of September.

- **We reached a mutual understanding of our rich fishing traditions**
  The project facilitated a more active communication, dialogue and contact between the countries' management, research, fisheries associations and local fishermen. Through mutual visits and meetings, we reached a better understanding of the rich fishing traditions, coastal and Sami culture of the area.

Introduction

The border areas between Norway, Russia and Finland have unique natural qualities and are rich in natural resources. The Atlantic salmon (*Salmo salar*) is a symbol of healthy and vital ecosystems and is of significant economic and cultural importance, both through commercial and recreational fishing. Fishing for Atlantic salmon has a long tradition in the area, as evidenced by a unique vocabulary about the species in the Sami language, and the existence of a large number of traditional fishing methods. Because of its accurate natal homing, it is presumed that every salmon river has its own unique population adapted to physical and biological characteristics of the river, and some rivers have even several unique sub-populations.

The *Kolarctic salmon* project was a unique venture between scientists, managers and commercial fishermen from northern Norway, Finland, Northwest Russia and the White Sea area, aiming at providing a better knowledge-base for the countries salmon management.

Through our joint efforts, we gathered a unique bio-specimen sample collection along the North-Norwegian coast and in Russian Barents and White Sea areas, generating the most comprehensive ecological and genetic data sets for Atlantic salmon until now, over 25 000 adult salmon samples from the sea and over 12 000 juvenile salmon samples from 185 rivers were collected and included in the project.

Why salmon is important for people along the coast?

Culture and history of the traditional coastal fisheries in Norway and Russia

Russia

The first references of regular salmon coastal fishery in Russia are from the Pomors, fishing along the White Sea coast. This fishery has been documented in the chronicles of Novgorod of the 1300s, showing that the Pomor lifestyle has been influenced for centuries by the salmon sea fishery, which also became the fundament for Pomor villages and settlements. The coastal salmon fishery remains an important source of income for Pomor villages today. However the effort in commercial coastal fisheries in the White Sea has been reduced considerably since the1990s, aiming at conserving Atlantic salmon stocks and enhancing recreational in-river fisheries.

Coastal salmon fisheries in the Barents Sea have not been permitted over the past 60 years. The coastal catches in the White Sea fluctuated from around 50 tonnes in 1990s to around 30 tonnes since the year 2007. The total allowable catch for Atlantic salmon is established annually. Commercial, recreational and Sami net fisheries are allowed at defined fishing sites

Figure 1. Kolarctic salmon project area. Blue dots indicating the coastal adult salmon samples in Norway and red dots indicating the in-river juvenile salmon samples

only. In Russia the Regional Commissions on Regulation of Harvesting the Anadromous Fish allocate quotas to users of fishing sites. The Territorial Directorates of the Federal Agency for Fisheries issue licenses for users of the fishing sites in accordance with the quota allocation.

Finnmark and northern Norway

A multi-stock Atlantic salmon sea fishery operates off the coast of Finnmark, the northernmost county in Norway. The annual catches at sea in Finnmark the last 20 years have been around 100–200 tonnes and in the rivers around 100–150 tonnes with high annual fluctuations. The sum of the river and sea-fishery catches in Finnmark constitutes around 50 % of the total catch of Atlantic salmon in Norway. The salmon sea-fishery in Finnmark has long cultural traditions, but has been under strong debate the last 10 years due to the complexities involved in the potential mixed stocks harvesting of Norwegian, Russian and Finnish salmon during the sea-fishery along the North-Norwegian coast.

The coastal salmon fisheries along the coast of northern Norway have been an important economic and cultural factor since the 1800s and in some areas of Eastern Finnmark, such as Jarfjord and Bøkfjord, even earlier. The shore-based coastal fisheries were from the beginning an integral part of a flexible combination household economy based on sea fisheries, reindeer husbandry and farming, supplemented by hunting and gathering.

The shore-based coastal catch in northern Norway, with bag- and bend nets, peaked during the 1950s and 1960s, driven by better fishing gear and easier access. A new peak was seen in the late 1970s/early 1980s, driven by offshore drift net fishery. In the best years, the coastal catch in Finnmark alone was close to c 500 tonnes. Weakening stocks in the northern rivers led to the closure of the drift net fishery in 1989. In the following decades, the shore-based coastal fishery has been increasingly regulated and the catches and number of active fishermen have declined rapidly.

Challenges with a mixed-stock fishery, can it be solved?

Mixed-stock fisheries are defined as fisheries exploiting a significant number of salmon from two or more river stocks. In a mixed stock fishery, some exploited stocks could be at full reproductive capacity, while other stocks may be below their Conservation Limits. This creates a challenge for management, particularly in coastal waters or on the high seas, because it is difficult or impossible for the fisheries to target only the stock at full reproductive capacity. Rational management of mixed-stock fisheries requires knowledge of which stocks that are exploited in the fishery and the status of each of those stocks.

The *Kolarctic salmon* project provides the countries' management authorities with unique a possibility and reliable basic information and tools for development of future adaptive management regimes.


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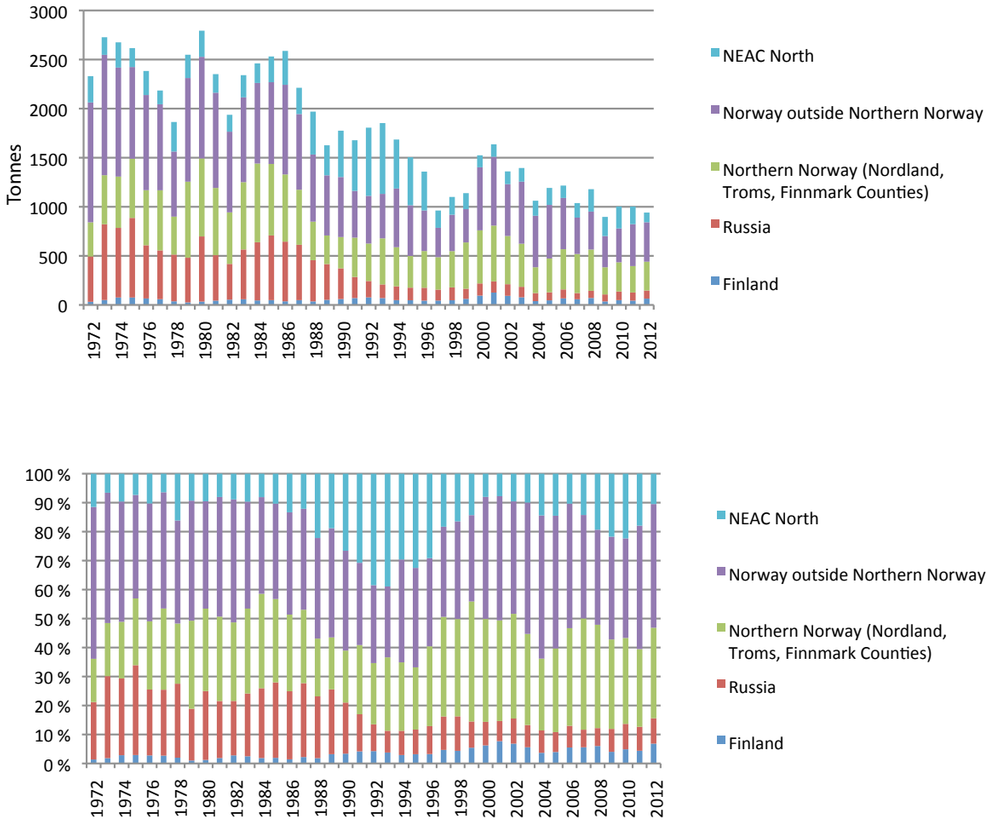


Figure 2. Nominal catches of salmon (rivers and sea, in tonnes and %) in Northern countries (northern NEAC area of NASCO) by country and by region (for Norway) in 1972-2012 (ICES, 2013). NEAC North (= Island, Sweden only).

Chapter 1
Ecology and life history of the Atlantic salmon in the north

Atlantic salmon is an anadromous fish, reproducing in fresh water and spending its adult life at sea. Pea-sized eggs develop for 6-8 months in redds (a hollow in the riverbed made by the spawning fish) in rivers. Hatched juveniles then grow in the freshwater environment for 2–8 years and after reaching a length between 12 and 24 cm they transform to "smolts" and leave their natal rivers for ocean feeding migrations. After one to five years at sea, salmon mature and start navigating back to their natal home rivers to spawn. The return migration may cover thousands of kilometres from feeding grounds in the North Atlantic to the home rivers. A small proportion of salmon survive spawning to repeat their sea and spawning migrations, i.e. repeat spawners.

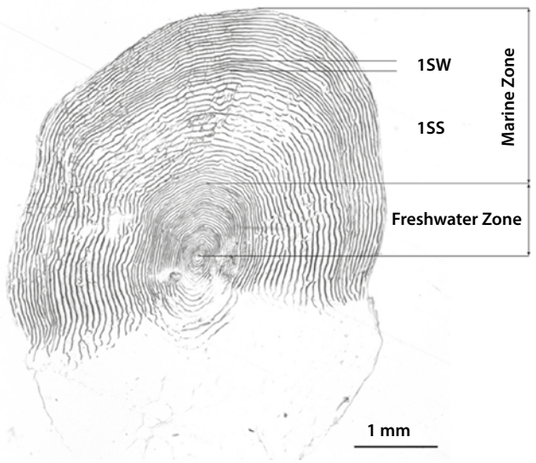
For these reasons, salmon caught in fisheries in the fjords and outer coastal areas constitute a high diversity of life-history types originating from a wide range of rivers. In the *Kolarctic salmon* project we investigated the life-history characteristics of salmon caught in the coastal fisheries. One-sea-winter, salmon returning to natal home river to spawn after one year at sea, two-sea-winter – two years at sea and so on.

- **Salmon age structure show that they originate from multiple spawning years**
  The mean smolt age of Atlantic salmon in the North and the Barents Sea rivers is c 4 years and the mean smolt age for salmon in the White Sea rivers is c 2–3 years. There are many smolt and sea-age combinations observed, and this wide variety of different age groups indicates that catches at sea are originating from multiple spawning years and smolt cohorts.

- **Female salmon of all ages and older males return first to the coastal areas**
  Older salmon (=multi-sea-winter, MSW), i.e. two-, three- and four-sea-winter salmon and repeat spawners return to the coastal areas earlier than one-sea-winter salmon. C 60 % of the catch in May-June consists of two- and multi-sea-winter salmon, whereas the one-sea-winter salmon catch is highest in July (Figure. 3). Females in all sea-age groups arrive earlier to the coastal areas than the males.

- **Majority of the White Sea catch consist of autumn run one-sea-winter salmon**
  99% of salmon from the White Sea rivers of the Murmansk region are one-sea-winter autumn run salmon, the rest 1% are two-sea-winter and repeat spawners. Salmon from rivers of the Archangelsk region has a higher proportion of two- and three-sea-winter salmon. Over 70% of the fish in September and October were two-sea-winter salmon. No repeat spawners were found in samples in the Archangelsk region during the project.

- **Salmon caught in the White Sea fisheries originate from the White Sea rivers**
  None of the adult salmon sampled in the White Sea area originated from the rivers outside the White Sea basin. The bulk of salmon originated from 17 different rivers of the Murmansk region. 70% of the commercial coastal catches in Tersky cost of the Murmansk region consisted of fish from the Varzuga river.



Atlantic salmon scale image. This salmon spent four years in the river before its seaward migration as a smolt, then it spent one summer and one winter feeding at sea before migrating back to its home river to spawn. The age of this salmon is five years.

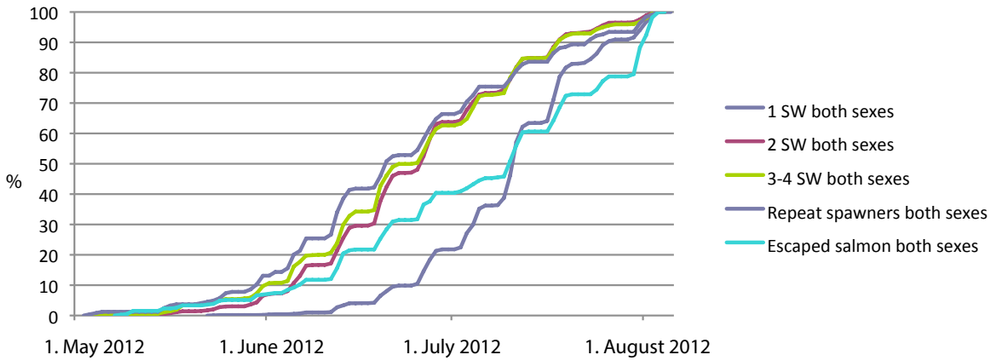


Figure 3. Cumulative catches (in %) in coastal areas for female and male 1-4 sea-winter salmon (SW), repeat spawners and escaped farmed salmon throughout the summer 2012 in Finnmark County

Chapter 2
Genetic structure of the northern salmon populations

The *Kolarctic salmon* project collected and analysed thousands of juvenile salmon samples from rivers spanning a large geographical area with the aim to describe the genetic variation of salmon stocks. Genetic profiling of salmon inhabiting different rivers allowed assessing their relationships as well as building a genetic baseline for the salmon in the Barents region. In earlier genetic studies covering part of this area, it has been suggested that the currently observed genetic patterns are the results of colonization processes after the last glaciation as well as contemporary evolutionary processes. The rivers in the area are diverse both in physical conditions, biological conditions and life history patterns of the salmon. This is also reflected in the genetic structure.

- **The main genetic barrier is observed between the eastern Russian populations and populations on Kola Peninsula and northern Norway**
  Major genetic divisions were found at different geographical scales; the main genetic barrier appeared between the eastern populations of Russia, including the White Sea populations, and populations from northern Kola and northern Norway (Figure. 4).

- **Eastern Russian salmon populations have the highest genetic divergence**
  The level of genetic differentiation between populations, overall and within a region, was highest for the eastern populations of Russia and lowest for the western populations of northern Norway.

- **Salmon rivers of the study area were grouped in seven separate regional groups**
  Genetic barriers/shifts were observed also at finer geographic scales, allowing for the definition of reporting groups for individual assignment (Figure 5).

- **Larger river systems foster multiple salmon populations**
  Genetic structuring was observed also within the major river systems such as Pechora, Ponoi and Tana/ Teno. These river systems thus appear to foster multiple salmon populations, a valuable quality which should be taken in to account devising management plans.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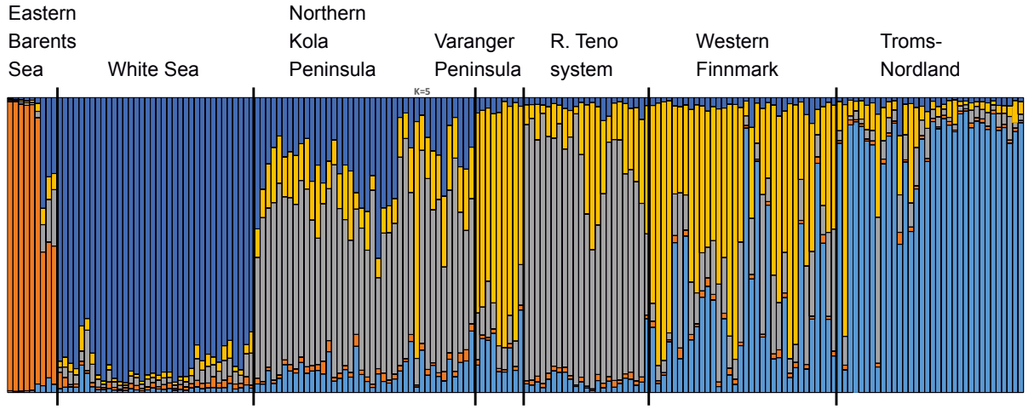

Figure 4. Plot showing the main genetic barriers observed. The plot shows how the salmon populations in the area can be divided into seven main groups. In the plot, each bar represents one population, and the colors represent their "membership" in the main clusters.


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Chapter 3
Genetic stock identification - Identifying the river of origin for salmon at sea

Atlantic salmon have a predisposition to return to their natal river to reproduce, a behaviour known as *homing*. Because of this accurate natal homing, salmon inhabiting different rivers are largely reproductively isolated from each other. Colonization patterns after the last glaciation, evolutionary processes and the reproductive isolation have resulted in accumulation of significant genetic variation among salmon populations in different rivers.

The genetic differences between populations and geographic regions provide a genetic "tag" or "fingerprint" showing river or region of origin for salmon caught in the sea. By comparing the genetic fingerprint of the individual salmon to the genetic compositions of all potential river stocks, the river of origin can be determined with a certain probability.

- **We found the salmon's home-river**
  Genetic stock identification (GSI) allowed the partitioning of samples from the mixed-stock fishery catches into smaller units and if not always representing single rivers, representing regions with genetically similar stocks (Figure 5). At regional level the power of resolution was high throughout the study area. In general, salmon from the largest river stocks could be assigned to their river of origin with high probability.

- **Identification of salmon from Tana/ Teno river system and the Russian rivers was most precise**
  Highest accuracies were observed for rivers in the Eastern Barents and White Sea and River Tana/ Teno system salmon stocks (90%), while lowest were observed for the Troms and Nordland stocks (54%). Individuals from Russian rivers and River Tana/ Teno system were correctly identified to their respective regions with 94-99% accuracy, while slightly lower assignment success was obtained for the samples from rivers in Finnmark County; 86%, Troms County; 80% and Nordland County; 72%.

- **Genetic analyses confirm exploitation of multiple stocks by coastal fisheries**
  Genetic stock identification analyses confirmed that coastal fisheries exploit multiple stocks. Altogether, >140 rivers were found to contribute to fishery samples. Fisheries generally exploited salmon from wide geographical areas with catch localities on the open coast showing greater stock diversity than catch localities within fjords.

Figure 5. Map with regional groups of salmon stocks

Chapter 4
The big coastal migration

Migratory patterns of Atlantic salmon stocks

To determine the home river of the captured salmon, each fish was compared to genetic profiles from 185 river stocks in the Barents Sea area. Thus, more than 16 500 of the salmon captured in the Kolarctic salmon project, could be identified to the river of origin, and consequently be used to describe the coastal migration pattern of the different Barents Sea stocks. Further, a stock-specific migratory model was developed for some of the largest stocks, i.e. Målselv salmon in Troms County, Alta and Tana/ Teno river salmon in Finnmark County and the Kola river salmon in the Kola Peninsula, Russia.

- **We mapped the salmon's migratory patterns**
  Most Atlantic salmon stocks reached the North-Norwegian coast in June-July, with the multi- sea-winter salmon arriving almost a month earlier than the one- sea-winter salmon.

- **Målselv salmon display an accurate homing behaviour**
  The Målselv stock, being the largest salmon stock in Troms County, approached the coast more or less directly from the open sea, i.e. showing an accurate homing from the open ocean. This was true both for multi-sea-winter and one-sea-winter salmon.

- **Alta salmon display a more widespread homing behaviour**
  The large Alta stock, and especially the multi-sea-winter fish, approached the western coast of Finnmark fairly directly from the open sea, although in a broader area compared to the Målselv river salmon. The one-sea-winter Alta stock entered the coastal waters in a more widespread manner.

- **Tana/ Teno salmon approach the coast both form west and east**
  Tana/ Teno salmon reach the coastal areas both from southwest, west, north and east, i.e. approaching the coast from all over the Barents Sea.

- **Russian salmon migrate earliest along the coast**
  Most Russian Atlantic salmon approached the North-Norwegian coast in Eastern Finnmark, whereas a small portion approached the western Finnmark coast in May, before migrating eastwards. Russian salmon populations were caught in the Varangerfjord until late August - in the research fishery.

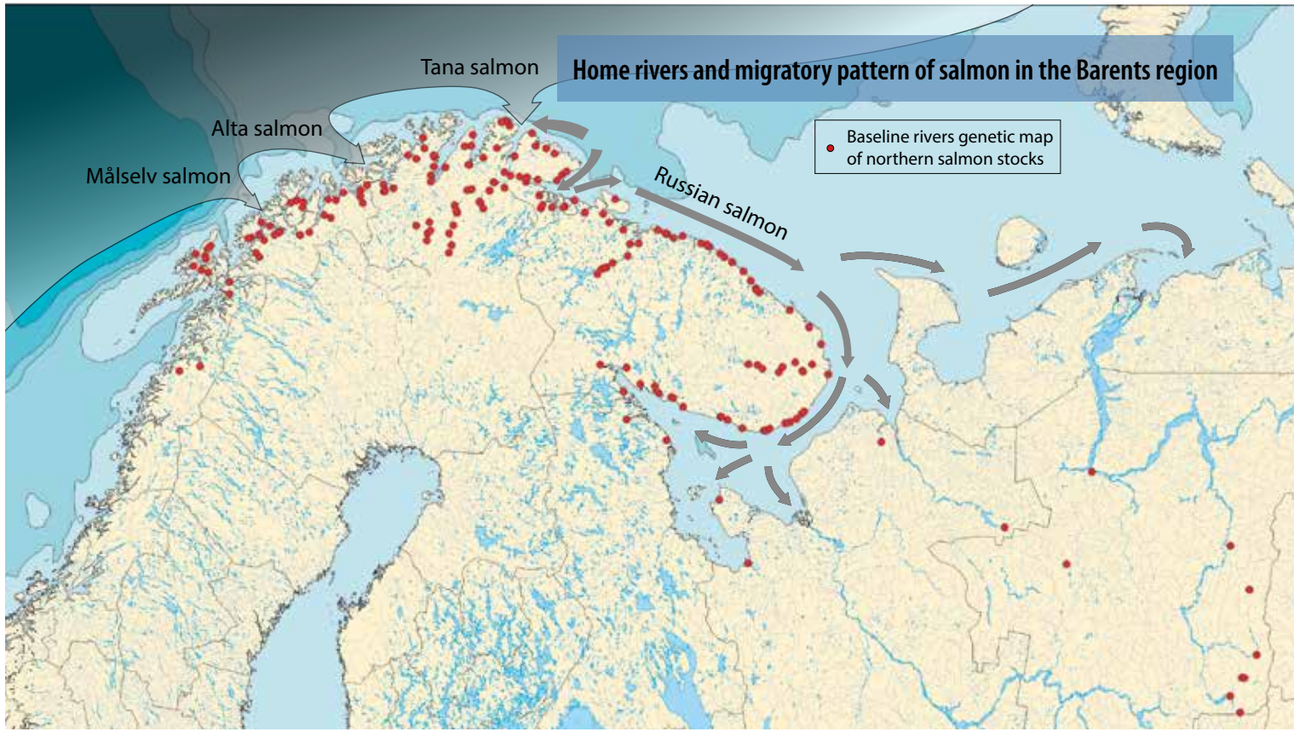

Figure 6. The Målselv salmon stock approaches the coast fairly directs from the open sea. Alta salmon stock approaches the western coast of Finnmark also fairly directly from the open sea. The Tana salmon reach the coastal areas both from the west, north and the east, i.e. approaching the coast from all over the Barents Sea. The Russian stocks seem to migrate along the outer coastal region and are mainly exploited in the eastern part of Northern Norway, in the Varangerfjord area.

Chapter 5
Which salmon stock is caught where?

In Finnmark the official fishing time for coastal fisheries covers a period from June 1st to August 4th, with many spatial and temporal differences between the municipalities. The official fishing time in Troms and in Nordland Counties is limited to six–eight days in July.

According to the official catch statistics the highest wild salmon catches in 2011 and 2012 were taken in Sør-Varanger municipality, Finnmark. Genetic identification tools allowed assessing the contribution of different salmon rivers to the reported catches of Norwegian coastal fisheries. Especially in Troms and Finnmark Counties the salmon catch consisted of fish from a large geographical area; however there are remarkable differences in the catches on the municipality level.

- **The bulk of salmon caught in northern Norway originated from rivers in western Finnmark**
  Most salmon caught on the coast of northern Norway during the official fishing time in 2011 and 2012, originated from rivers in West Finnmark (40%), while Russian, East Finnmark, Tana/ Teno system and Troms rivers, as well as farmed salmon contributed nearly equal amounts (7-18%) (Figure 7).

- **We identified salmon stocks exploited in northern Norway (Finnmark) - numbers of individual salmon harvested in 2012**
  During the 2012 fishing season coastal fisheries of northern Norway (Finnmark) harvested c 4500 individual salmon originating from Russia, 3400 individual salmon originating from East Finnmark, 4500 salmon from Tana/ Teno river, 10 800 salmon from rivers in West Finnmark, 3400 salmon from rivers in Troms, and only 250 salmon originating from rivers in Nordland.

- **70% of salmon harvested in Finnmark County is of Norwegian origin**
  Of the c 50 000 salmon harvested in the coastal fisheries in Finnmark County during 2011–2012, 70% were of local origin (West Finnmark c 19 900, Tana/ Teno system 8 900, East Finnmark 5 900) and 30% non-local with 8 500 salmon from Russian rivers, 3000 from Troms rivers and 3 500 farm escapees.

- **Most of the Russian salmon caught in the North Norwegian coastal fisheries are caught in eastern Finnmark**
  The occurrence of Russian salmon in the catches varied strongly within fishing season and among the fishing regions. The proportion of Russian salmon in the coastal catches decreased with time within the official fishing season. The majority of salmon of Russian origin harvested in the coastal fisheries of Norway were caught in Sør-Varanger municipality where Russian salmon made up 64% of the catches, which equals c 2700 salmon annually in 2011–2012.

- **Tana/ Teno salmon migrate both from west and from east into the Tanafjord and Tana/ Teno river system**
  Tana/ Teno salmon were to a large extent harvested in Tanafjord in Tana municipality (41%). Salmon originating from River Tana/ Teno were caught mainly in the area west for the Tanafjord, but some 15% also in eastern Finnmark (Figure 8).


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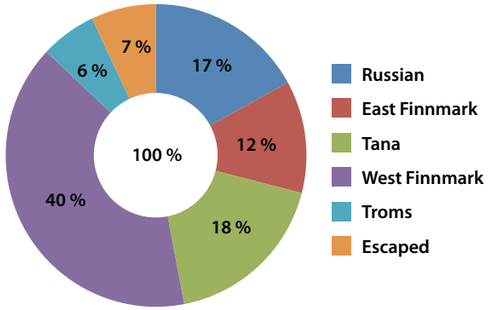

Figure 7. Origin of salmon caught in Finnmark 2011-2012. Number of salmon caught, N=49 974

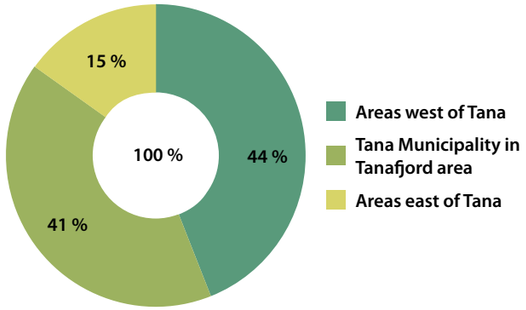

Figure 8. The proportions of Tana/ Teno salmon in the coastal catches

Chapter 6
Mixed stock mystery

Exploitation patterns and exploitation allocation

There is a large number of salmon rivers from Nordland in the southwest to the eastern Barents areas of Russia in the northeast. Salmon from all these rivers might be present in the coastal salmon fisheries along the coast of northern Norway. From a management perspective this is a challenge, as these stocks differ in status and the actual coastal exploitation experienced by the stocks have remained largely unknown until now.

At its core, salmon fisheries management is about allocation. Every year a number of salmon from a stock undertakes their spawning migration from the oceanic feeding grounds towards their home river. This number of salmon is called the pre-fishery abundance of a stock. Management becomes a process of allocating a minimum proportion to spawning, and allocate the remaining sustainable harvest proportion to coastal fishermen and riverine fishermen.

- **More salmon stocks are present in the outer coastal areas, than in the inner fjord areas**
  Outer coastal regions had a higher stock diversity and a lower percentage of local stocks than the inner fjord regions. This supports the current region-based management system as a template for regulating the coastal salmon fisheries.

- **Stock-specific models can be formulated to predict effects of various management regimes**
  Based on the *Kolarctic salmon* dataset, stock-specific coastal exploitation models can be formulated and used to simulate and evaluate the effect of various management regimes, e.g. the effect of changing fishing times in different fishing areas (Figure 9).


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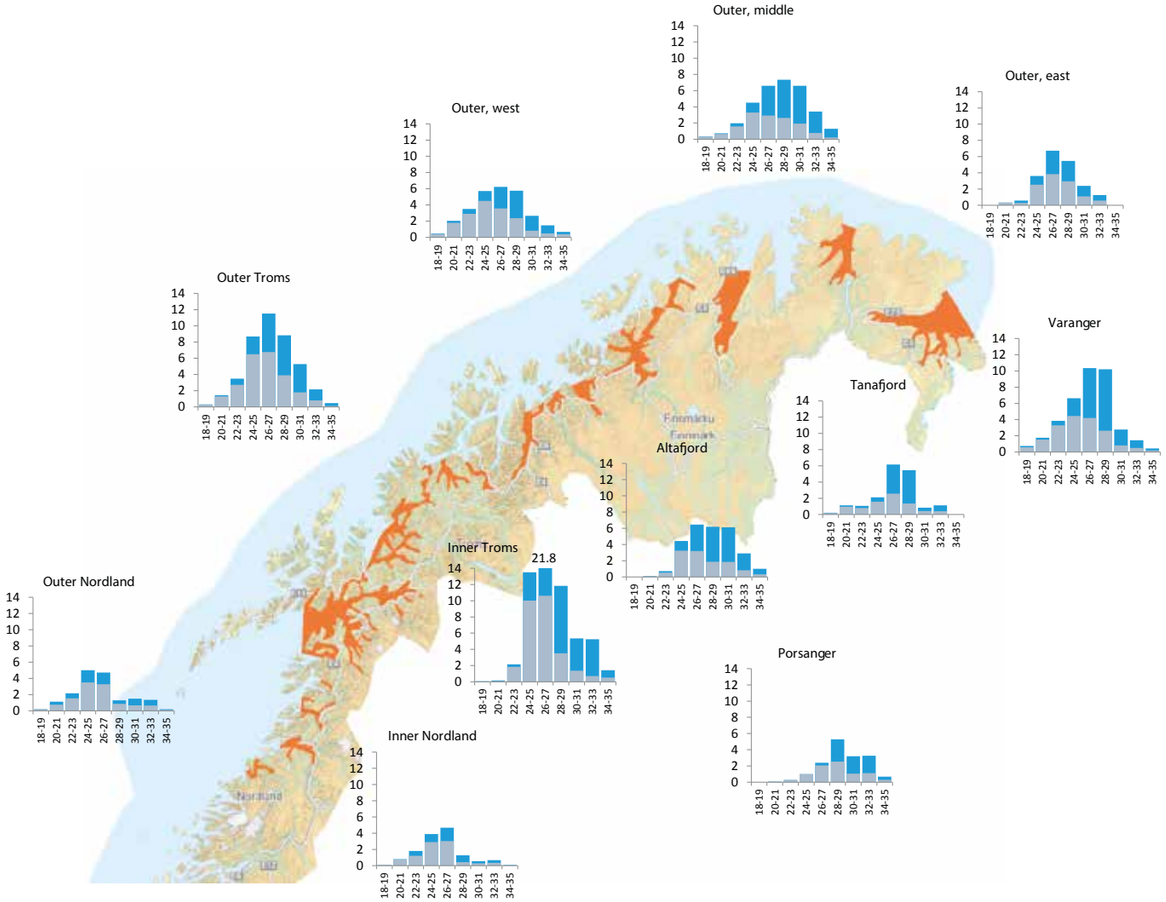

Figure 9. Regional catch of salmon, given as a number of salmon per day per fishing gear over two-week-periods. Light blue bars=female salmon catch rate, dark blue=male catch rate.
The highest catch rates were consistently found in July in all regions. The highest overall catch rates were observed in Troms (both the outer and inner part) and Varanger.

Chapter 7
Intruders in the "fish pond" – farm escapees

The salmon farming industry is well established in the Norwegian part of the area studied in the project, with annual production exceeding 400 000 tons. In Russia the salmon farming industry is rapidly expanding with annual production now exceeding 8500 tons in the Murmansk region alone. Occasionally large numbers of farmed salmon are unintentionally released from net-pens in the coastal waters, into the habitats of their wild counterparts. The Kolarctic salmon project studied the spatial and temporal occurrence of escaped salmon in the coastal waters, as well as their contribution to the commercial fishery catches.

- **We estimated the proportions of farmed salmon in the Norwegian coastal fishery**
  Escaped farmed salmon occurred in the coastal fishery catches of northern Norway throughout the summer from early May to the end of September.

- **Farming intensity is comparable to the occurrence of escaped salmon in the commercial catches**
  Escaped salmon were most frequent in Nordland County accounting for up to 44% of the commercial catches, while in Troms and Finnmark Counties they constituted up to respectively 22% and 10% of the commercially harvested salmon (Figure 10).

- **The proportion of farmed salmon increased throughout the season in the coastal catches**
  The contribution of farmed salmon to fisheries catches increased during the season in all areas accounting for up to 35% of all salmon harvested in August.

- **Distinction of escaped farmed salmon from wild salmon appears to be challenging**
  Separating farmed salmon from its wild counterparts appeared difficult, as fishermen in general identified only half of escaped salmon in their catches. For example the tail of an escaped salmon (next page photo below) is usually rounded and it has some damages to the fin rays. Ends of the tail fin of wild salmon (photo above) are sharp.

- **Escaped salmon are bigger and all escapees were mature in the end of the summer**
  Mean lengths and weights of wild salmon were smaller than those of the escaped salmon. All escaped salmon were mature in the end of summer.

- **In the White Sea area no escaped salmon was found**

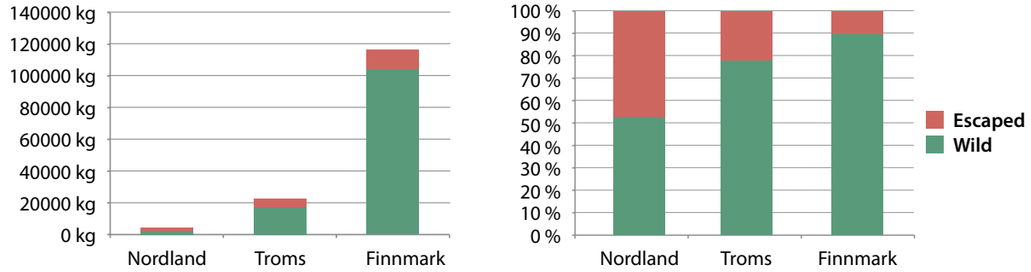

Figure 10. Proportions of wild and escaped salmon in weight 2011 in Northern Norway

Chapter 8
Repeat spawners are an important asset and safeguard for Atlantic salmon stocks of the north

Salmon can survive from one spawning to repeat reproduction. The occurrence of repeat spawners in Atlantic salmon populations is typically low, mainly less than 10%, but it may be important as a safeguard against occasional reproductive failure in small or periodically overexploited stocks. In addition to their role in life-history complexity, repeat spawners contribute significantly to the catches in northern Norway, both in numbers and in weight, especially in the beginning of the official fishing season in June.

- **Repeat spawners make up to 10% in terms of weight in the early June catches**
  In the year 2012 repeat spawners made up to 10% of the catches in terms of weight in the early June fishery. And 75% of all female fish longer than 110 cm were repeat spawners.

- **Repeat spawners arrive first and females arrive before the males**
  In eastern Finnmark repeat spawners came first to the coastal areas. And females migrated before the males. Early arrival to the coastal areas indicates that the repeat spawners are the first salmon to enter the rivers.

- **Alternate spawners were the most common type of repeat spawner**
  The most common type of repeat spawners was the *alternate spawners*. These salmons are spawning for the second time in their life, after one full year reconditioning at sea.

- **We mapped the migratory pattern for repeat spawners**
  During the official fishing period in northern Norway repeat spawners originating from a large geographical area were also caught in most of the municipalities in Finnmark. Russian origin repeat spawners were caught during the official fishing period mainly in Sør-Varanger municipality. Repeat spawners originating from rivers in western Finnmark were caught both in Troms and Finnmark Counties. Repeat spawners caught in Nordland and Troms Counties, were originating mainly from their own counties.

- **Repeat spawners from River Tana/ Teno system migrate both east- and westwards**
  Repeat spawners originating from the River Tana/ Teno system were mainly caught in the inner Tanafjord, as well as in smaller amounts in eastern Finnmark and North-Troms. This pattern indicates that these salmon stocks migrate from their oceanic feeding grounds far away from their natal river to the coastal area, both eastward and westward.

- **Salmon stocks in the Varangerfjord area show a high degree of mixture**
  Repeat spawners caught in the Varangerfjord represent salmon stocks from a large geographical area, stretching from North-Troms to the eastern part of the Kola Peninsula. This indicates that the Varangerfjord is an area where the salmon stocks are highly mixed, and that the salmon are migrating both to the east and the west at the same time.


Eero Niemelä

Chapter 9
New technologies

SNP markers

Technological advances in polymorphism detection and genotyping have made the single nucleotide *polymorphisms* (SNPs) the marker of choice for many high density genotyping studies. High-throughput microarrays containing assays for thousands of SNPs are becoming available for a number of non-model organisms. Nowadays, SNPs are more frequently applied in ecological and evolutionary studies, including population genetics studies as well as mixed-stock analysis. Despite the recent technical advances, genotyping large numbers of individuals with thousands of SNPs still remains prohibitively expensive.

Within the *Kolarctic salmon* project we tested a cost-effective alternative to individual genotyping of SNPs, known as *allelotyping*, using DNA pools of multiple individuals from a population to 1) obtain accurate allele frequency estimates for Atlantic salmon and to 2) identify highly informative SNPs for accurate *genetic stock identification* (GSI).

- **DNA pooling approach provides accurate allele frequency estimates**
  We observed high similarities between allele frequency estimates derived from individual genotyping and DNA pools, indicating that DNA pools can provide accurate allele frequency estimates for a given sample. After applying multiple quality control filters we obtained allele frequency estimates for 2880 bi-allelic SNP loci.

- **DNA pooling approach reveals similar population genetic structuring as with individual genotyping**
  The inferred population structure revealed with SNP allele frequencies derived from DNA pools was consistent with the current knowledge of population history and geographical distribution, and similar to that obtained using microsatellite data (Figure 11).

- **Small number of top-ranked SNPs allows accurate genetic stock identification**
  The selection procedures reduced the number of SNPs required for accurate GSI, but estimated accuracy level was more affected by populations in the study group rather than the ranking method itself. Despite this we showed an excellent performance of our 100-150 top ranked SNPs on an independent set of populations covering the main European distribution range of Atlantic salmon.

- **SNP markers are more effective for genetic stock identification**
  When comparing the individual assignment power for a given number of independent alleles between two marker classes, the performance of STRs (Short Tandem Repeats, also known as microsatellites) was lower than that of random and top-ranked SNPs. In this study 25 STR loci (374 independent alleles) provided similar GSI accuracy as ~ 100 top-ranked SNP loci (100 independent alleles).

- **Combination of two marker classes improves the power of genetic stock identification**
  The combination of 31 STR markers and 25 top-ranked SNPs increased the overall assignment success from 97% to 99%, representing a significant improvement of GSI by the reduction of the individual assignment error from 3% to 1%.

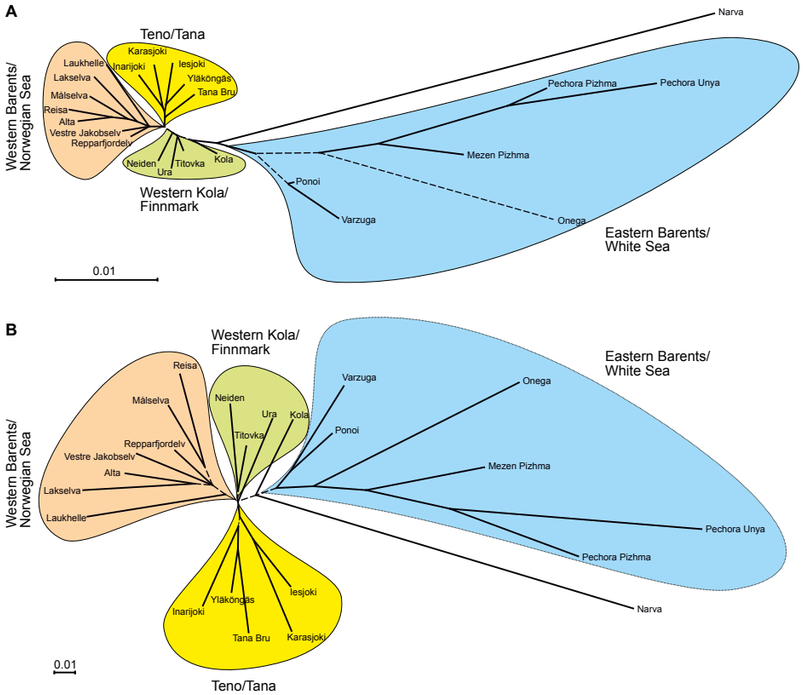

Figure 11. Genetic relationships among 23 Atlantic salmon populations in northern Europe. Neighbour-joining dendrogram is based on Nei's DA genetic distances estimated using (A) 2880 SNPs and (B) 31 STR markers. Both marker classes revealed very similar population genetic structuring. Distinct population groups are colored. The branches with bootstrap value support <80% are drawn as dashed.

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Partners and associates*

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Natural Resources Institute Finland (Luke)

We found the salmon's home-river

We mapped the salmon's migration patterns

We identified the salmon stocks exploited in Northern Norway

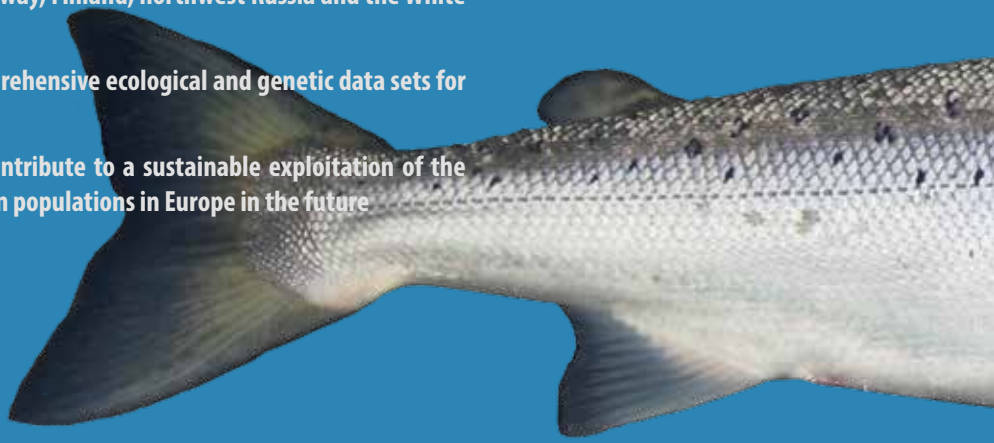
We estimated the amount of farmed salmon in Norwegian coastal fishery

We reached a mutual understanding of our rich fishing traditions

We had a unique cooperation with scientists, managers and commercial fishermen from northern Norway, Finland, northwest Russia and the White Sea area

We generated the most comprehensive ecological and genetic data sets for Atlantic salmon until now

We hope our findings will contribute to a sustainable exploitation of the northernmost Atlantic salmon populations in Europe in the future



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