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Reported Escape incidence analysis

Genetic Intrusion Risk Assessment

ICES – GIRAF working paper

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Abstract

This report provides an analysis of reported escape incidents involving farmed salmon in Icelandic fjords from 2018 to 2023, specifically addressing the risk of genetic introgression. It details significant events across key locations such as Hringsdalur, Laugardalur (2018), Haganes (2021), and Kvígindisdalur (2023). Methodologies for estimating escape numbers, including vaccination and slaughter rates, are discussed. The report also highlights the use of fatty acid analysis to determine fish origin and life history.

Furthermore, the expanding Atlantic salmon aquaculture in Iceland, as assessed by the Marine and Freshwater Research Institute (MFRI), emphasizes the need for monitoring genetic introgression risks from escaped farmed salmon into wild populations. Ova producers are mandated to maintain genetic databases that trace the origin of any escaped salmon, ensuring the ability to analyse genetic impacts from individual escape events.

Further sections cover maturation rates within farmed cages and instances of untraced escapees. Conclusions suggest that both light regulation in cages and smoltification methods profoundly impact salmon maturation, informing recommendations for future mitigation strategies.

Keywords: farmed salmon, escape incidents, genetic intrusion, Iceland, maturation, smoltification, fatty acid analysis.

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1 Introduction

Atlantic salmon aquaculture is expanding in Iceland. Since 2017, the Marine and Freshwater Research Institute (MFRI) has been tasked with assessing the environmental impacts associated with the risk of genetic introgression from escaped farmed salmon into wild populations, modelling the potential intrusion of these escapees in native salmon stocks. This research provides a vital foundation for informed political decisions regarding the regulation and development of the aquaculture industry in Iceland.

As salmon ova producers, according to regulation, are required to maintain databases of the genetic markers of farmed salmon so that the origin of farmed salmon, which escape and are later caught, can be traced back to specific sea cage farming operations. Additionally, ova producers must preserve genetic material from parent fish in databases and keep records of which parent fish are sold to each operation, ensuring that the origin of farmed salmon caught can always be traced back to specific farming facilities. This gives us unique position to trace the effect of individual escape events and fine-tune the model according to data.

2 Report Analysis

2.1 Reported Escape Incidences

The first escape event after the risk assessment for genetic introgression was established year 2017, occurred during a storm on 11 February 2018, when salmon escaped from cages in Hringsdal in Arnarfjörður and Laugardalur in Tálknafjörður. In total, about 27,000 fish were estimated to have escaped during these two events.

Two years later, there was an escape event from Arctic Fish at Eyrarhlíð, but on a much smaller scale, in which two fish were caught in rivers that were suspected to be from this escape event. One was confirmed with DNA analysis, but it was not possible to confirm the other. These fish entered the rivers Víðidalsá and Staðará. Based on the rate of incursion, it is estimated that the magnitude of the escape was around 1,000 fish.

The largest escape occurred likely on 11 June 2021, during a net transfer at cage number 11 near Haganes, when about 83,000 smolts, weighing on average 850 grams, escaped from the net-pen of the company Arnarlax. This is the only early escape that has been traced to escaped fish in rivers.

Undoubtedly, the most consequential escape was a relatively small one from Arctic Fish in Kvígindisdalur in Patreksfjörður, likely around 8 August 2023, where it is estimated that about 3,500 fish escaped. A significant number of the escapees entered freshwater in the autumn of 2023, with over 400 caught during control operations comprising of drift diving and other efforts that same autumn, and six salmon escapees were caught in 2024, which could be traced back to this escape event.

Table 1. Reported escape incidents during the period from 2018 to 2023. The reasons for escapes are categorised in accordance with the classification in Norway. The table is based on data from MAST (The Food and Veterinary Authority), excluding the estimated number of escaped fish that is assessed.

Company	*Fjord*	*Site*	*Date incident*	*Date report*	*Estimatd number*	*Average weight*	*Course*	*Further*
Arnarlax	Arnarfjörður	Hringsdalur	11.2.2018	12.2.2018	21.000	7.2 kg	General operation	Bad weather
Arnarlax	Tálknafjörður	Laugardalur	11.2.2018	12.2.2018	5.250	3.5 kg	General operation	Bad weather
Arnarlax	Tálknafjörður	Laugardalur	6.7.2018	7.7.2018	300	3.5 kg	Work on pen	Hole in net
Arnarlax	Arnarfjörður	Hringsdalur	21.1.2019	22.1.2019		1.3 kg	Work on pen	Hole in net
Arnarlax	Tálknafjörður	Laugadalur	16.8.2019	17.8.2019		280 g	Unknown	
Kaldvík	Glímeyri	Berufjörður	17.9.2019	17.9.2019	10		Work on pen	Hole in net
Arctic Sea Farm	Dýrafjörður	Eyrarhlíð	1.2.2020	1.2.2020	1.000	2.4 kg	General operation	Bad weather
Arnarlax	Arnarfjörður	Hringsdalur	2.4.2020	2.4.2020		7.2 kg	General operation	Bad weather
Arnarlax	Patreksfjarðarflói	Eyri	15.4.2020	15.4.2020			General operation	Bad weather
Arnarlax	Tálknafjörður	Laugardalur	8.5.2021	8.5.2021	1		Work on pen	Lice counting
Arnarlax	Arnarfjörður	Haganes	29.8.2021	29.8.2021	82.000	800 g	Work on pen	Change of net
Arnarlax	Tálknafjörður	Laugadalur	29.10.2022	29.10.2022		105 g	Unknown	Hole in net
Háafell	Ísafjarðardjúp	Skarðshlíð	27.2.2023	27.2.2023		500 g	Work on pen	Hole in net
Arctic Fish	Patreksfjarðarflói	Kvígindisdalur	ágú.23	20.8.2023	3.500	6.2 kg	Work on pen	Hole in net
Total:					113.061			

2.1.1 Individual Events

The escape incidents where farmed salmon have verifiably returned to freshwater each have their unique circumstances. This section discusses the events of 2018 in Hringsdalur in Arnarfjörður and from cages in Laugardalur in Tálknafjörður together, as they share similar characteristics and occurred during the same storm. The fish involved in these escapes were nearing slaughter weight and were at an early stage of sexual maturation. Next, the escape at Haganes in 2021 is addressed, involving post-smolts that follow migration patterns of wild fish and hunt pray, exhibiting a different behavioural pattern from grow-out fish. Finally, the escape in Kvígindisdal is considered, where there was significant sexual maturation in the cage, and the fish were at harvest size. Additionally, escaped salmon that were not traced to specific escape events will be discussed separately.

2.1.2 Escapes from Hringsdalur and Laugardalur 2018

This involved fish that were nearing harvest size but exhibiting an early stage of sexual maturation. The escape incident occurred in February 12th, 2018.

2.1.2.1 Number of Escaped Fish from Hringsdal/Laugardal:

The number of escaped fish was estimated based on vaccination and slaughter rates as described in section 1.2.2.2, "Assessment of Escapes." Data from Arnarlax cages at Steinanes, where there was no suspicion or report of escapes, were used to assess variability in average mortality between farming cages. The observed average reduction was 18.9% with a standard deviation of 3.2%. In Hringsdal, escapes were reported from cages number 2 and number 6.

Table 2. Arnarlax farming site at Hringsdalur. Numbers of smolts stocked and numbers at harvest. Holes were found in cages number 2 and 6. The loss from cage 2 is greater than expected (bolded). The average is taken from cages other than cage 2.

Pen N°	stocked	Harvested	Losses	%
1	170.000	135.547	34.453	20,30%
2	**159.000**	**103.683**	**55.317**	**34,80%**
3	182.644	132.790	49.854	27,30%
4	167.000	142.179	24.821	14,90%
5	152.000	116.742	35.258	23,20%
6	157.000	125.123	31.877	20,30%
			μ	21,20%
			s	4,10%

2.1.2.2 Natural Losses and Assessment of Escaped Fish

Natural losses were comparable in five of the six sea cages in Hringsdal (Table 2.2 and similar to the reduction observed at Steinanes (18.9%), where no escape occurred. The average losses in these five cages were 21.2% with a standard deviation of 4.1%. Cage #2 was excluded from this calculation as it was evident that fish had escaped from there; as previously mentioned, a potential escape was reported from cages #2 and #6. However, the fish loss did not appear to be greater in cage #6 compared to other cages, leading to the conclusion that any escape from this cage was negligible. Therefore, it is assumed that all escapes in Hringsdal originated from cage #2. The number of escaped salmon is estimated by subtracting natural losses from total losses using Equation (4):

Number of escaped salmon = total losses – natural mortality = (34.8% - 21.2% = 13.6%).

Given that 159,000 fish were placed in the cage, the number of escaped salmon is estimated to be 21,600. This method could not be used for the cages at Laugardal due to two escapes and fish transfers between cages, which introduced uncertainty in loss assessments. By assuming comparable recovery rates in rivers from both escapes, escape estimates from Laugardal can be indirectly assessed based on the recovery number of escaped salmon in rivers for each cage site. Since three escaped salmon can be traced to Laugardal, compared to 12 from Hringsdal, it is estimated that 1/4 of the number from Hringsdal escaped from the Laugardal site, bringing the total number of farmed salmon that escaped from Hringsdalur and Laugardal in February 2018 to an estimated 27,000 fish.

2.1.2.3 Capture of Escaped Salmon from Hringsdal and Laugardal Escapes

A total of 15 salmon were traced to these two escape events. Ten of these fish were caught the same year, and five were caught the following year.

Table 3 Escaped salmon traced to the 2018 escapes at Hringsdal and Laugardal. Ten fish were caught in 2018 and another five in 2019.

Fish Nr.	River (place)	Smolt station (company)	Pen site (fjord)	Day:
F2018001	Selá (Ísafjörður)	Bæjarvík, (Arnarlax)	Laugardalur(Tálknafjörður)	24.7.2018
F2018002	**Staðará (Steingrímsfjörður)**	**Ísþór (Arnarlax)**	**Hringsdalur (Arnarfjörður)**	**30.7.2018**
F183110	**Staðarhólsá/Hvolsá (Breiðafj.)**	**Bæjarvík, (Arnarlax)**	**Laugardalur (Tálknafjörður)**	**18.8.2018**
F181303	Mjólká (Arnarfjörður)	Bæjarvík, (Arnarlax)	Hringsdalur (Arnarfjörður)	31.8.2018
F183504	**Vatnsdalsá (Húnaflói)**	**Bæjarvík, (Arnarlax)**	**Laugardalur (Tálknafjörður)**	**31.8.2018**
F183503	Eyjafjarðará (Eyjafjörður)	Bæjarvík, (Arnarlax)	Hringsdalur (Arnarfjörður)	9.6.2018
F2018009	**Laugardalsá (Ísafjarðardjúp)**	**Bæjarvík, (Arnarlax)**	**Hringsdalur (Arnarfjörður)**	**16.9.2018**
F2018010	Fjarðarhornsá (Breiðafjördur)	Bæjarvík, (Arnarlax)	Hringsdalur (Arnarfjörður)	25.9.2018
F2018011	Fífustaðadalsá (Arnarfjörður)	Bæjarvík, (Arnarlax)	Hringsdalur (Arnarfjörður)	15.10.2018
F2018012	Fífustaðadalsá (Arnarfjörður)	Bæjarvík, (Arnarlax)	Hringsdalur (Arnarfjörður)	15.10.2018
F192504	Mjólká (Arnarfjörður)	Ísþór (Arnarlax)	Hringsdalur (Arnarfjörður)[1]	30.8.2019
F192514	Mjólká (Arnarfjörður)	Ísþór (Arnarlax)	Hringsdalur (Arnarfjörður)[1]	30.8.2019
F192503	Mjólká (Arnarfjörður)	Bæjarvík (Arnarlax)	Hringsdalur (Arnarfjörður)[1]	30.8.2019
F192515	Mjólká (Arnarfjörður)	Bæjarvík (Arnarlax)	Hringsdalur (Arnarfjörður)[1]	30.8.2019
F192515	Mjólká (Arnarfjörður)	Bæjarvík (Arnarlax)	Hringsdalur (Arnarfjörður)[1]	30.8.2019

The distribution pattern of escaped salmon from this incident followed the expected trend for late-stage escapes, moving primarily northward with a distribution range of approximately 600 kilometres. Most fish were found near the escape site. Six fish were found in rivers with established populations, while nine were in rivers near the escape site, which are not considered to have such populations.

2.1.2.4 Fatty Acid Analysis of Escapes from Hringsdalur / Laugardalue to Determine Life Histories

A relatively new method has been developed to determine at which life stage the farmed fish escaped at, based on the relative proportion of linoleic fatty acid of the total fatty acids (FA). This allows differentiation between fish that have fed on wild food sources compared to those that escaped late in the production cycle. The analysis of FA ratios relies on the presence of linoleic acid (18:2n6), which originates primarily from terrestrial plants, with oils and meals made from them (such as soybean and rapeseed) used in salmon feed. Wild fish food contains little linoleic acid, resulting in much lower levels in wild salmon. In comparison, wild fish has a typical C18:2n6 ratio (of total fats) of 1,0 but farmed salmon in cages have approximately ten times the amount of linoleic acid or about 10-15%. If farmed salmon escape early and feed on wild sources, the ratio becomes comparable to that in wild fish or around 1%. Fish from these late escape events was caught in 2019, more than a year of freedom. If they had consumed wild food, this would be reflected in their fatty acid composition. However, the results strongly indicated that the fish had fed exclusively on aquaculture feed during their year of freedom as seen in table 4.

Table 4. Fatty acid analysis of escaped fish from the Hringsdal escape. The fish were caught one year after they escaped and have only eaten feed during that period, presumably near the farming cages. In comparison, wild fish has a typical C18:2n6 ratio of 1,0 ±0.1

Sample N°	Ratio C18:2n6	Escape type:	River	Pen site	Day of catch
F192514	**13,7**	Late escape	Mjólká	Hringsdalur (Arnarfjörður)	30.8.2019
F192504	**15,4**	Late escape	Mjólká	Hringsdalur (Arnarfjörður)	30.8.2019
F192515	**15,3**	Late escape	Mjólká	Hringsdalur (Arnarfjörður)	30.8.2019
F192513	**15,0**	Late escape	Mjólká	Hringsdalur (Arnarfjörður)	30.8.2019
F 192503	**15,5**	Late escape	Mjólká	Hringsdalur (Arnarfjörður)	30.8.2019

2.1.3 Escape from Haganes 2021

This section concerns fish that escaped as smolts, with an average weight of 850 grams. The escape is therefore classified as an early-stage event, and the fish typically migrate to feeding areas during the winter, where they consume wild food, returning in the spring to seek upstream migration routes near the escape site. The escape occurred in June 2021, and their presence in rivers was not expected until the spring of 2022.

2.1.3.1 Number of Escaped Fish from Haganes

Table 5. Calculation of number of escapes from Haganes 2021

	105.801
Ratio after escape:	38%
Number after 16000 added in July	39.522
Numer with addition subtracted	23.522
Number of escapees	81.659

Table 2.2 shows the escapes from Haganes in 2021 calculated using the ratio (SFR)escaped/(SFR)average. For the escape, there were 105,181 fish in the cage, and the SFR was the same as the average of other cages. After the escape, the ratio had fallen to 38%, although 16,000 fish had already been added in early July, which increased the ratio. Subtracting these 16,000 fish suggests that approximately 23,000 fish remained after the escape. Therefore, the estimated number of escaped fish is around 82,000. A similar result is obtained when comparing the slaughter numbers from this cage with those from comparison cages (=81,000 fish) or using vaccination and slaughter rates as was done in Hringsdal (=80,000 fish).

2.1.3.2 Assessment of Returns After Wintering in Feeding Areas

The Institute of Marine Research of Norway conducted a series of organized releases of farmed salmon from sea cages between 2005 and 2008. Large smolts (post-smolts) and adult Atlantic salmon were released from various locations at different times of the year (Skilbrei et al., 2015). The large smolts released in their first summer migrated relatively quickly to the open sea. Some of these returned to spawn and were caught after 1-3 years at sea. In the risk assessment report of 2020, data from this study were further analysed. The number of salmon caught in rivers after 1-3 years decreased as the average size at release increased (50-1900 g). It is assumed that the catch rate was 60%. The total number of large smolts (post-smolts) released in these trials was 61,344 salmon.

The recapture rate of fish from the escape decreases exponentially with fish size (Figure 2.1, blue dots). Each point represents % recapture spitted into size classes. The decline was modelled using the equation L = Ae (-Bx) + C.

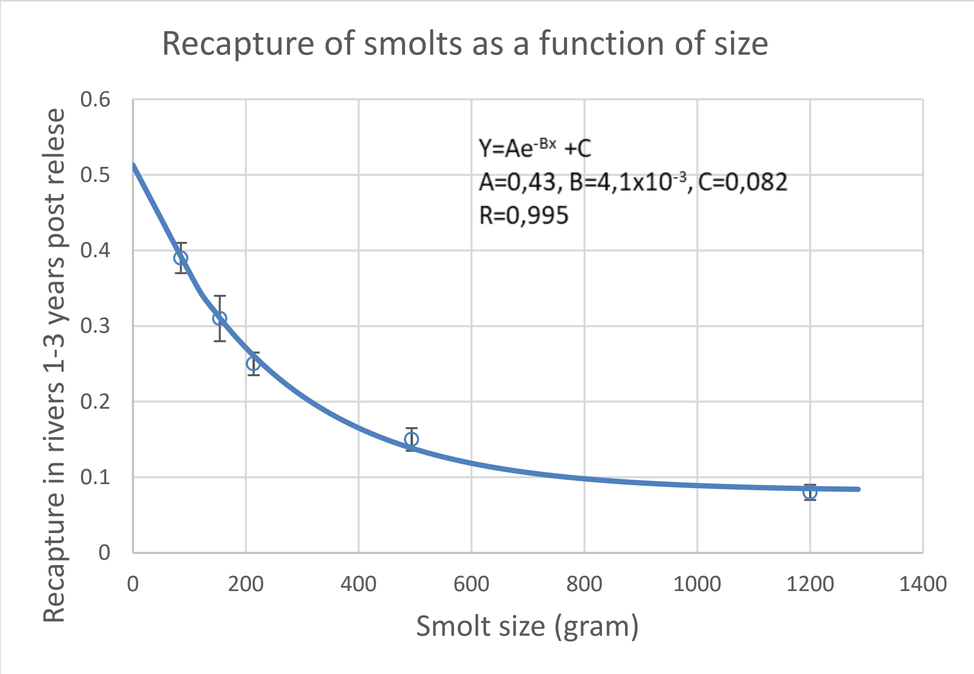

Figure 1: The recapture of large smolts 1-3 years after release in rivers. Blue dots: %Recapture as a function of fish weight grouped in size classes. Data from the results of release trials conducted by IMR from 2005-2008 (60,000 fish) (Skilbrei 2015). The blue curve approximates the equation $E = Ae^{-Bx} + C$.

There results were used to predict the recapture from the escape event at Haganes in 2021, where approximately 82,000 smolts with an average weight of 850 grams escaped on June 11, 2021. According to the coefficients derived from the equation, it was expected that a total of 78 fish should be caught in total 1-3 years after the escape of the 82,000 smolts of size 850 g.

2.1.3.3 Capture of Escaped Salmon from the Haganes Escape 2021

The prediction and the actual number of escaped salmon that returned to rivers after 1-3 SW is presented in table 2.5. The actual number returning was in line with the estimates, although lower. It is assumed in the Skilbrei experiment that rate of recovery of escapees had been around 65%. According to Directorate of Fisheries in Iceland the rate of recovery of fish from fishing was around 60% (Guðni Magnús Eiríksson 2022 personal comm.).

Table 6. Comparison of Estimated Number of Fish Returning from Feeding Areas vs. Actual Catches

Number in Escape (individuals)	**82,000**
Size at Escape (g)	850
Estimated Catch According to Equation:	
After 1 Year	36
After 2 Years	26
After 3 Years	16
Total for 1-3 Years	78
Actual Catch:	
After 1 Year	27
After 2 Years	5
After 3 Years	0
Total for 1-3 Years	32

Most of the fish were caught near the farming site, as shown in Table 2.5. The majority of fish were caught after 1SW in Mjólká (20), followed by Ósá in Patreksfjörður (4), and Sunndalsá (2). In 2023 five fish were caught, including in Kársstaðaá in Snæfellsnes (1) in Hússadalsá in Steingrímsfjörður (1) and in rivers in Tálknafjörður and Arnarfjörður (3). Most of the fish was caught very close to or less that 50 km from the cage site (30). Two fish where caught further away i.e. Kársstaðaá and Hússadalsá after 2SW.

Table 7. Escaped Salmon from the Early Escape at Haganes 2021 Caught in Mjólká, Sunndalsá in Arnarfjörður, and Ósá in Patreksfjörður 2022. Five fish were caught in 2023, including one in Kársstaðaá in Snæfellsnes and one in Hússadalsá in Steingrímsfjörður

Fish No.	Waterbody	Region	Farming Site (Fjord)	Date
F181507	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	Autumn 2022
F181509	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	Autumn 2022
F181511	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	Autumn 2022
F181512	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	24.8.2022
F181513	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	Autumn 2022
F181516	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181518	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181519	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181521	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181522	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181527	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181531	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181532	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181533	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	25.8.2022
F181555	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	30.8.2022
F181535	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	17.9.2022
F214310	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	14.9.2022
F214311	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	14.9.2022
F214312	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	15.9.2022
F214313	Mjólká	Arnarfirði	Haganes (Arnarfjörður)	15.9.2022
F214336	Ósá	Patreksfirði	Haganes (Arnarfjörður)	16.9.2022
F214339	Ósá	Patreksfirði	Haganes (Arnarfjörður)	21.9.2022
F214340	Sunndalsá	Arnarfirði	Haganes (Arnarfjörður)	12.9.2022
F214342	Sunndalsá	Arnarfirði	Haganes (Arnarfjörður)	13.9.2022
F238205	Botnsá	Tálknafirði	Haganes (Arnarfjörður)	24.10.2023
F231971	Húsadalsá	Steingrímsfirði	Haganes (Arnarfjörður)	26.10.2023
F237132	Sunndalsá	Arnarfirði	Haganes (Arnarfjörður)	16.10.2023
F237177	Kársstaðaá	Snæfellsnes	Haganes (Arnarfjörður)	5.11.2023
LaxF_F8	Fífustaðadalsá	Arnarfirði	Haganes (Arnarfjörður)	18.9.2023

2.1.3.4 Fatty Acid Analysis from Haganes 2021 to Determine Life Histories

To further confirm life histories, a fatty acid analysis was conducted on the fish that originated from the Haganes escape, as well as on fish that could not be identified via genetic analysis but may have been from the same escape. Additionally, four samples of wild fish were measured for comparison.

Table 8: Fatty Acid Ratios of Fish from the Early Escape at Haganes on June 11, 2021. For comparison, the ratio of linoleic acid (18:2n6) in wild fish caught in Mjólká on the same day is presented. The average ratio in wild fish and farmed fish caught in Ósá is the same, but slightly higher in fish caught in Mjólká

Sample:	Ratio C18:2n6	Type of escape	River	Pen site	Date (caugt or delivered)
F214310	2.1	supersmolt	Mjólká (Arnarfjörður)	Haganes (Arnarfjörður)	14.9.2022
F214311	1.4	supersmolt	Mjólká (Arnarfjörður)	Haganes (Arnarfjörður)	14.9.2022
F214312	1.6	supersmolt	Mjólká (Arnarfjörður)	Haganes (Arnarfjörður)	15.9.2022
F214313	1.6	supersmolt	Mjólká (Arnarfjörður)	Haganes (Arnarfjörður)	15.9.2022
F181519	1.3	supersmolt	Mjólká (Arnarfjörður)	Haganes (Arnarfjörður)	30.8.2022
F181518	1.1	supersmolt	Mjólká (Arnarfjörður)	Haganes (Arnarfjörður)	30.8.2022
F214336	1.0	supersmolt	Ósá (Parteksfjörðir)	Haganes (Arnarfjörður)	16.9.2022
F214337	1.1	supersmolt	Ósá (Parteksfjörðir)	Not match [1]	21.9.2022
F214338	1.0	supersmolt	Ósá (Parteksfjörðir)	Tjaldanes (Arnarfjörður)[2]	21.9.2022
F214339	0.9	supersmolt	Ósá (Parteksfjörðir)	Haganes (Arnarfjörður)	21.9.2022
F181528	0.9	wild salmon	Mjólká (Arnarfjörður)	wild	30.8.2022
F181510	1.1	wild salmon	Mjólká (Arnarfjörður)	wild	30.8.2022
F181530	0.9	wild salmon	Mjólká (Arnarfjörður)	wild	30.8.2022
F181520	1	wild salmon	Mjólká (Arnarfjörður)	wild	30.8.2022

[1]could not be traced, but likely Haganes. [2]Regisered in Tjaldanes but probably from Haganes

The results clearly indicate that all the fish analysed showed signs of having exclusively consumed wild food. However, a sample from fish caught in Mjólká exhibited a slightly higher ratio of linoleic acid, which could suggest that they may have grazed on salmon feed while passing by their home cages in Haganes.

2.1.4 Escape from Kvígindisdal 2023

The escape originated from Arctic Fish in Kvígindisdal in Patreksfjörður, likely around August 8, 2023. Approximately 3,500 fish escaped.

S E K U N D A skráningar m/ framleiðanda INNOVA

Date:27.8.2023 00:00 - 27.8.2023 23:59

Arctic Fish

Afurð	Gæðaflokkur	Kví	Fjöldi	Þyngd	Meðalþyngd	Hlutfall	Hlutfall af heild
SEKUNDA Lítill	SEKUNDA Lítill	K 8	25	44,06 kg	1,8 kg	0,33%	0,04%
SEKUNDA Sár	SEKUNDA Sár	K 8	2269	9.764,84 kg	4,3 kg	73,13%	9,28%
SEKUNDA Kynþroska	SEKUNDA Kynþroska	K 8	301	1.527,55 kg	5,1 kg	11,44%	1,45%
SEKUNDA Vanskapaðir	SEKUNDA Vanskapaðir	K 8	67	275,70 kg	4,1 kg	2,06%	0,26%
SEKUNDA Svartir Blettir	SEKUNDA Svartir Blettir	K 8	32	127,86 kg	4,0 kg	0,96%	0,12%
SEKUNDA Vélaskemmdir	SEKUNDA Vélaskemmdir	K 8	380	1.612,51 kg	4,2 kg	12,08%	1,53%
			3.074	**13.352,5 kg**	**4,3 kg**	**100,00%**	**12,68%**

Figure 2: SECUDA registration for Fish from Cage 8 in Kvígindisdal. The ratio of maturity was identified as 1.45%.

A significant number of these fish migrated to freshwater in the autumn of 2023, with over 440 caught during the autumn operations, and six salmon were captured in 2024 that could be traced back to this escape.

It quickly became apparent that the escape was not large, significantly smaller than the escapes from Hringsdal, Laugardal, and Haganes. Nevertheless, reports of escaped salmon began to surface in various rivers. Suspicions arose regarding significant maturation among these fish, prompting requests for slaughter reports, referred to as Secondary Reports, from Arctic Fish. According to the report, the ratio of mature fish was estimated as 1.45% of the total. It should be noted that this assessment is based solely on a visual evaluation of external characteristics of sexual maturity slaughtered fish, and the maturity of females may have been underestimated.

Subsequently, personnel from the Marine and Freshwater Research Institute were sent to the Dimla slaughterhouse in Bolungarvík, where fish were still being processed from the Kvígindisdal site.

2.1.4.1 Measurements of Maturation at Slaughter in Dimla and of escapees in Captured Rivers

During the measurement of the maturation ratio of fish from Kvígindisdal conducted at the Dimla slaughterhouse, it was discovered that a significant portion of the fish was mature, comprising approximately 80% males and 20% females, resulting in an average maturation rate of 40%. This was considerably higher than what the SEKUNDO report had indicated

Table 9: Measurements of the Maturation Ratio of Fish from the Kvígindisdal Farming Site Conducted at the Dimla slaugherhouse.

Sex	Number	Mature Fish	Percentage (%)	Adjusted for Sampling Bias
Males	16	10	62.5	79%
Females	24	4	16.7	21%
Total	40	14	35	40%

It is evident that this high level of maturation will have a significant impact on the migration ratio as maturation is the main driver of salmon runs. This fact should be considered as a case distinct from the escapes in Hringsdal and Laugardal in 2018. Measurements were taken of the gonadosomatic index (GSI) of 103 farmed fish from the escape that migrated this year. All the fish were sexually mature and capable of participating in spawning in the autumn of 2023.

Table 10: Ratio of Sexes in 103 Escaped Salmon that Migrated in 2023 from sampled escaped fish in captured in rivers

Sex	Count	Percentage (%)
Males	63	61%
Females	40	39%
Total	103	100%

The sex ratio of the escapes in rivers was measured. The ratio of females was lower than that of males, as expected, but higher than measured during slaughter at Dimla. It cannot be concluded whether this difference is statistically significant due to the limited sample size during the measurements at Dimla.

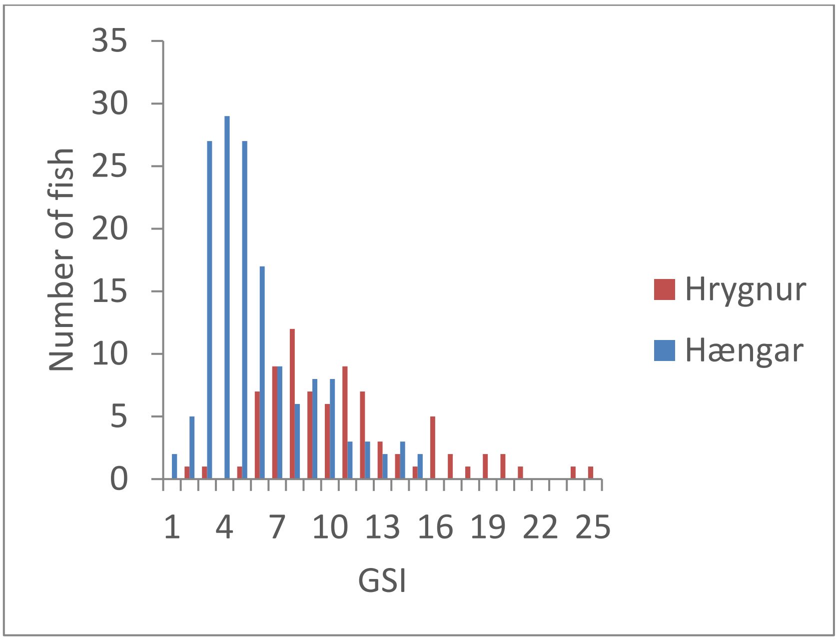

Figure 3: Gonadosomatic Index (GSI) of About 100 Fish that Migrated Following the Escape in Kvígindisdal. All these fish could participate in spawning. Orange: females Blue: males

2.1.4.2 Capture of Escaped Salmon from Kvígindisdalur 2023

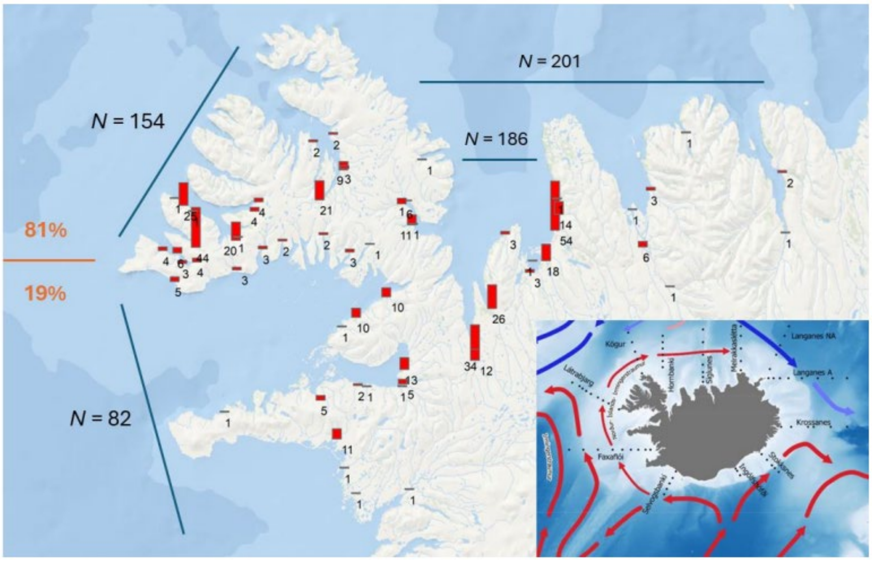

Figure 4: Distribution of Escaped Salmon Caught in Rivers in 2023 with Confirmed Farmed Origins (N=440). The inset shows the main ocean currents around Iceland (Steingrímur Jónsson and Sólveig R. Ólafsdóttir, 2021

The distribution of escaped salmon was consistent with the distribution from the escapes in Hringsdal and Laugardal in 2018, which were also late-stage escapes.

2.1.5 Escaped Fish Not Traced to Farming in Iceland

Some escapees have not been traced back to farming in Icelandic fjords. They are shown in Table 2.3 below. In most cases, the fish have been traced to producers, but this has not been done for three fish. One fish, caught in Breiðdalsá, matched the broodstock of Salmobreed (now Benchmark Norway), which has never been used in Iceland. To determine the origin of these unidentified escapees, samples were sent for analysis using the same method Benchmark Iceland employs at Identigen in Ireland. Since the same genetic markers are used, we are able to send our results to Benchmark and received feedback on whether the broodstock male had been used for roe sales domestically or internationally. If the broodstock male had been used for sales abroad, it is only noted that the roe was sold internationally without specifying country or company, as this information is confidential.

Eight of the samples in the table below and which were sent for this analysis at Identigen were found to be descended from broodstock males from Benchmark, of which the roe had been sold internationally and not used for production in Iceland. Further analyses are needed to confirm this more thoroughly. This could be done with a 16-marker microsatellite analysis of the corresponding females, as genetic samples are available at MAST.

Table 11: Fish that could not be traced to Icelandic producers using Salsea microsatellite markers. New samples were made for 8 fish and send to Identigen on Irland and compared to Benchmark database. According to the database the broodfish was used for export of eggs

Fish No.	River (Region)	Father	Producer	Customer	Date:
F181304	Mjólká (Arnarfjörður)	Unknown	Benchmark Iceland	Unknown	31.8.2018
F183113	Breiðdalsá (Breiðdalur)	Unknown	Salmobreed	Unknown	15.9.2018
F192520	Ytri Rangá (South Iceland)	Unknown	Benchmark Iceland	Unknown	15.8.2019
F204913	Víðidalsá (Steingrímsfjörður)	Unknown	Unknown	Unknown	18.12.2020
F181508	Mjólká (Arnarfjörður)	Unknown	Unknown	Unknown	Aut. 2022
F214337	Ósá (Patreksfjörður)	Unknown	Unknown	Unknown	21.9.2022
F230084	Kálfá (South Iceland)	2016_2_0417CA55F2	Benchmark Iceland	NON-ICE	18.9.2023
F231926	Hrútafjarðará (V-Hún.)	2016_2_0417CA55F2	Benchmark Iceland	NON-ICE	1.10.2023
F237077	Hvítá í Borgarf (West Iceland)	2016_2_0417CA55F2	Benchmark Iceland	NON-ICE	26.9.2023
F237117	Hvannadalsá (Ísafjarðardjúp)	2016_2_0417CA55F2	Benchmark Iceland	NON-ICE	9.10.2023
F237168	Búðardalsá (Dalasýsla)	2016_2_0417CA55F2	Benchmark Iceland	NON-ICE	30.10.2023
F237197	Botnsá (Tálknafjörður)	2016_2_0417CA55F2	Benchmark Iceland	NON-ICE	25.10.2023
F214313	Mjólká (Arnarfjörður)	2016_2_0417CA55F2	Benchmark Iceland	NON-ICE	15.9.2022
F211960	Varmá (South Iceland)	2015_2_04173BCF8F	Benchmark Iceland	NON-ICE	

Although it would certainly be better to have more detailed confirmation with further analyses, and in light of results regarding BKW (*vide infra*), it seems clear that some salmon, likely from foreign produces, are appearing in Icelandic rivers. It is known that salmon occasionally get caught in pelagic trawl nets of ships fishing for mackerel east of Iceland. Reports from fishermen and observations from fisheries inspectors show that over 400 salmon were caught as bycatch during mackerel fishing in two fishing seasons 2012. This corresponds to 5.5 salmon per thousand tons of mackerel and herring. Interestingly, only about 5% of these salmon are believed to originate from Icelandic salmon rivers. Therefore, it is not unlikely that among the foreign salmon around Iceland are escaped salmon that could find their way into Icelandic rivers.

2.1.6 General Status of Maturation in Farmed Cages

2.1.6.1 Measurements of Gonadosomatic Index (GSI) from Other Producers

It was essential to determine whether this was an isolated incident or part of a broader condition observed in cages throughout the fjords. Therefore, samples were collected from all producers by staff from the Marine Research Institute from autumn 2023 through early spring 2024 in cages where fish had reached a size indicative of impending maturation. Samples were taken from a total of 1,128 fish across 11 cages from all producers.

Table 12: Sampling for GSI Measurements from Producers Conducted in Autumn 2023 and Early Spring

Producer	Number of Samples
Kaldvík	698
Arnarlax	200
Háafell	100
Arctic Fish	130
Total:	1,128

The results indicated that there was almost no sign of maturation in the cages where the GSI index was measured (see Figure 3). It appears that maturation is not a widespread phenomenon, although further risk factors must be examined to rule out events similar to the escape event in Kvígindisdal in 2023 if possible.

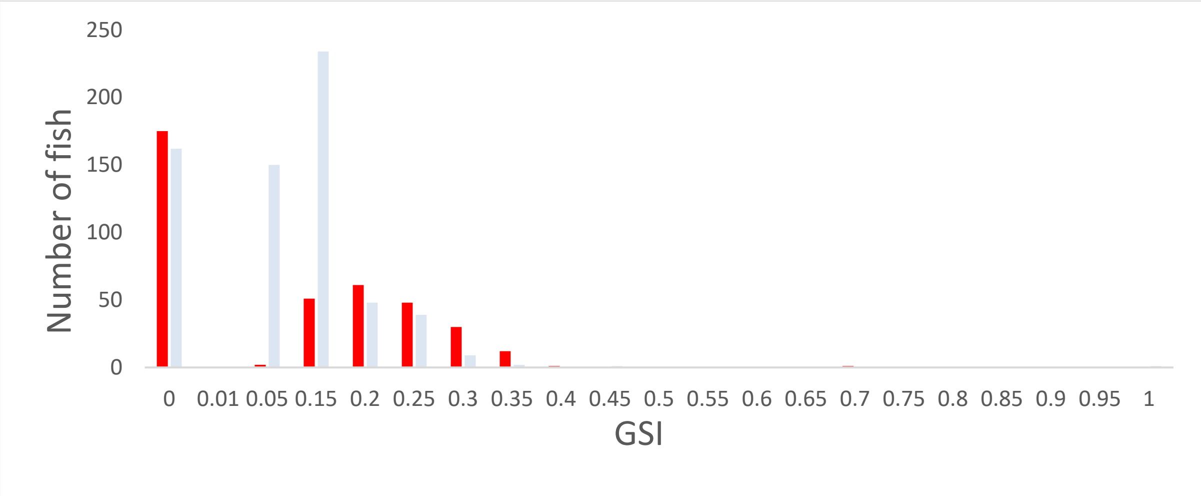

Figure 5: : **GSI Index in 11 Cages Across All Farming Areas**. Red bars represent females, while blue bars represent males. Notice the scale on x-axis

2.1.6.2 Monitoring of Maturation According to paragraph 38 in Regulation for fish farming

In accordance with regulatory changes made on May 1, 2024, the GSI index was monitored in fish in cages from late June through July. Significant maturation was evident only in measurements from Cage C8 at Háafell, where clear signs indicated that some of the fish would mature by autumn, closely following the criteria set forth in Peterson et al. (2005). The smolts in this cage came from Arctic Smolt's smolt facility in Tálknafjörður. It is known that light regulation was appropriate, as fish from the Háafell facility in Nauteyri in nearby pen did not show similar signs of maturity. Thus, the explanation likely lies in other factors. All fish were slaughtered a few weeks later, and monitoring of the net bags was conducted every 14 days.

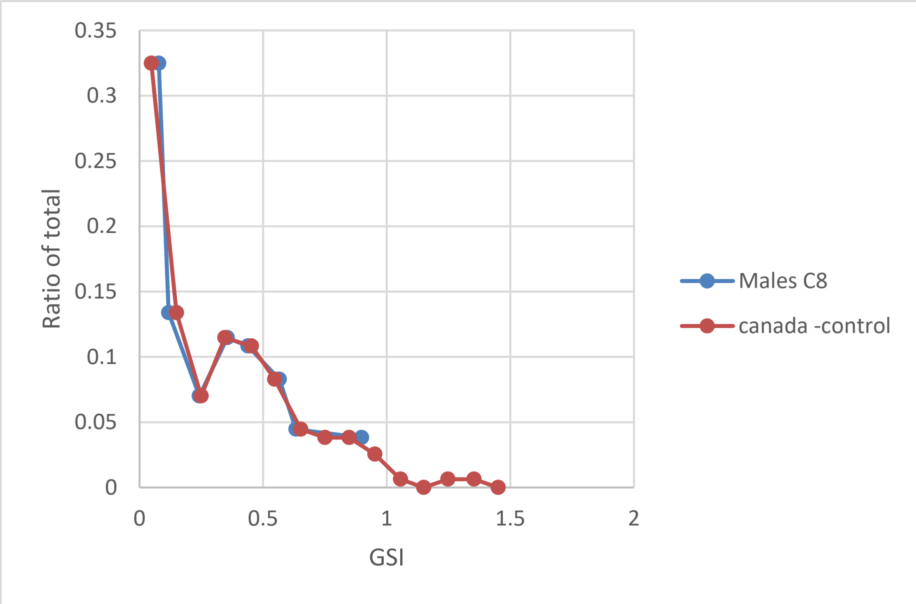

Figure 6: GSI Measurements in Cage C8 at Háafell Compared to Measurements from Fish in Natural Light (Non-Light-Regulated) in Peterson et al. (2005). The blue line represents the GSI of fish from Cage 8, and the yellow line represents fish that are not light regulated.

Following these results, monitoring continued for fish in other cages within the same farming facility until the turn of the year. There is a notable difference in the smoltification methods employed at the Arctic Fish facility compared to those used by Háafell at Nauteyri.

Cages with Fish from Arctic Smolt (Cages C5, C8, C10):

- **Smoltification:** A light-regulated smoltification process is used with six weeks of continuous darkness (winter), followed by an 18:6 (light:dark) cycle (spring). The temperature for fish from 10 grams to smoltification is set at 12°C.
- **Cage 5:** The maturation rate according to the company's report was approximately 1.2%. It should be noted that this is based on external examination of slaughtered fish and does not significantly highlight signs of maturation in females. Therefore, it may be estimated that the actual maturation rate could have been about 2.4%.
- **Cage 8:** As previously mentioned, this cage was slaughtered during the summer. GSI measurements indicated that 40% of males were approaching maturation, while approximately 20% of females could have reached maturation, accounting for about 30% of the total.
- **Cage 10:** The maturation rate according to the company's report was around 16%. As with the previous example, this is based on external examinations of slaughtered fish, and it is likely that the maturation of females is underestimated. Therefore, it may be estimated that the actual maturation rate could have been about 30%.

Cages with Fish from Nauteyri Station (Cages C1, C2, C3, C4):

- **Smoltification:** The temperature for fish from 10 grams to smoltification ranges from 9-10°C. A small amount of seawater is initially added to the tanks and gradually increased over a long period until full salinity is achieved. No smolt feed or light-regulated smoltification is utilized. Continuous light is maintained from the point of 10 grams until exposure.
- **Visible maturation:** No visible signs of maturation

2.1.6.3 Smoltification Methods of Other Producers

- Arnarlax: I hereby confirm that all our smolts are smoltified with salt feed and are subjected to a 24-hour light regime throughout the production cycle, from start-feeding until the smolt/post-smolt is delivered to the well boat." (Björn Hembre, CEO) The temperature remains below 10°C from 10 grams until smoltification.
- Kaldvík: Uses only salt feed and a 2-hour light period, similar to Arnarlax. The temperature remains below 10°C from 10 grams until smoltification
- Háafell: As described above for cages C1-C4. A small amount of seawater is initially added to the tanks and gradually increased over a long period until full salinity is achieved. No smolt feed or light-regulated smoltification is utilized. Continuous light is maintained from the point of 10 grams until exposure.

2.1.6.4 Conclusions

- Both light regulation in cages and the methodology of smoltification can significantly impact maturation.
- If maturation is absent, the migration ratio (L_G) is very low, at or below 1 ‰.
- Smoltification at excessively high temperatures, combined with a six-week darkness period followed by an 18:6 light cycle, appears to be highly questionable.
- If precautionary measures are implemented, this method should be banned until further research demonstrates that it can be applied safely.
- Mitigation measures must be established to ensure that fish do not mature during the farming period in cages.

References

Ove T. Skilbrei , Mikko Heino, Terje Svåsand (2015). Using simulated escape events to assess the annual numbers and destinies of escaped farmed Atlantic salmon of different life stages from farm sites in Norway. *ICES Journal of Marine Science,* Volume 72, Issue 2, January/February 2015, Pages 670–685, https://doi.org/10.1093/icesjms/fsu133

HAFRANNSÓKNASTOFNUN

Rannsókna- og ráðgjafarstofnun hafs og vatna