Internship report

5th year

Capture of outmigrating impact of smolt trap design and placement as a means to optimize capture efficiency and costs

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Acknowledgement

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Contents

Hosting structure

The NORCE group is an independent research institue that is majority-owned by the University of Bergen. Through their six research Areas - Climate, Energy, Environment, Health, Social Sciences and Technology - NORCE conducts independent research for both public and private sectors since 2017. NORCE has a presence throughout Norway. Their missions can be divided in four focus areas:

- Energy of the future
- Climate and Environmental risk
- Safe and good societies
- Sustainable seas and coasts

During my internship at NORCE I worked on the climate and environmental research area in NORCE. In this department, there are several research groups :

- Laboratory for Freshwater Ecology and Inland Fishery (LFI)
- Gene technology, environment and society
- Industrial Biotechnology
- Marine Ecology
- Molecular Ecology and Paleogenomics - MEP
- Marine Biotechnology

I spent my intyernship in the LFI group. With over 50 years of experience in studying fish, benthic fauna, and river hydromorphology, LFI possesses a wealth of scientific and technical knowledge about Norwegian rivers. Since joining NORCE in 2019, LFI has been collaborating with environmental authorities and hydropower companies to ensure the sustainability of salmon populations in the region. LFI conducts monitoring, research, control, measurement and mapping of environmental changes in rivers and fjords.

1 | INTRODUCTION

1.1 | Context

Norway is located in the northwestern part of the Scandinavian Peninsula and is bordered by the Atlantic Ocean to the west and the Arctic Ocean to the north. Norway's long coastline facing the sea has always provided a privileged access to fish resources and is an integral part of the local culture (Hjellnes et al., 2020).
Norwegians have made a living from fishing in the sea. The salmon fishery is not only of vital importance but also of cultural, economic and social importance today (Liu et al., 2011).
Norway is now known for its recreational fishing of Atlantic salmon (*Salmo salar*). Annually there are about 80,000 Norwegian fishermen but also 35,000 foreign fishermen who through the intermediary of the British upper class in the mid 1800's became very interested in the sport and now attract thousands of enthusiasts.

In the late 1960s and early 1970s, rural fishing communities faced a sharp decline in the economy due to the decline of wild fisheries. Salmon farming thus began as a livelihood for rural fishing communities (Liu et al., 2011). Fish farms appeared in the fjords built by former fishermen. The fish farmers were members of the same community, which made it difficult to oppose those of them who placed prime importance on the aesthetic appearance of the farms, as they lived among the population and were closely linked to it (Sønvisen, 2003).
Within a few decades, salmon farming has replaced wild salmon production.

Today « Norway has become the world's largest producer of farmed salmon, and farmed salmon is now the fourth biggest export commodity (behind oil, gas and metals) »(Liu et al., 2011). Since the 1970s, with the emergence of salmon farming, the dynamics in the sector have changed dramatically.
Currently different types of salmon fisheries, whether commercial or recreational, have different management strategies. These activities are also directed by different government agencies.
« The Ministry of Environment is responsible for the wild salmon stocks and escaped farmed salmon, while the Ministry of Fisheries and Coastal Affairs is in charge of the salmon farming industry »(Sønvisen, 2003).
Today, management agencies face conflicts between resource conservation, recreation and the salmon farming sector. There are also conflicts between the different salmon production companies (salmon farming, wild salmon fisheries, fishing in the sea, river recreational fishing).

Once abundant, salmon stocks have been in major decline since the 1980s. In the same period Norway has become the world's largest producer of farmed Atlantic salmon and the second largest exporter of seafood, exporting 95% of its farmed and wild fish (Hjellnes et al., 2020; Sønvisen, 2003). There is a general concern that the growth of the aquaculture has had an negative impact on the wild Atlantic salmon as catching volumes are now half what they were in the 1970s, as shown in Figure 1 .(Liu et al., 2011)

Figure 1 - Sea and river catches of wild salmon by fisheries, 1975-2008 (Liu et al., 2011)

However, the decline of the wild salmon populations has been linked not only to the growth of the aquaculture but also to a number of other anthropogenic activities that directly or indirectly affect the environment like acid rain, hydropower and some physical impacts (road construction/flood mitigation) and aquaculture impacts as elaborated in the next paragraphs.

The Atlantic salmon is an anadromous fish. Because of this status, throughout its life cycle it fluctuates in various habitats with bottlenecks for all its life stages that drastically reduce stock volumes. These bottlenecks, already very impactful, are made even stronger by the addition of the anthropogenic pressures we will see below. Additionally, changes in ocean climate affect salmon survival after smolts leave the river, which we will not address in this report (Welch et al., 2008).

1.2 | Impacts acid rain

In the 1910s, Norway experienced a significant decline in its salmon population in certain regions of the south. They lost up to 80% between 1885 and 1920. By 1960, these regions witnessed the near-extinction of the species. Acid rain as cause was only discovered in the late 1960s and 1970s (Sandøy & Langåker, 2001). Similar observations of declining freshwater fish populations occured in the United States, Canada and Sweden (Leivestad & Muniz, 1976). The emissions of sulfur dioxide (SO_2) in Europe starting from 1880 are believed to be the reason for the acidity. Acid rain is formed when emissions of sulfur dioxide (SO_2) and nitrogen oxides (NOx) from the combustion of fossil fuels combine with moisture in the air, forming sulfuric acid (H_2SO_4) and nitric acid (HNO_3). These acids can then fall to the ground as rain, snow, or fog. In the south of Norway, the concentration of sulfur dioxide was around 400 mg S/m² in 1890. However, the critical concentration was calculated to be approximately 300 mg S/m² (Henriksen et al., 1992).

According to Hesthagen, (1989) « Depression of pH did not cause instantaneous death, and peak abundance of carcasses found was delayed relative to the initiation of these episodes. This is probably because fish became stressed prior to death, as indicated by observations of downstream drifting of bodies. » Therefore, the flow conditions and the low precipitation or snow cover volumes in the affected regions seem to be related to the mortality. In the same study, the year 1985 supports this observation. The rains help all stages, both adult salmon and eggs, by preventing them from developing and dying due to the increased acidification of the water (Mills, 1986).

Today, pollution from acid rain in Norway has significantly decreased thanks to the 1979 Geneva Convention on Long-Range Transboundary Air Pollution, which was implemented starting in 1983 (Hongve et al., 2012). However, this remains insufficient. In certain regions of Europe and North America, regeneration will take several decades. The major impact is that the very slow recovery of soils and water means that they will not return to pre-acidification conditions for a very long time, if ever, even under the most aggressive pollution reduction scenarios (Clair & Hindar, 2005).

1.3 | Impacts of hydropower

As a threat to adult salmon, migration dams also influence the hydraulics of the major river and therefor early life stage survival.

As in the study by Welch et al. (2008) the low return of adults to the river is partly explained by mortality of seaward migrating smolts caused by the succession of hydroelectric dams that are heavily mistreat.
The rapid and frequent changes in physical conditions in Norwegian rivers with hydroelectric dams lead to ecological impacts on aquatic plants, benthic invertebrates and also fish communities (Bakken et al., 2023).

Changes in hydrological and hydraulic conditions due to hydropeaking operations are well described, while rapid changes associated with water temperature, gas saturation and sound are less studied but play an equally important role (Bakken et al., 2023).
The hydropeaking then represents an additional environmental pressure beyond the traditional impacts of hydroelectric regulation, such as compartmentalization of the environment and seasonal changes in habitat conditions.

1.4 | Physical impacts

Of all the natural disasters affecting European countries, flooding is one of the most damaging. With global warming, floods are likely to become more frequent and more intense. As a result, land use will have to evolve accordingly. For several years now, the focus has been on engineering structural flood mitigation measures for rivers, but also on the growing development of road infrastructure. Traditional flood protection measures, such as dykes and river channel dredging, threaten ecosystems including salmon populations (Juárez et al., 2021). However, this work has been shown to have a major impact. Firstly, the developing eggs, then the newly hatched fry, deeply buried in the gravel of the spawning stream bed, can be asphyxiated by the sediments resulting from the effects of land drainage, ploughing, road building, etc., and secondly, they can be damaged by the effects of the construction work (Mills, 1986).

Modifications to the riverbed itself, affecting spawning and shelter areas. According to (Brookes et al., 1983) « In France [too] the destruction of the natural substrate through the resectioning of watercourses has had an adverse effect on the fish populations and the survival of salmonoid eggs and reduced benthic-invertebrate populations »

As explained (Clavel et al., 1978) “ In some cases, it is only possible to limit damage, not avoid it. In such cases, to at least reduce mechanical pollution downstream of the worksite, it is necessary to:
- separate the extraction zone from the rest of the watercourse by means of a sufficiently watertight temporary dyke;
- or, to put the newly dug sections of the bed in communication with the watercourse only when the dredging work has been completed;
- and, finally, to cease all operations likely to cause mechanical pollution during periods of low flow and/or high temperatures, when the watercourse is particularly vulnerable.

It should be added that all operations in the minor bed of a watercourse should in any case be prohibited in certain particularly "sensitive" areas, such as:
- salmonid breeding grounds, especially salmon “

1.5 | Aquaculture impact

1.5.1 | Disease

« During this rapid expansion, the number of fish farms in Norway has decreased, while individual farm size and production levels have increased» (Bannister et al., 2014). These changes have an impact on the environment close to the farms but also further away. According to Glover et al. (2013) statistics on the number of reported escapes recorded by the Norwegian Directorate of Fisheries (NDF), would not only be in the hundreds of thousands during most years of the period 2000-2011, but rather an actual number of escapes in the millions. These escapes result in the spread of diseases.

Heart and skeletal muscle inflammation (HSMI) is an infectious disease that can be associated with a virus, piscine reovirus (PRV), that have been detected lately (Glover et al., 2013). « This virus is

associated with the disease, shows elevated viral load in diseased fish, and is potentially responsible for the disease »(Glover et al., 2013).
Garseth et al. (2013) estimates a prevalence of 13.4% versus 55.2% in wild Norwegian salmon compared to escaped farmed salmon for the piscine reovirus. In their annual report Eirik Biering et al. (2013) point out «The obvious question, as raised by McVicar in 1997, is whether this is due to a low infection pressure or if wild fish infected by a virulent agent rapidly die and thus avoid to be sampled».

1.5.2 | Genetic

The study of Fleming et al. (2000) « indicate that such annual invasions [of salmon farm] have the potential for impacting on population productivity, disrupting local adaptations and reducing the genetic diversity of wild salmon populations. » This creation of hybrids is all the more likely when the escape of salmon is large.
Indeed, over the generations, breeding has modified the genetic composition of farmed salmon for productivity. As pointed out by Skaala et al. (2006) « Farmed salmon differ genetically from wild salmon both in genetic marker loci and in fitness-related traits » and thus its ability to survive in the natural environment.

McGinnity et al. (2003) has shown that farmed and "hybrid" offspring have reduced survival compared to wild salmon. However, they have the ability to grow to juvenile size more quickly than wild salmon. In the absence of suitable habitat for these wild parr, there will be a reduction in wild smolt populations.

1.5.3 | Lice

As we have seen above, the salmon industry poses many environmental problems.
According to Barlaup et al. (2018) a major problem in the Vosso stock is low numbers of returning adults as the sea survival is very low. i.e. ca. 1% compared to a more normal sea survival of > 3%. It is also suggested that the low sea survival is caused by premature death of smolt during the first part of the smolt migration before the smolts has reached the open sea, and that sea-lice induced mortality is an important factor (Vollset et al. 2023).

Atlantic salmon smolts migrate to the sea in spring and enter puberty. Their weight is then between 10 and 80g (Fjelldal et al., 2020). Fragile, due to their size and weight post-smolts can be infected by a copepod *Lepeophtheirus salmonis*. In addition to this, their passive mode of movement increases the time they spend in the fjords.

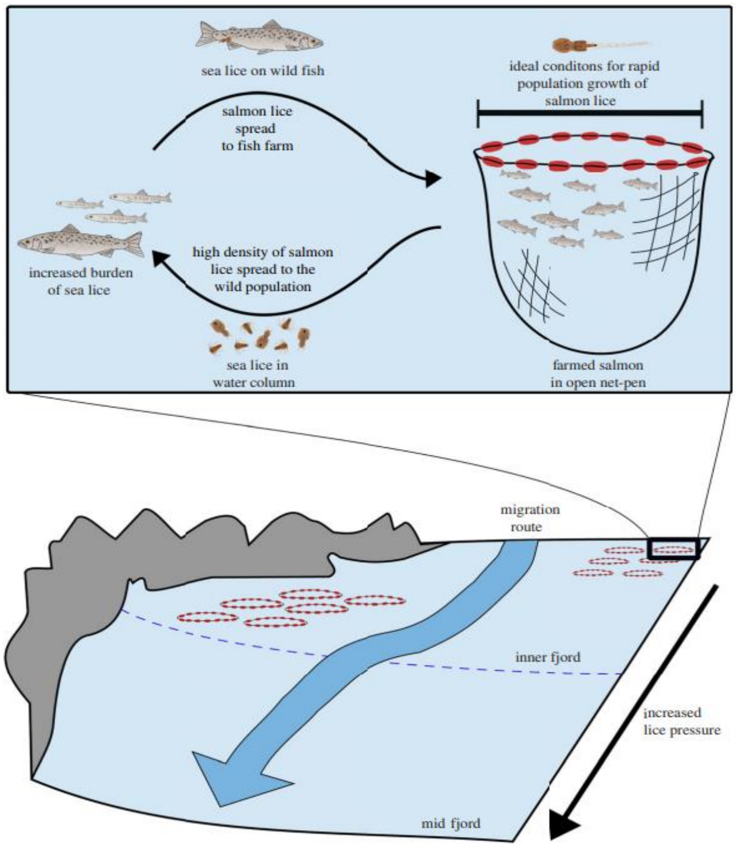


Figure 2 - Illustration of parasite spillover–spillback dynamic between fish farms and wild salmonids. Credit: Cecilie Iden Nilsen

Naturally present in the environment, aquaculture increases the infection rate with sea lice in the environment very strongly (Fjelldal et al., 2020). Costello, (2009) and Krkošek et al. (2005) estimate that lice can disperse up to 30 km around each salmon farm.
In Norway, farmed salmon are 100 times more numerous than wild ones. According to Heuch et al. (2005) escaped farm salmon have 10 times more lice than wild salmon.
Their impact, however, remains insignificant compared to sea lice, which contaminate salmon during migration

Salmon lice damage the skin of the host as shown in the Figure 3. The mucus surface and dermal tissue are then damaged and the barrier between the sea water and the fish's body is threatened and the ionic balance is not given anymore (Fjelldal et al., 2020).

Figure 3 - Infestation of an Atlantic salmon by the sea lice Lepeophtheirus salmonis Credit : HAMEL Bastien

« Grimnes & Jakobsen, (1996) studied the physiological response to laboratory lice infection […] Atlantic salmon post smolts and observed that a mean infection intensity of ∼ 1.6 (lice g−1 fish) […] increase in mortality 25 days post infection. Based on the results, the authors suggested that an infection intensity of above ∼ 0.6 lice g−1 appear to cause death of Atlantic salmon post-smolts after the lice have reached the pre-adult stage. »(Fjelldal et al., 2020)

As mentioned above, Norwegian rivers face multiple pressures. In order to preserve the wild salmon population of the Vosso River, LFI organizes several field sessions each year in advance of the smolt migration as a part of a conservation project to restore the Vosso salmon stock.

The main aim of this campaign is to record important data on the time of the smolt run and the number of smolts leaving the river. This information is used to develop conservation strategies in order to enhance the survival of the smolts. The tagging of young salmon is an essential practice in salmon population management and scientific research.

The PIT (Passive Integrated Transponder) tags we will see later are minimally invasive for the smolts and will provide information on the return rates over time. These data are crucial for understanding the overall health of salmon populations and for developing appropriate management strategies. They allow for the evaluation of restoration programs and their effectiveness. Thus, conservation and management measures can be taken if the data shows low survival rates for young salmon in a certain area. These measures may include improving habitat, reducing the impacts of human activities, or implementing stricter fishing quotas. In our case, recapture of returning salmon that originates from the tagging during the coming years will give important information concerning sea survival and the impact of this conservation strategy based on capture and towing of smolts in order to decrese smolt mortality during the fist part of the smolt migration.

This thesis is an integrated part of the conservation project and evaluate and test different methods and locations for catching smolts.

Our research problem will be as follows : What is the impact of using traps at various locations on the understanding of smolt migrations, and how can this approach help optimize capture efficiency and reduce monitoring costs ?

In this report, we delve into the impact of using traps at different locations on our understanding of smolt migrations. By strategically placing traps in diverse areas, we can gather comprehensive data on smolt movements, which helps us gain valuable insights into their migration patterns.
This approach allows us to consider various environmental factors that might influence smolt behavior, leading to a more comprehensive understanding of their migration dynamics.

Then, we will present the results and findings obtained through the use of traps at diverse locations. We will analyze how these results enhance our understanding of smolt migration patterns. We will discuss observed migration patterns, environmental factors that may impact smolt movements and how this information can be beneficial for aquatic resource management and conservation.

Finally, we will focus on the practical benefits of employing traps at various locations. We will discuss how this approach can contribute to improving smolt capture efficiency in future studies. We will explain how a deeper understanding of migration patterns can optimize study planning, reduce unnecessary data collection efforts, and consequently lower the costs associated with researching smolt migrations.

2 | MATERIALS AND METHODS

2.1 | Study site

The study is located in western Norway, in the county of Vestland. With a catchment area of 1491,53 km², the Vosso river catchment is the second largest in western Norway. It boasts numerous lakes, including two main ones, Vangsvatn further upstream and Evanger downstream (Figure 4). The river is 74 km long, but only 35 km long for anadromous species, and flows into the estuary at Bolstad. Since 1969, the Evanger Hydropower plant has been installed upstream of Lake Evanger.

It has a strong influence on the environment and is largely responsible for the water flow further downstream. “In low-water periods (particularly in winter), the hydropower production contributes more than 50% [...], whereas the contribution is usually only c. 10% during the spring floods when the smolts are thought to be migrating.”(Barlaup et al., 2018).

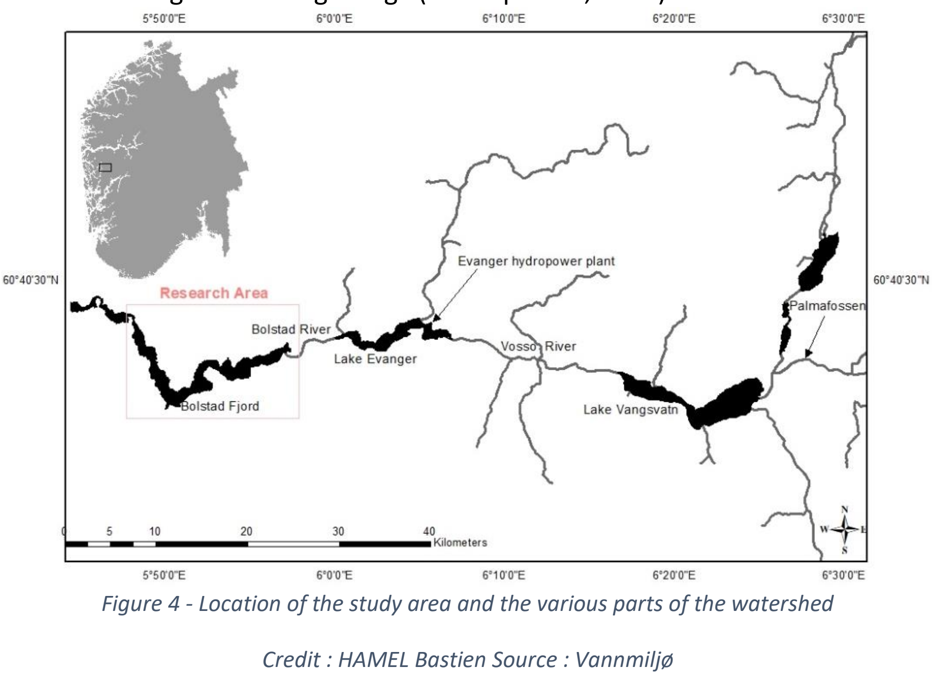


Figure 4 - Location of the study area and the various parts of the watershed

Credit : HAMEL Bastien Source : Vannmiljø

The Vosso River flows into the Bolstad Fjord, where most of the study took place. Between the lake Evanger and the fjord, the Vosso river bears the name of the municipality, Bolstad river.

All smolts caught during the campaign are transported to the sea in a net cage near the town of Herdla, north of Bergen, some 180 km from the study area. This measure is taken in order to limit the time they spend in the fjords, and thus any possible contamination by sea lice.

2.2 |Traps

This year, old and new catchment systems were installed. Firstly, upstream of the Vosso river, at the Palmafossen site (Figure 4, APPENDIX I : Capture ramp at a dam on the palmafossen site). The smolts are caught at the dam of the hydroelectric power station. Using a screened ramp on the right bank of the river, the smolts are directed into a recovery tank. The fish are collected every morning, and the trap is cleaned at the same time, at least once a day, to avoid injuring or killing fish sliding down the ramp.

Further downstream, near the mouth of the fjord, a smoltscrew (floating trap) was installed (Figure 5). It was the first trap installed this year, i.e. the 26 April. Shaped like a screw, it directs the fish into a suitable compartment. The owner of the land where the trap is installed is responsible for setting the trap every evening and collecting the fish every morning. They are then collected later in the morning to be marked.

Figure 5 - Picture smoltscrew

On a system similar to the Palmafossen site, the "Nora" trap takes up the idea of the ramp as well as that of the smoltscrew. The aim is to capture smolt in the river current, before they disperse into the fjord. The special feature of this trap is that it is strong enough to withstand the current and the debris arriving at high speed at the mouth of the fjord.

The trap is made up of 3 parts, as shown in the photos below (Figure 6).

Figure 6 - Pictures of Nora trap in the outlet of the Bolstad river Credit : HAMEL Bastien

The first part, the ramp, allows you to fish at depths of up to 1m. The smolts are then redirected to the first compartment by the current. The fish are then recovered, along with any large debris that could injure them, and the force of the current is dissipated by a barrier installed in the middle. A neoprene mat has been installed at the overflow to protect smolts as they enter and provide shelter. The last part, further back, allows the fish to remain sheltered from debris and strong currents, thus avoiding death from exhaustion. As in Palma, the trap is emptied and cleaned every morning. In fact, the access ramp is wire-meshed and the presence of concocted bits of wood can injure fish arriving at high speed in the trap.

Finally, the last type of trap, installed in larger quantities, are the nets placed at various points in the fjord. We used two types of custom med trap nets, 5m or 10m deep. The trapnets have 4 sections, as shown in the Figure 7. The last chamber and the entrance to the chamber (Hals) are the only fully submerged sections. Like all the other traps, the trapnets are emptied every morning. To retrieve the fish, we hoisted the most downstream part of the last chamber (fangstrom) onto the boat and opened it to retrieve the fish with a net.

In some cases, leading net are added upstream to extend the range.

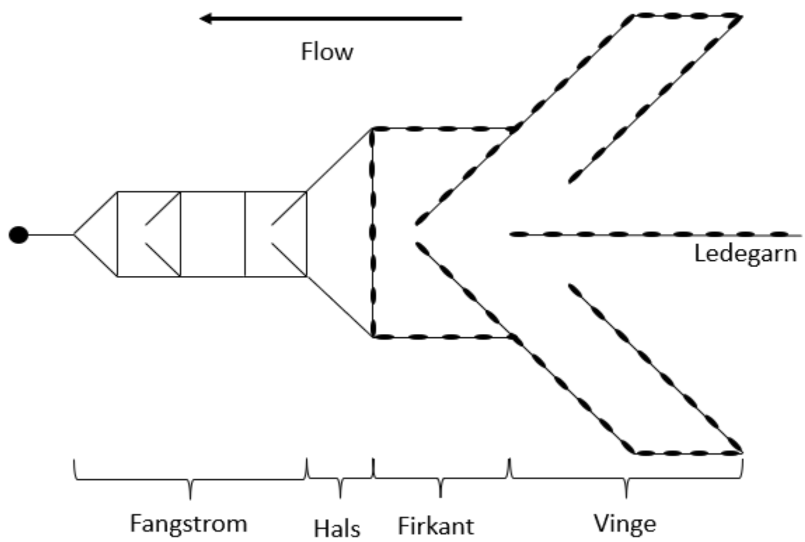


Figure 7 - Drawing of a net with various compartements Credit : HAMEL Bastien

A final net was installed much further downstream near a narrowing in the fjord near the town of Straume. In the continuation of the trapnet, a pipe is connected to a submerged cage (Figure 8). This arrangement was chosen because, in previous years, large numbers of fish were caught here. This system makes it easier to retrieve fish and reduces the density of fish in the trap and therefore potential negative impact or mortality of smolts.

Figure 8 - Picture of the submersible cage connected to the fangstrom Credit : HAMEL Bastien

All traps are emptied every day, mainly in the morning, except in specialcases, to limit the time spent in each trap. Smolts, trout and other fish are sorted on site, so that only smolts are transported. Smolts are caught and deposited in buckets. On sunny days, care is taken to change the water in the buckets during transport to avoid high water temperature that may cause the smolts to experience low oxygen contents or thermal problems. The smolts are then deposited in submersible cages in the tagging zone (Figure 9) while waiting to be tagged.

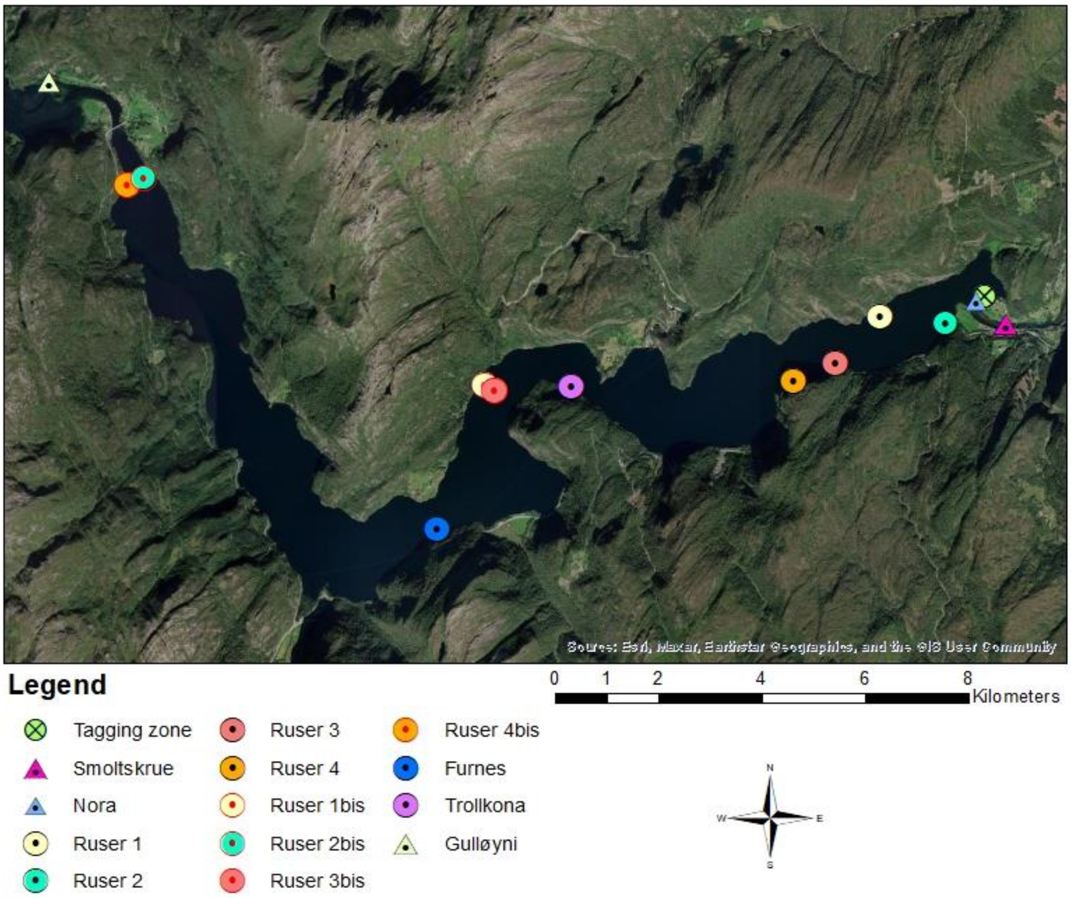


Figure 9 - Map of the different locations for each traps since 2001

Credit : HAMEL Bastien Source : ESRI

This year we used the following trapnets called Ruser 1, Ruser 2, Ruser 3, Ruser 4, the one smolt trap called Nora and the smoltscrew.

2.3 | Location changes

This year's fishing campaign saw the utilization of a diverse range of traps and nets, aiming to optimize the capture of smolts. Notably, the trapnets had two different depths, namely 5 meters and 10 meters. This strategic approach aimed to maximize the efficiency of the fishing operation by targeting smolts at varying depths within the water column. In previous years only trapnets that were 5 m deep had been used and by introducing 10 m deep nets it was hoped that the catch efficiency would increase.

Examining Figure 9, we can observe that certain trapnets, denoted with a "bis" suffix, are essentially the same as their counterparts without this indication, Ruser 1 and Ruser 1bis, for example, correspond to the same trapnet but have been moved. However, these nets were relocated during the campaign due to specific circumstances. One such circumstance was the significant presence of debris in the nets, which posed challenges to the fishing process. To mitigate this issue, the decision was made to relocate the nets periodically to areas with lower debris accumulation.

The decision to move the trapnets was further motivated by a relatively low number of catches observed in certain locations. By relocating the nets, the fishing team aimed to enhance their chances of capturing a higher quantity of smolts. Additionally, the movement of the trapnets aimed to minimize rope breakage caused by the accumulation of debris, ensuring the durability and effectiveness of the fishing equipment.

It is important to note that the presence of debris and its adverse effects on fishing operations can vary depending on environmental factors and other considerations. The decision to relocate the nets was a dynamic response to optimize the capture process and adapt to the prevailing conditions.

2.4 | Tagging

The smolt marking procedure generally begins at around 11 a.m., once all the smolts have been recovered from the various traps. Marking follows a strict protocol. The fish are placed in a bucket containing an anesthetic (Finquel Vet 1 MS-222) at a rate of 100 ml per 1 liter, i.e. around 15 smolts. Once the fish is asleep, a small 1 to 5 mm incision is made on the ventral flank, between the pectoral and pelvic fins. No sutures are applied, due to the short length of the incision and to minimize handling. The smolts is tagged by use of a 12 mm PIT-tag (APPENDIX III : Photo of an incision). PIT tags are electronic marking devices used to track and identify fish, including in our case, smolts. Being small and thin, they are well-suited for smolts, minimizing any discomfort.

PIT tags are small passive transponders that emit an electronic signal when activated. Each PIT tag is programmed with a unique identifier, which is a specific numerical code for the fish. This identifier allows for differentiating each tagged individual and tracking them throughout various stages of their life cycle. They are designed to operate for many years, enabling the tracking of fish over long periods and collecting long-term data on their movements and behaviors. The tags can be read using portable or fixed sensors; however, in our case, the 12mm PIT tags have a range of only 1 or 2 meters, which may require the installation of additional antennas for monitoring in natural environments.

After marking (about 10 seconds of handling), the fish are transferred on the tag's reading and identification table, it is then measured and moved to a bucket, then to a cage in the fjord (APPENDIX IV : Tagger worktop). At the end of each week, the smolts are transported out to sea, near the town of Herdla.

2.5 | Side experience

In our study, we captured smolts with the intention of releasing them back into the wild. Additionally, we conducted complementary experiments involving the tagging of some smolts with acoustic tags. This allows us to track their movements and gather valuable data on their migration patterns.

Furthermore, a portion of the captured smolts was sacrificed for various purposes. Some were used for DNA sampling, providing insights into their genetic profiles and population dynamics. Branchial analyses were conducted to assess the health and physiological conditions of the smolts. Additionally, age determination techniques were employed to understand the age structure of the captured population. They were also captured to examine a subset of smolt returns for various diseases.

These additional experiments allow us to gain a comprehensive understanding of the smolt population in terms of genetics, health, and age distribution. The combination of acoustic tagging, genetic analysis, branchial examination, and age determination enhances our knowledge of the smolt life cycle and their interactions with the environment.

Such multidimensional investigations provide valuable insights into the factors influencing smolt migration, population dynamics, and potential impacts of diseases. The results obtained from these experiments contribute to the broader scientific understanding of salmonid ecology and aid in the development of effective management and conservation strategies.

3 | RESULTS & DISCUSSION

3.1| Summary of traps in various locations

The smolt fishing campaign has been taking place since 2001, using various methods as seen in table 1**Error! Reference source not found.**. The number 1 indicates the use of a particular type of trap, while 0 indicates its absence. The "several trapnets" column indicates that we have used other trapnets, but that the data has been grouped together, which means we can't analyze the data and therefore use it as a witness to evolution. However, distinguishing between them is impossible because the data has been mixed, making it impossible to differentiate the timing and quantities of catches in the respective nets (APPENDIX V : Detailed table of traps used from 2001 to 2022).

Table 1 - List of traps used by year

Year	Smoltscrew	Several trapnets	Trapnet Furnes	Trapnet Trolkona	Antenna	Fishlift
2023	**1**	**1**	**1**	0	0	0
2022	**1**	**1**	0	0	0	0
2021	**1**	**1**	0	0	0	0
2020	**1**	0	**1**	0	0	0
2019	0	0	**1**	0	**1**	0
2018	0	0	**1**	0	0	0
2017	**1**	0	**1**	0	0	0
2016	**1**	0	**1**	0	0	0
2015	**1**	**1**	0	0	0	0
2014	**1**	0	**1**	0	0	0
2013	**1**	0	**1**	0	0	0
2012	**1**	0	**1**	0	0	0
2011	**1**	0	0	0	0	0

2010	**1**	0	0	0	0	0
2008	0	0	**1**	0	0	0
2007	0	0	**1**	0	0	0
2006	0	0	**1**	0	0	0
2005	0	0	0	**1**	0	0
2004	0	0	**1**	**1**	0	0
2003	**1**	0	**1**	**1**	0	0
2002	**1**	0	**1**	0	0	1
2001	0	0	0	0	0	**1**
Total	**13**	**3**	**14**	**3**	**1**	**2**

We noticed that over the course of 22 years, the Smoltscrew and Furnes nets were used 13 and 14 times, respectively. However, other locations were individually tested with different nets, such as Trollkona and Furnes.

This year, once again, the Smoltskrue and Furnes nets were used. Therefore, we will use the results from previous years as benchmarks for the capture efficiency of this year, allowing us to determine if the catches were similar to those of previous years.

3.2| Capture efficiency through strategic trap placement

As we have just seen, since 2001, numerous locations have been used. This approach can potentially help identify possible migration corridors. However, this technique can be costly and may proove to be ineffective.

As we can see from Figure 10, this year has been relatively good in terms of quantity. It is the second-best year in terms of catches since 2001. However, we need to put these results into perspective because we used a larger number of traps this year. Therefore, we will focus on the number of captures in relation to the number of traps and the effective fishing days.

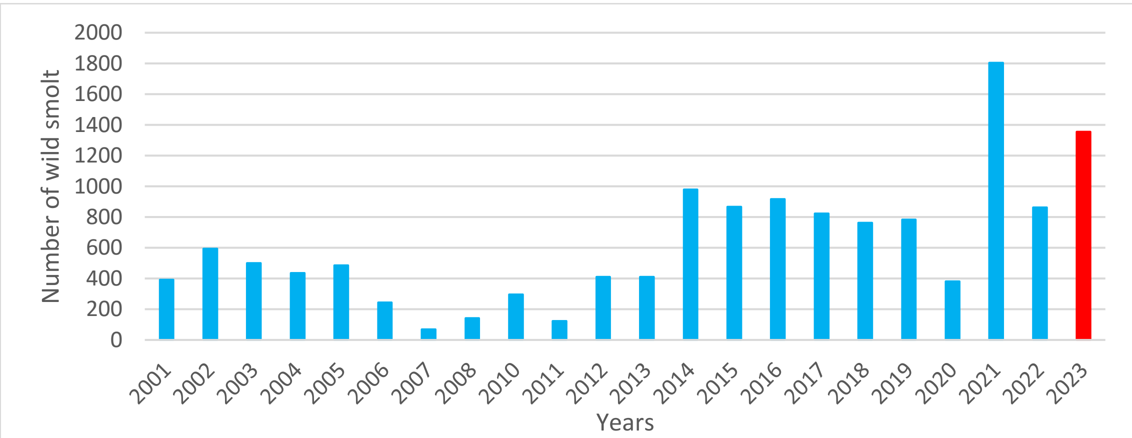


Figure 10 - Chart of total number of smolt catches in all traps that have been operated in 2001-2023 period

Indeed, this year, a wide variety of traps and locations were tested. As we can see from Table 2, 9 traps were used during this campaign compared to only 1 to 3 traps between 2001 and 2022.

Table 2 - Table summarizing the number of traps used per year (smoltscrew, trapnets)

Quantity of traps	9	3	2	1
Years	2023	2022	2020	2018
		2021	2019	2011
		2015	2017	2010
		2003	2016	2008
			2014	2007
			2013	2006
			2012	2005
			2004	2001
			2002	

As we can see from Figure 11, this year has been relatively disappointing in terms of yield and trap efficiency. It ranks as the 8th worst year in terms of catch when considering the number of captures per day during trap deployment. With 3.91 smolts/day/trap, we are well below the average of 7.86 between 2001 and 2022.

The year 2012 was the best by far, with over 25 smolts per day per trap. We can observe a significant disparity between the years, even with the same number of traps. Therefore, the results of each year should be interpreted with caution and taken into account within the context of these variations.

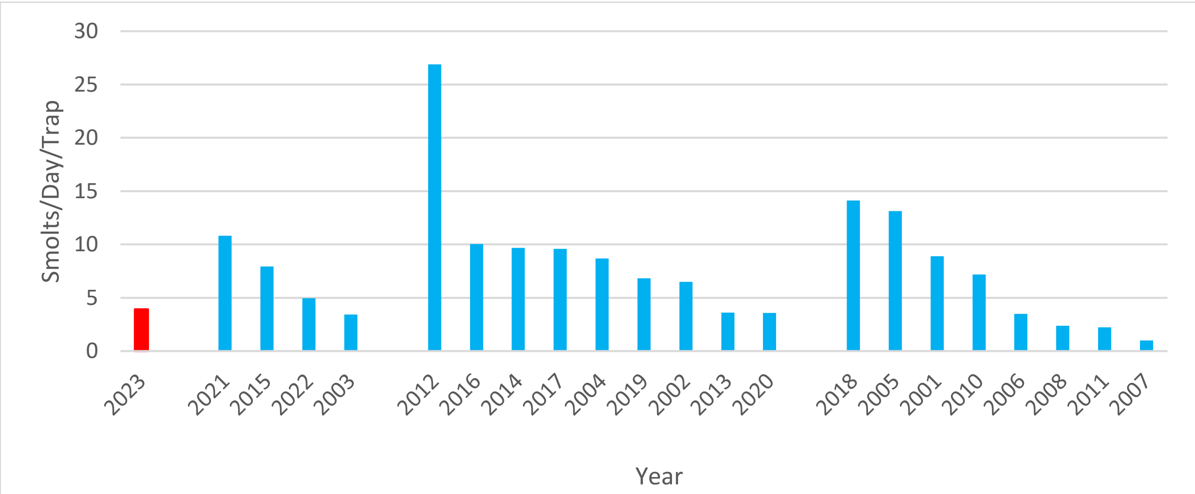


Figure 11 - Capture of smolts per day per trap from 2001 to 2023 (from left to right, 9 traps, then 3, 2, and 1)

This low score can be partly explained by the use of four traps that significantly reduced the number of captures, with values of 0.5, 0.7, 0.97, and 1.29 smolts/day/trap, respectively, for traps Net 4 (bis), 2 (bis), 1 (bis), and Nora.

The nets with and without "bis" were considered as one trap because they were simply moved during the period. However, it is important to note that this year was a testing year. The main objective was to capture as many fish as possible but also to understand how, where, and when they migrate in the fjord. Given that the fjord is deep and wide, it is essential to conduct trials in other untested locations to potentially find more favorable spots. Despite additional measures taken to improve the net results, adjustments will still need to be made to the trapping methods, including modifications to the location and depth of the nets, to increase catches in future years.

Despite the initially disappointing score given the resources invested, these tests have provided important additional knowledge.

3.3| Temporal evolution of smolt captures

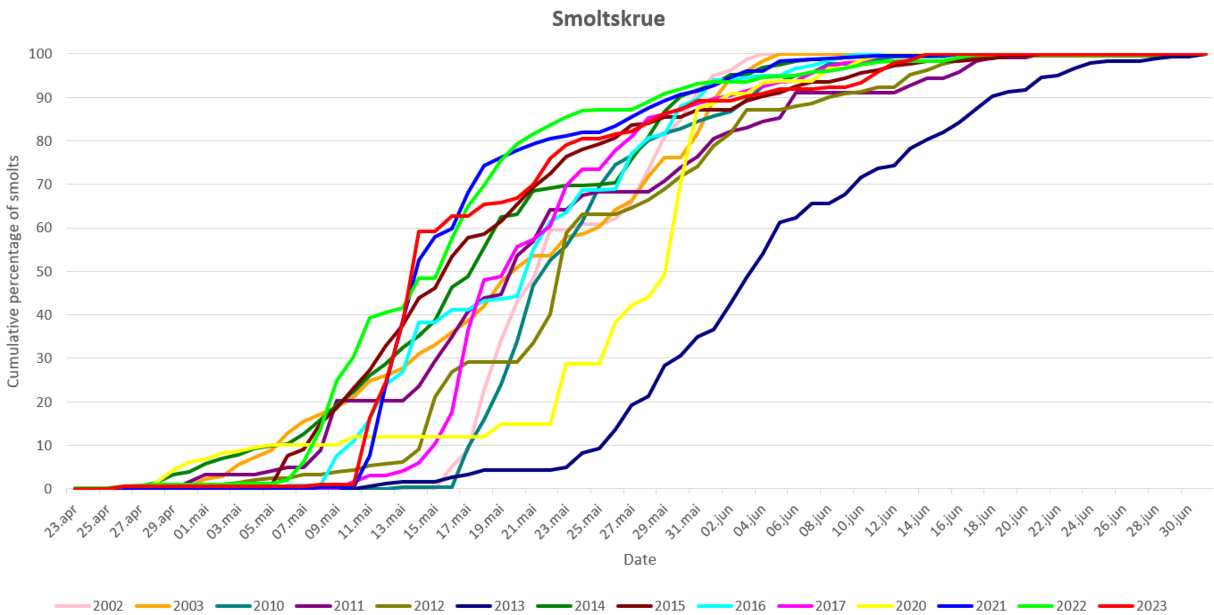
As mentioned above, since 2001, the Smoltskrue and Furnes nets have been extensively used, including this year. Indeed, when possible, the net in Furnes and the smoltskrue have been used for as many years as possible. This allows for the comparison of different years and highlights certain migratory parameters. They serve as reference stations.

As we can see in Figure 12, the distribution over time this year is relatively similar to previous years. We can observe that in the majority of cases, the smolt flow during the season can be divided into two phases. The first phase, characterized by the steepest curve, typically represents the initial wave.
The second phase becomes noticeable after capturing around 60% of the smolts. This phase is more gradual and spread out over time.

If we compare the evolution of this year, we can notice that the peak at the beginning of the season is also observed in Furnes. However, the first smolt peak is much more pronounced, which contrasts with previous years. It's important to note that Furnes is located 14 kilometers downstream in the fjord, far from the river outlet where the smoltskrue is situated.

Now, if we examine the time interval between the smoltskrue and Furnes at around 50% capture, we can observe that the capture interval at Furnes is much more spread out compared to the river. It takes approximately 10 days in the river, while it takes about 20 days at Furnes.

This difference could be attributed to the fact that smolts may exhibit different migratory behavior in the river compared to the fjord. In the river, smolts may be more concentrated near the outlet and move in larger groups, resulting in higher initial capture rates. As they disperse into the fjord, the capture rate may decrease, leading to less steep curves on the graph and thus a more spread-out distribution.



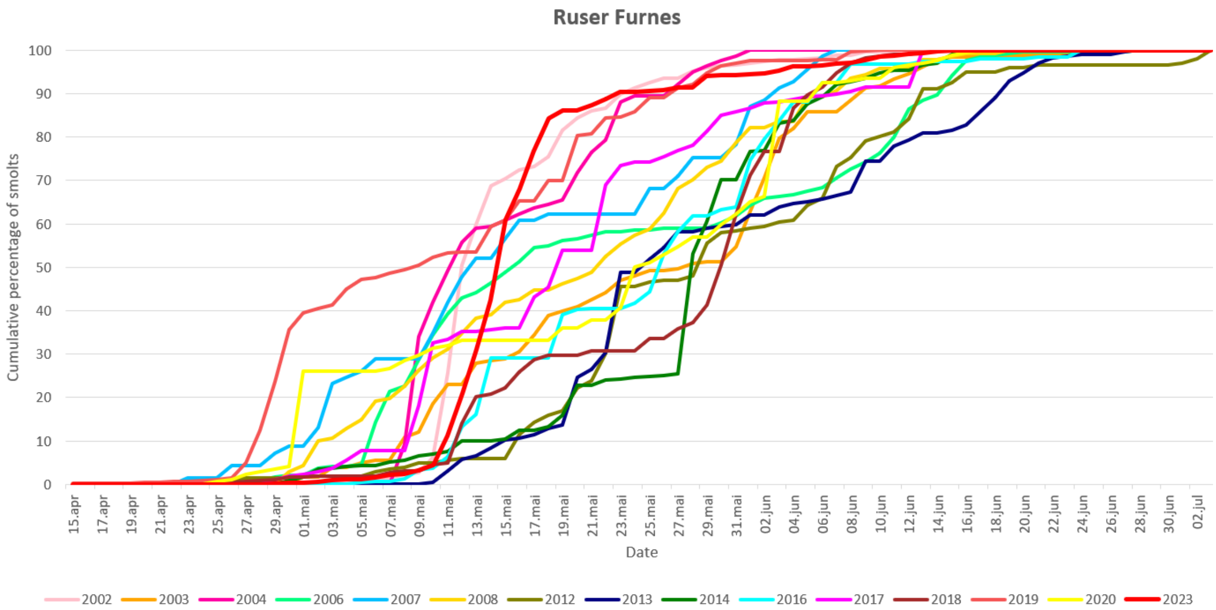
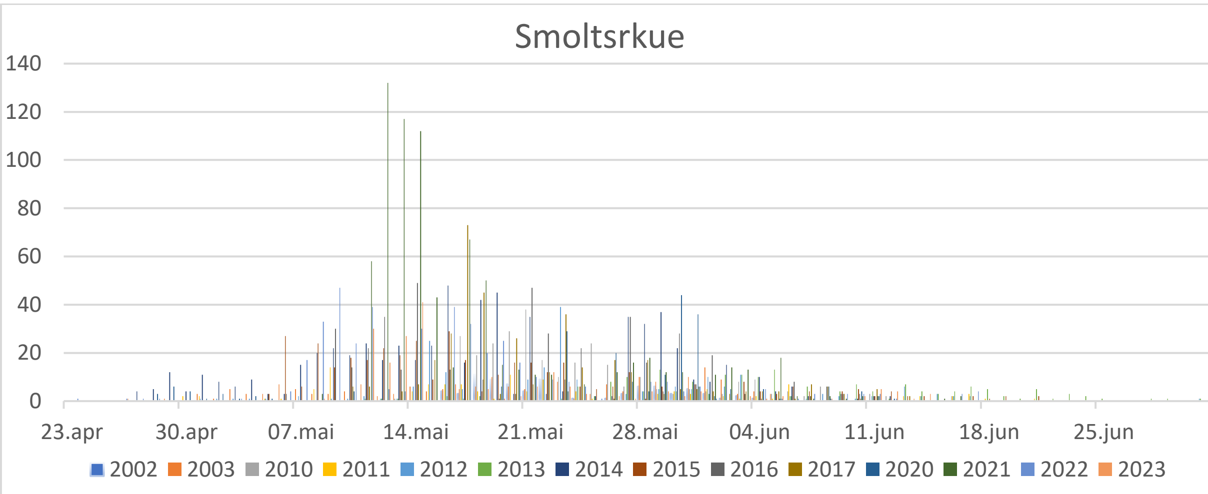


Figure 12 - Graph representing the accumulation of smolt captures as a percentage over time

This season is somewhat different from others because the first peak of smolt was significant but very short, without being followed by the usual occurrence of a second peak. We suspect a major effect of flow rate over time on smolt migration.

If we examine the daily capture numbers for Furnes and Smoltskrue over multiple years. On the Figure 13, we can observe that there are indeed two distinct phases in the river, unlike in Furnes. This observation is further supported by the slopes on the previous graphs. We will then use the smolskrue data to find the link between migration waves and flows.



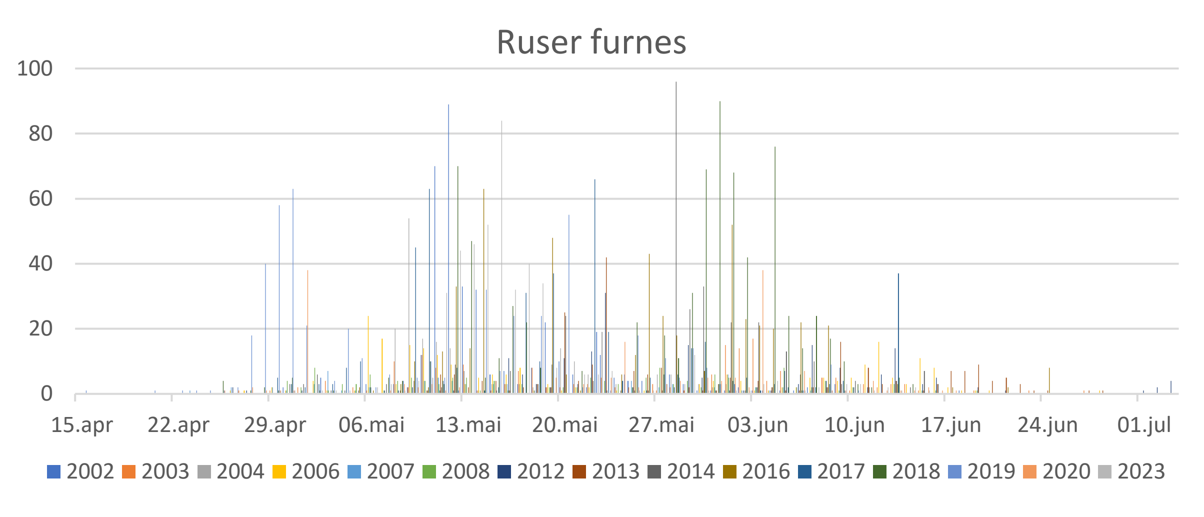


Figure 13 - Quantity of smolt captured per day for several years

Understanding the migration patterns of smolts reveals intriguing insights, with two distinct phases observed in their journey. Vollset et al. (2021) showed with their research in Norway, smolts display a fascinating adaptation to their specific latitudinal regions, with migrations commencing in early May in the south and delayed until June in the north. This clear correlation between their biological clocks and latitude highlights the intricacies of their migratory behavior. This same study seems to correlate with our initial findings.

3.4| Influence of discharge on smolt migration

Once their biological clock reaches maturity, indicating the possible onset of migration, we will investigate whether river discharge appears to be the abiotic factor initiating the migration. River discharge, influenced by various factors such as snowmelt, precipitation, and water release from upstream reservoirs, plays a crucial role in creating the conditions necessary for smolts to commence their journey to the sea.

We will try to understand and compare the years with the discharge. However, a major issue arises. The flow measurement station closest to our study area is located at Evangervatn but only has data from 2019 onwards, unlike Bulken at the outlet of Vangsatnet, where we have flow data prior to 2000. We created a graph Figure 14 of the flow rates between April 1st and June 30th from 2019 to 2022 at both stations to establish the equation that relates the two. This specific period was used as it corresponds to the period of our study since 2001.

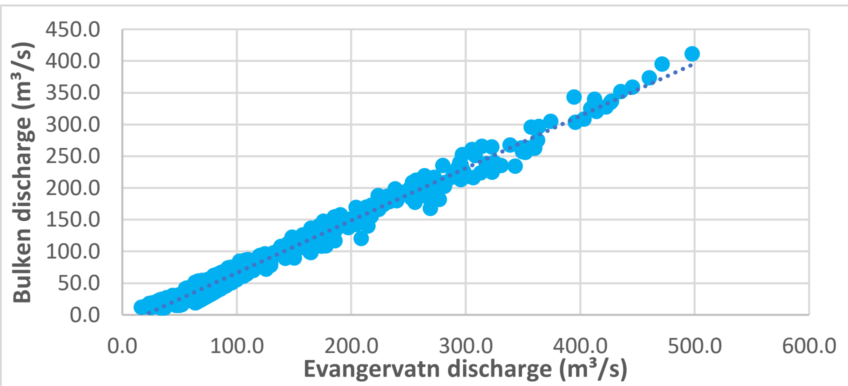


Figure 14 - Flow correlation graph between Bulken and Evanger lake

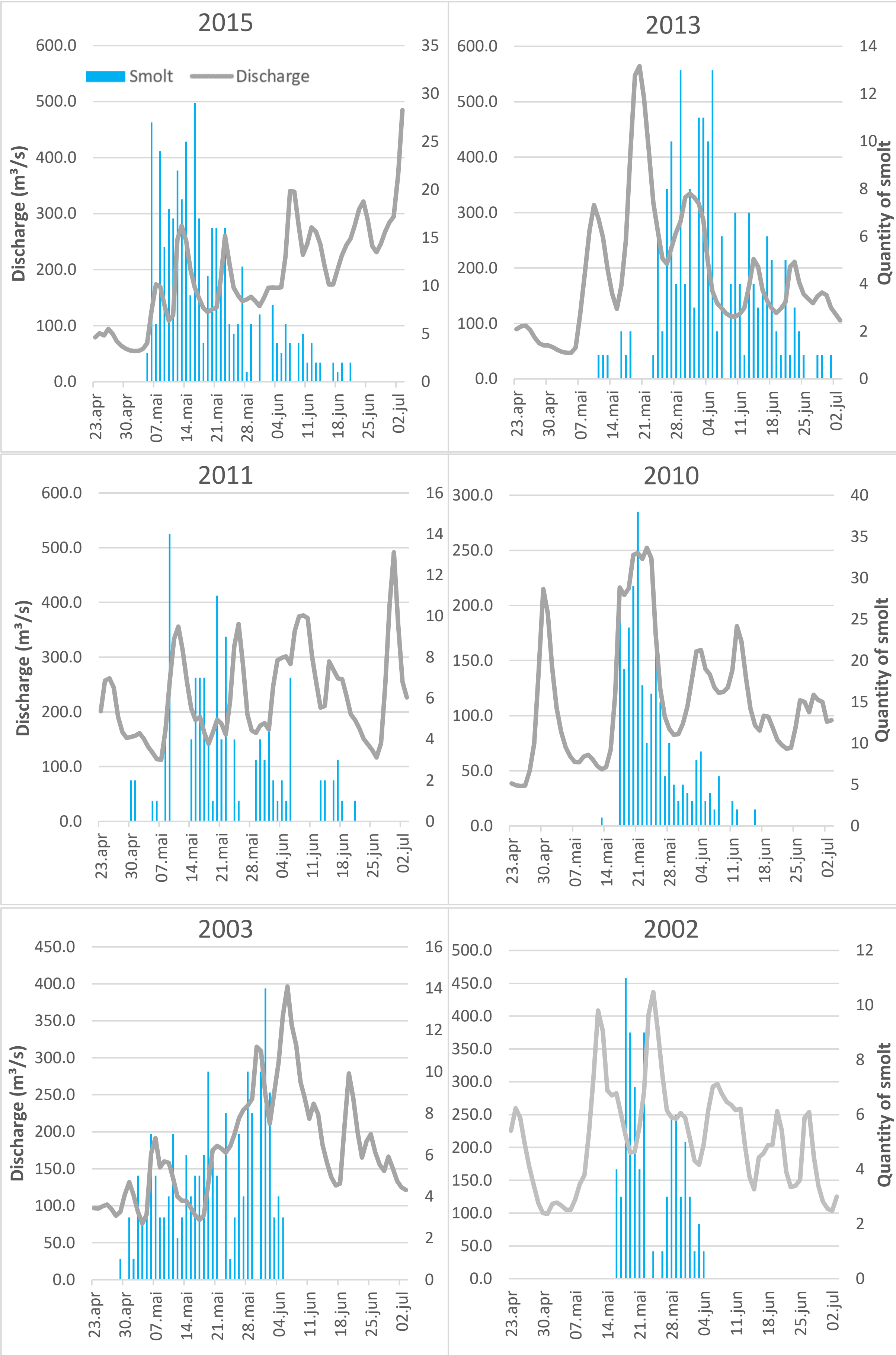
With an R^2 value of 0.9833, the correlation is significant. The equation $y = 0.8245x - 16.3$ will be used to correct the flow rates obtained at Bulken in order to analyze our data and approximate the flow values at the river outlet. Therefore, if x represents the flow rate at Evangervatn, we can calculate x as $x = (y/0.8245) + 16.3$.

As smolts want to reduce their energy consumption for migration, they use the current. We should notice a link between flow rate, which is directly linked to current speed, and catches at river outlets. As shown Figure 15 by the years 2010, 2013, from 2015 to 2017, 2021, and this year. Flow rates below 100 m^3/s did not allow migration in late April.

However, a flow rate above 100 m^3/s seems to be favorable. In fact, we can observe a triggering of migration from late April to early May when the flow rate approaches 100 m^3/s. The years 2003, 2020, and 2022 appear to be consistent with the observations. Furthermore, we can note this very distinct characteristic for the years 2010, 2015, 2016, and 2021. The start of the migration is clear, with a peak shortly before or after the significant threshold of 100 m^3/s. A higher water flow facilitates the movement of smolts.

When the flow rate is stronger, it creates a current that helps smolts move more easily and quickly in the river. This allows them to overcome obstacles. A higher water flow can also reduce the risk of predation for smolts. When the flow rate is strong, it makes it more difficult for predators to catch the fish due to the current and a greater column of water. Smolts can take advantage of this increased protection during their migration to the ocean.

As we have just seen, a sufficient flow rate seems necessary for migration; however, a flow rate that is too high before migration seems to delay it. In 2002 and 2010, we had peaks above 200 m^3/s before early May. It is difficult to justify this because we do not have enough data, but we can hypothesize that excessively high flow rates before the onset of migration may delay it. Another hypothesis is that the temperature threshold may not have been reached, and that the smolts were therefore not mature enough to migrate when the flow increased at the end of April in 2002 and 2010.


2015
Smolt
Discharge
Discharge (m³/s)
2013
Quantity of smolt
2011
2010
2003
2002
23.apr
30.apr
07.mai
14.mai
21.mai
28.mai
04.jun
11.jun
18.jun
25.jun
02.jul

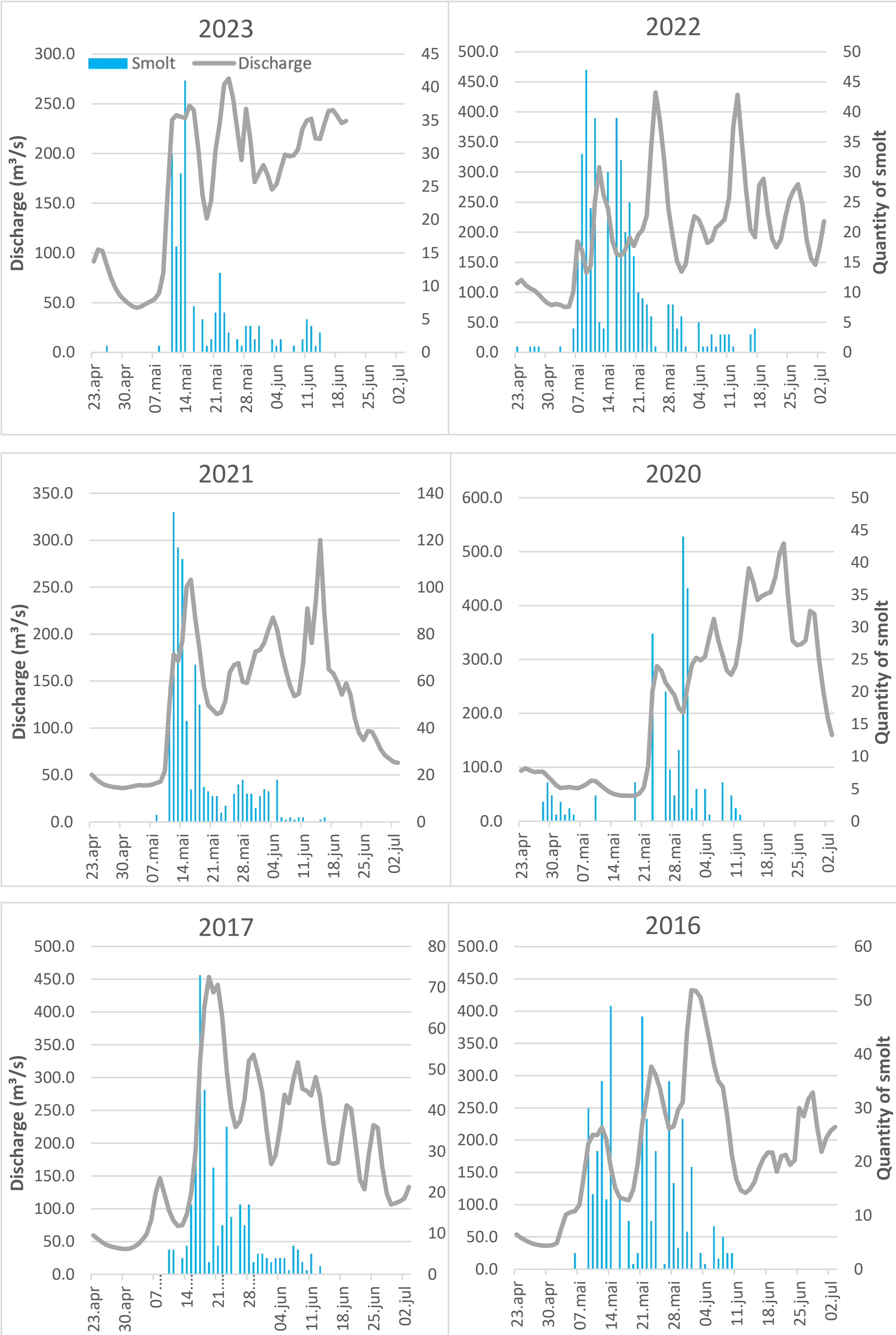


Figure 15 - Evolution of discharge and quantity of smolt captured over time with smoltscrew

3.5| Influence long-term evolution of captures in fixed traps: anticipating migration with placement

As we can see from Figure 16, there is a noticeable shift between the two catch accumulation curves for the upstream Smoltskrue and the more downstream Furnes net. On May 6th, we observe that 25% of the total catches are achieved by the Smoltskrue, while it takes an additional 5 days for Furnes to reach the same level of catch accumulation. This gap continues to widen, with 50% and 75% of the catches being achieved with an 8-day and 10-day interval, respectively. This time lag of several days in smolt captures between the two traps is an interesting observation. The "smoltskrue" is a relatively easy-to-set-up trap, which offers the advantage of lower costs and serves as an early indicator of smolt migration.

Indeed, due to the ease of setting up the "smoltscrew" we can obtain preliminary data on the onset of smolt migration at a lower expense.

However, this year, we observed the use of numerous traps, resulting in substantial costs. Therefore, it is crucial to anticipate the smolt migration using less expensive yet equally effective traps. This approach would help save financial resources while maintaining adequate monitoring of smolt migration.

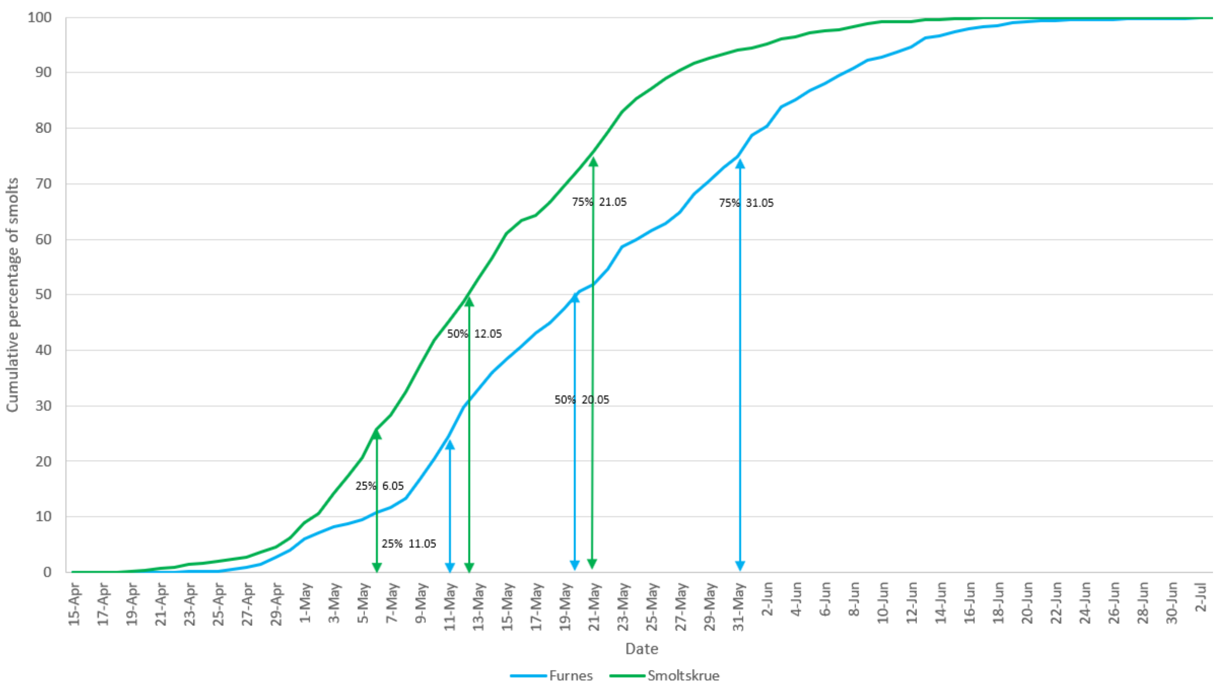


Figure 16 - Accumulation of smolt catches from two traps for 2023

Nevertheless, it is important to note that interannual fluctuations do not always follow a predictable pattern. The graph in the Figure 17 shows that some years, smolts appear to be captured first in Furnes, despite the use of different trap types.

This highlights the complexity of the various conditions imapcting catch efficiency and smolt migratory behavior and underscores the importance of conducting in-depth research to understand the factors influencing their movements.

However, we can observe that the 25% catch accumulation curves are more predictable and closely follow the 50% catch accumulation curve for the Smoltskrue compared to Furnes. The Smoltskrue trap's less random nature appears to be more advantageous for anticipating migration patterns.

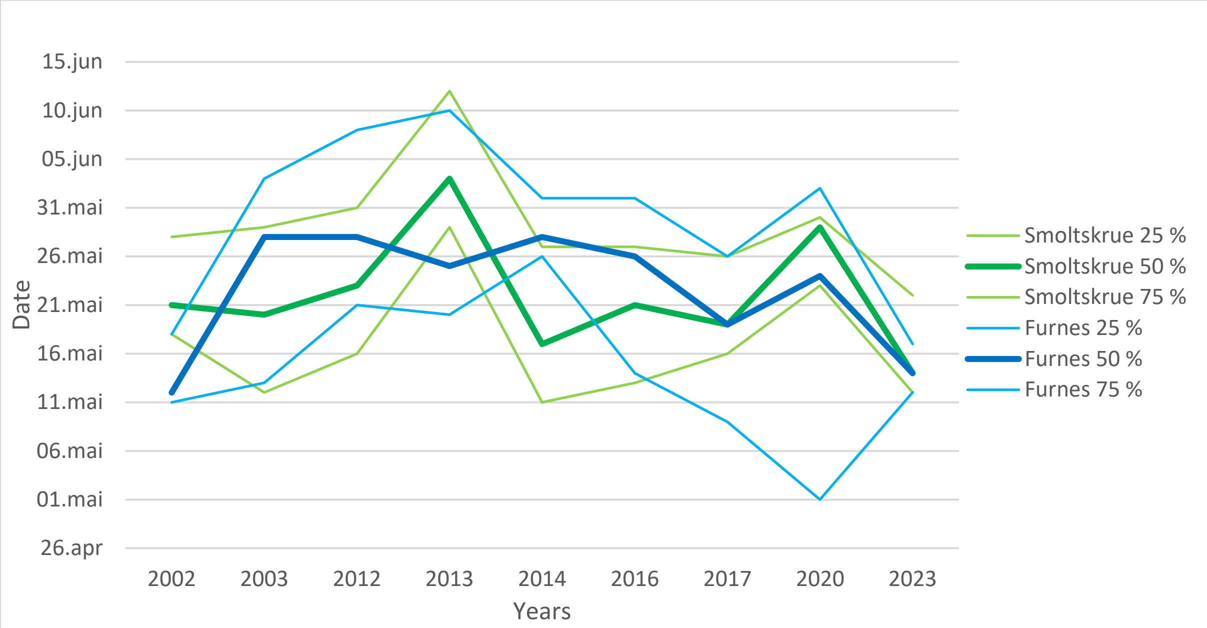


Figure 17 - Percentage of Smolt captures over the total for each season in various years

In conclusion, using the "smoltskrue" as a cost-effective and efficient preliminary trap to detect the onset of smolt migration is a promising approach. It enables us to better anticipate the smolt migration season and make informed decisions for resource management. However, due to the complex interannual variations, it is essential to continue research efforts to refine our understanding of smolt behavior and improve our capture and management strategies in the future and mainly upstream from the river.

As we have just seen, one of the main indicators of the onset of smolt migration is an increase in river discharge. Studies have shown that when the discharge exceeds 100 m^2 from late April onwards, it indicates the beginning of migration in the majority of cases.

The "smoltskrue," on the other hand, has proven to be a reliable tool for monitoring the onset and development of smolt migration. By using this trap, it is possible to make relative measurements of the number of migrating smolts between years. This provides valuable data for assessing migration trends and understanding annual variations. A better understanding of these variations is crucial for adapting smolt capture and management strategies in the future.

The significance of knowledge about the onset of smolt migration lies in optimizing the use of trap nets. By knowing the precise timing of the migration, it is possible to position the trap nets for maximum efficiency. Consequently, by focusing fishing efforts in areas with higher smolt presence, the cost-effectiveness of trap net fishing can be increased. This approach maximizes catches while reducing costs associated with trap net operations.

The results of various studies have also demonstrated that smolts require several days to travel from the "smoltskrue" in the river to the downstream trap net at Furnes. This information is crucial for optimizing the capture efficiency of the trap nets. By taking into account the time it takes for smolts to reach the trap, operations can be planned more precisely, thereby enhancing capture chances.

Furthermore, the use of multiple trap nets in different locations has identified specific areas that play a crucial role in optimizing capture efficiency. Research has revealed that the ideal location for smolt capture is in the Furnes region. Therefore, future efforts should be concentrated in this area to maximize results. On the other hand, trap nets positioned closer to the mouth of the Bolstad River have shown low capture efficiency and should be avoided.

In conclusion, the use of the "smoltskrue" as a preliminary trap to detect the onset of smolt migration offers numerous possibilities for improving aquatic resource management. By observing river discharge, relying on the reliability of the "smoltskrue" as a monitoring tool, and understanding smolt behavior, it is possible to optimize the use of trap nets and increase capture efficiency while reducing costs. However, ongoing research is necessary to further refine our understanding of smolt behavior and enhance capture and management strategies, particularly upstream from the river.

4 | CONCLUSION

In conclusion, the results of this study have revealed that this year ranks as the second-best in terms of smolt captures since 2001. However, when comparing the fishing effort, the number of traps used, and the time invested, we are far behind the best years. The trend in smolt captures resembles that of previous years. We have also identified the significant influence of timing, as the smolts need to spend a certain number of days in the river (around 130-140 days for the Vosso River) before migration. This explains why we observe limited migration before early May, especially with insufficient water flow. However, once this required time has passed and with adequate water flow, the migration can start.

It is evident that there are still aspects we do not fully comprehend, emphasizing the importance of continuing to use traps in various locations, even if it incurs higher costs. By doing so, we may unveil further insights into the migratory behavior of smolts and improve our management strategies.

To mitigate expenses, it is crucial to optimize the use of traps by anticipating smolt migration. Installing traps in the fjord at the last moment, based on monitoring smolt captures with less expensive traps placed upstream, can help save financial resources while still achieving comprehensive data on migration patterns.

Overall, the findings from this study provide valuable information for understanding smolt migration patterns and the factors influencing their behavior. Continuing research efforts and employing a strategic approach to trap placement will contribute to a more efficient and cost-effective management of smolt populations, ultimately benefiting both conservation efforts in the long run.

Regarding my feelings about my end-of-studies internship, I realize how fortunate I have been to work abroad in Norway with passionate teams about their work. I now understand that this internship has provided me with much more than just technical knowledge for my future professional career. Today, I have a different perspective on management and the importance of trusting my teams. I have discovered another aspect of myself and my adaptability. Moreover, I have gained confidence in English, which will no longer be a constraint.

However, I also realize that research is not suitable for me. Indeed, I feel the need to work on various projects, communicate with different stakeholders, and engage with the community.

5 | APPENDICES

APPENDIX I : Capture ramp at a dam on the palmafossen site

APPENDIX II : Photos of the smoltscrew

APPENDIX III : Photo of an incision

APPENDIX IV : Tagger worktop

Years	Date	Smoltskrue	Date	Mix Ruser	Date	Ruser Furnes	Date	Ruser Trolkona	Date	Antenna	Date	Fishlift
	23.04.2022		27.04.2022									
2022	17.06.2022	1	17.06.2022	Furnes, 1bis								
	08.05.2021		25.04.2021									
2021	16.06.2021	1	16.06.2021	Furnes, 1bis								
	28.04.2020				25.04.2020							
2020	12.06.2020	1			17.06.2020	1						
	Shortage of human resources				15.04.2019				16.04.2019			
2019					10.06.2019	1			11.06.2019	1		
					25.04.2018							
2018					14.06.2018	1						
	10.05.2017				29.04.2017							
2017	13.06.2017	1			13.06.2017	1						
	06.05.2016				05.05.2016							
2016	10.06.2016	1			24.06.2016	1						
	05.05.2015		01.05.2015	Furnes,								
2015	21.06.2015	1	30.05.2015	Trolkona								
	27.04.2014				30.04.2014							
2014	12.06.2014	1			16.06.2014	1						
	11.05.2013				10.05.2013							
2013	01.07.2013	1			28.06.2013	1						
	01.05.2012				26.04.2012							
2012	01.07.2012	1			03.07.2012	1						
	30.04.2011											
2011	21.06.2011	1										
	13.05.2010											
2010	16.06.2010	1										
	Financing problems				30.04.2008							
2008					19.06.2008	1						
					23.04.2007							
2007					07.06.2007	1						
					26.04.2006							
2006					28.06.2006	1						
							03.05.2005					
2005							08.06.2005	1				
					08.05.2004		09.05.2004					
2004					01.06.2004	1	01.06.2004	1				
	29.04.2003				29.04.2003		04.05.2003					
2003	05.06.2003	1			27.06.2003	1	27.06.2003	1				
	16.05.2002				30.04.2002						04.05.2002	
2002	04.06.2002	1			18.06.2002	1					14.05.2002	1
											04.05.2001	
2001											16.06.2001	1
Total		13		3		14		3		1		2

APPENDIX V : Detailed table of traps used from 2001 to 2022

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Capture of outmigrating impact of smolt trap design and placement as a means to optimize capture efficiency and costs

Abstract : Norway historically has had a significant relationship with aquqtic resources, both maritime and freshwater. This utilization of resources inevitably impacts aquatic environments. For several decades, Norwegian salmon populations have been affected by significant declines in stocks, and in certain rivers, some populations have almost disappeared. Direct or indirect anthropogenic pressures such as acid rain, hydroelectric power plants, salmon farming, and construction projects weigh on the environment.

This report is part of an annual smolt capture campaign on the Vosso River, aimed at understanding migration patterns and safeguarding the salmon population along with its genetic heritage. Since 2001, the LFI group has been capturing, tagging, and releasing as many smolts as possible at sea to increase the adult salmon's return and hopefully reduce future interventions.

This year, numerous traps were used to try and find new suitable areas for smolt migration and optimize capture. Two traps were placed in the same location as in previous years to provide an internal point of comparison. The study reveals that an increase in river flow is a key indicator of the start of smolt migration. The "smoltscrew" has proven to be a reliable tool for monitoring smolt migration and assessing annual variations. By positioning capture traps based on the precise timing of migration, it is possible to optimize fishing efficiency while reducing costs. Further research is needed to improve understanding of smolt behavior and refine capture and management strategies.

Keys words : Aquatic environments, salmon populations, smolt capture campaign, Vosso River, migration, tagging, monitoring, capture strategies, traps

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