

Towards environmental compatibility and genetic containment and the Icelandic story of salmon on land



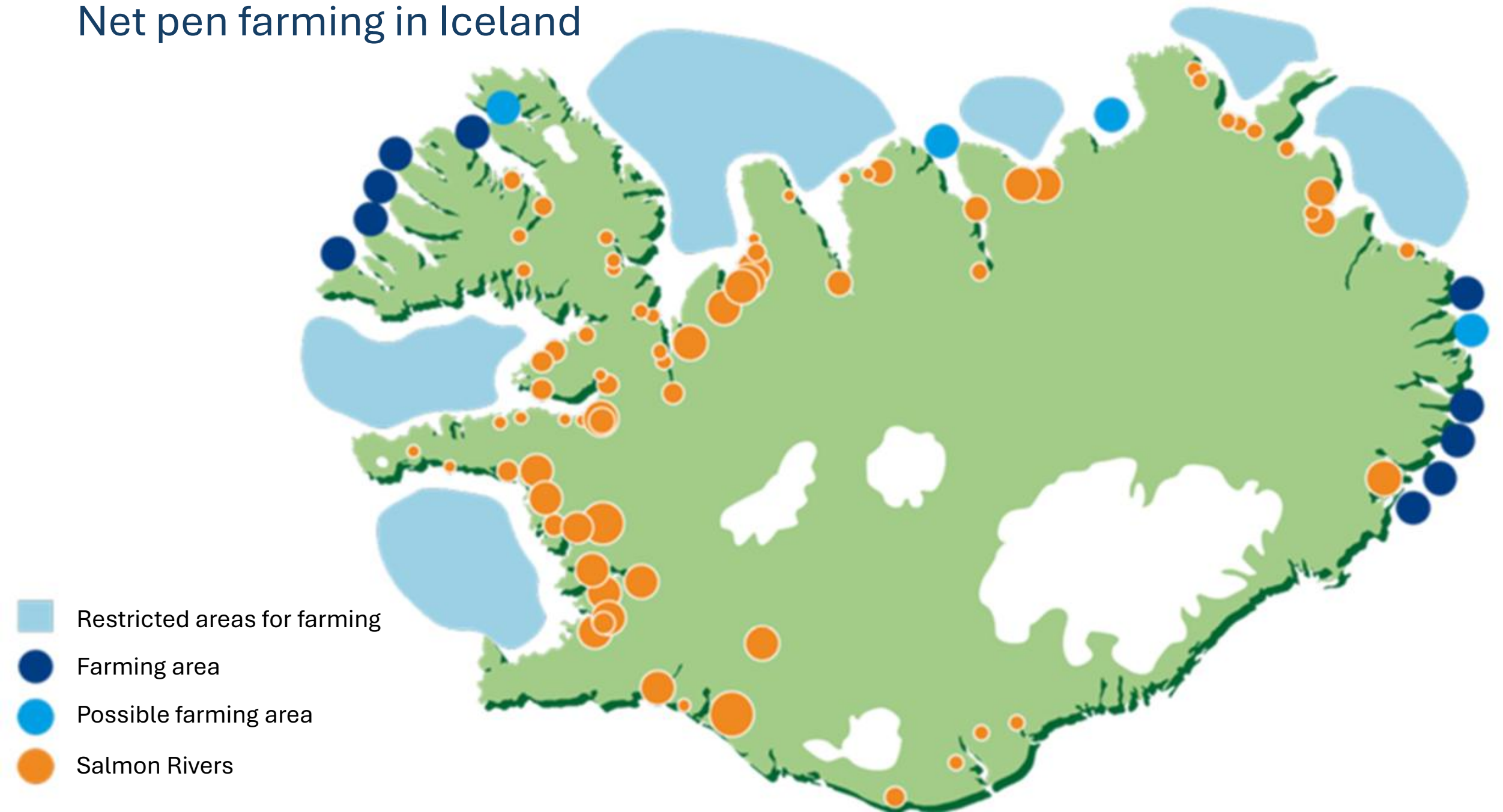
Research station Grindavík





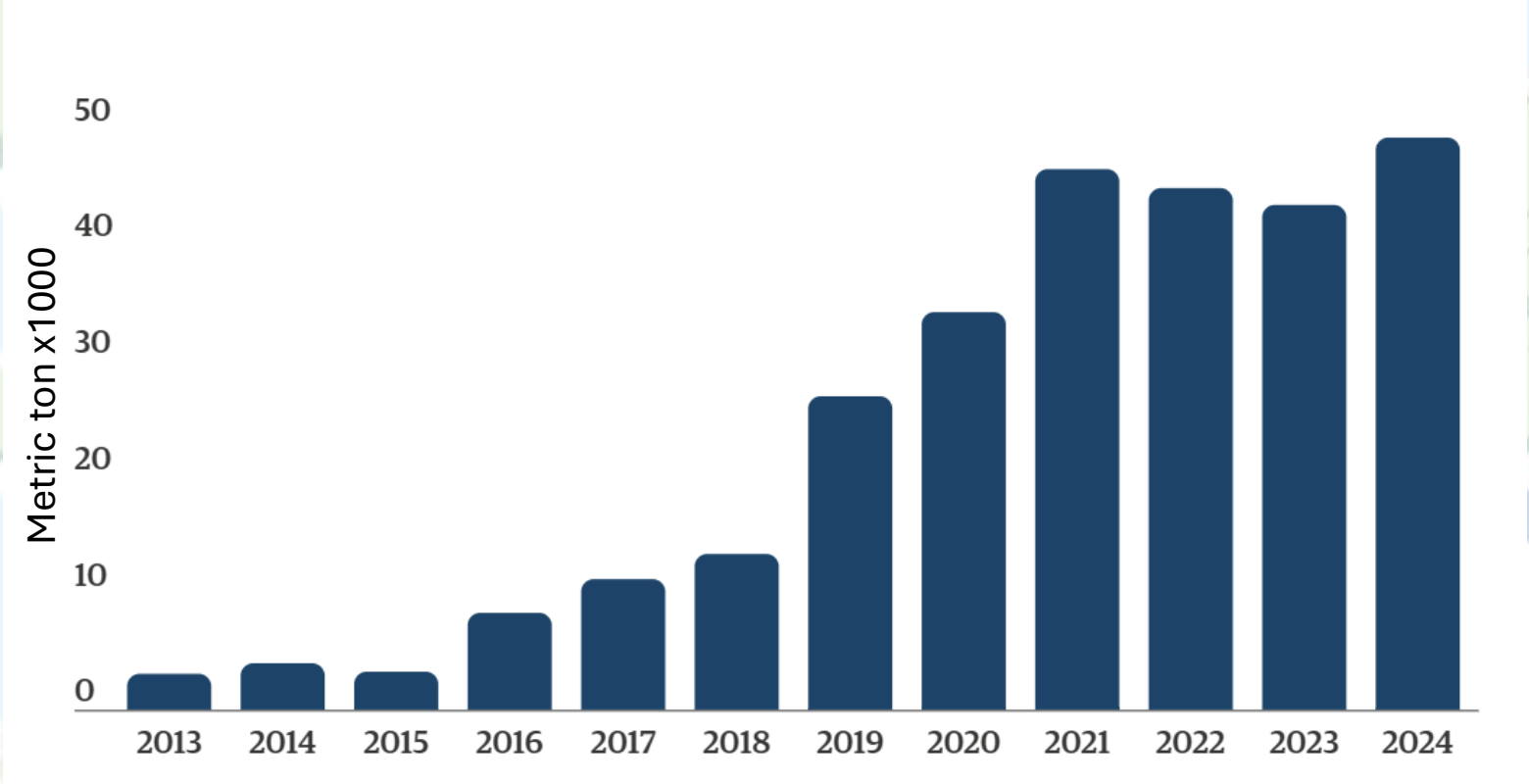


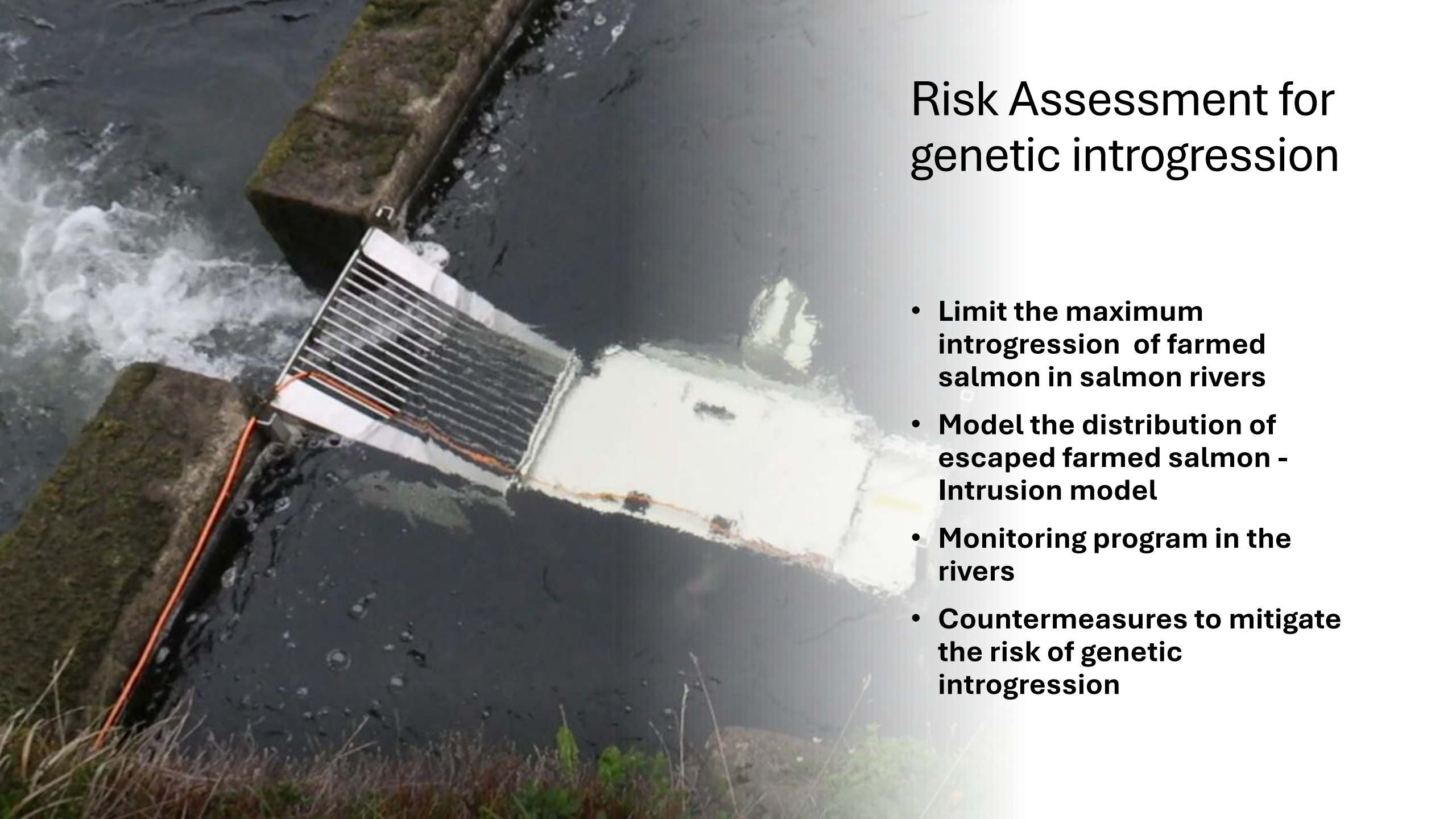
Net pen farming in Iceland



Net pen farming of salmon in Iceland

- Restricted areas for farming
- Farming area
- Possible farming area
- Salmon Rivers





Risk Assessment for genetic introgression

- **Limit the maximum introgression of farmed salmon in salmon rivers**
- **Model the distribution of escaped farmed salmon - Intrusion model**
- **Monitoring program in the rivers**
- **Countermeasures to mitigate the risk of genetic introgression**



Threshold for intrusion level

- In Norway rivers are classified depending on the percentage of farmed fish of the total number of fish.
- Kevin Glover *et al.* 2025 : Modelling the Consequences of Domestication-Introgression in Wild Populations Using Genetic Markers Under Varying Degrees of Selection.
 - Our results also suggest that management guidelines used in Norway and some other countries, setting 10% domesticated escapees in a river and/or 10% domestication admixture in wild populations as the limit for a “large” impact, will provide a high level of protection for wild salmon populations.
 - *In Iceland, an intrusion level of 4% limit is set as the maximum ratio of farmed fish*

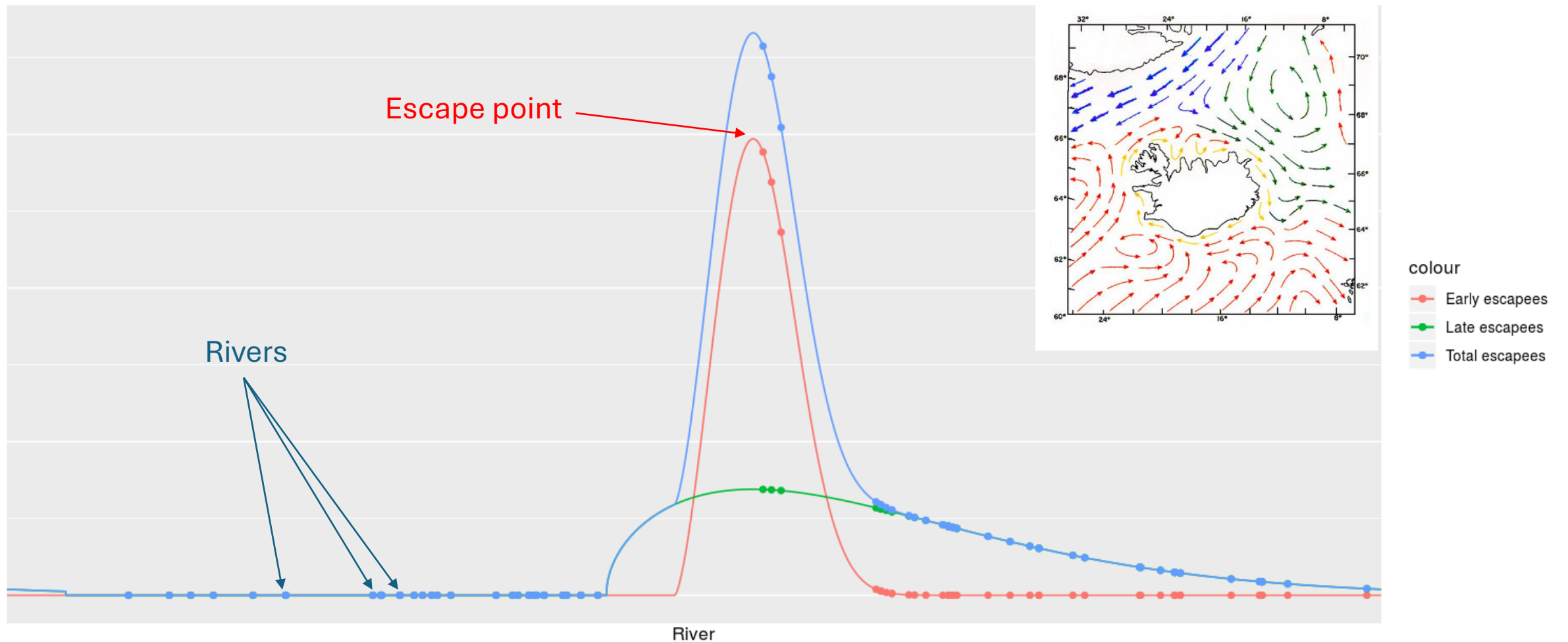
Parameters in the model:

$$E = P \times S \times L$$

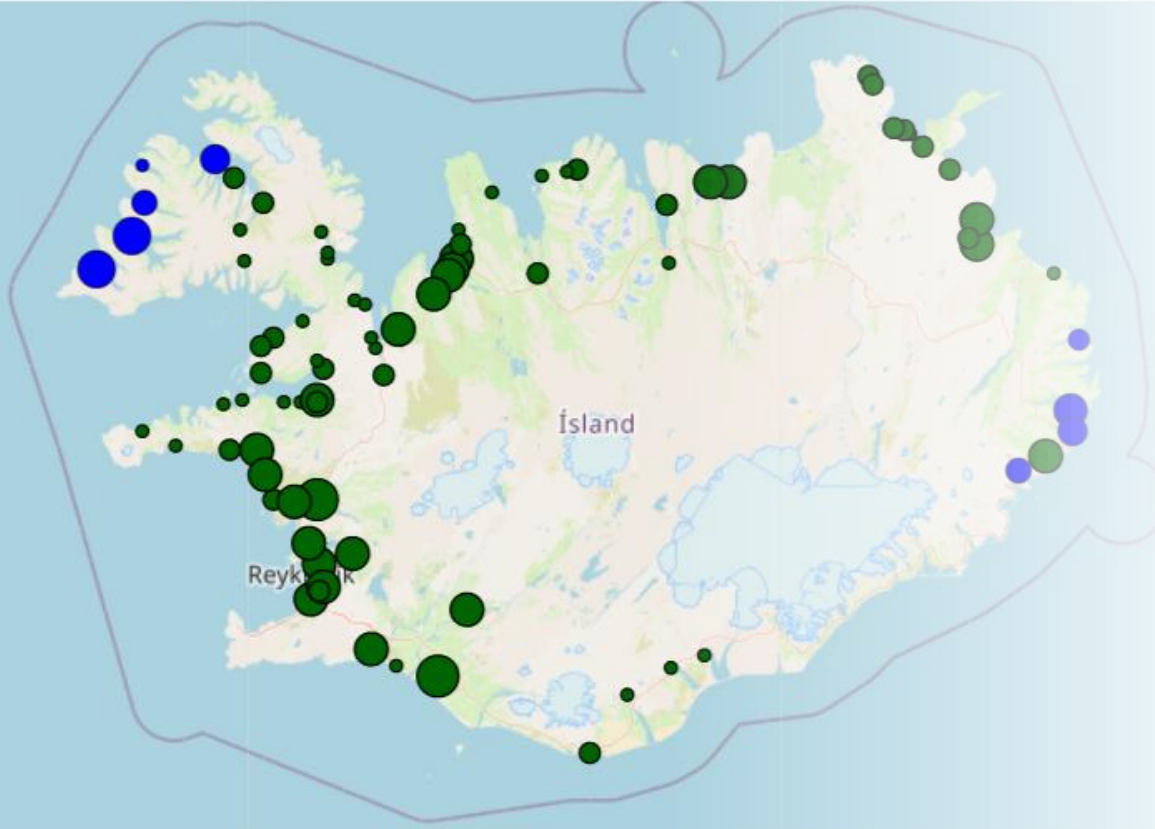
- Average number of escapees entering rivers annually; E
 - E_G for grow-outs and E_S for smolts.
- Production of each farming site, P_x
 - x denoting farm site x
- Number of escapees per produced ton, S_G and S_S
 - G denoting grow-outs and S denoting smolts escaping
- Return rate of escapees into rivers L (L_G and L_S)
- Large salmon that escape (grow outs) have different behavior than smolts that escape.
 - Grow-outs generally move with the current and can go very far before they migrate to a river – true for the first
 - Smolt that escape return to the origin of escape and enter rivers nearby



Distribution curve for escapees



The use of the model



Calculated the distribution for early (smolts) and late (grow-outs) escapees separately for each site of farming. These two distributions were then added together to get the total distribution for each river i.e., from all farming sites to all salmon rivers.

2025 model includes stochasticity in stock sizes in rivers and escape event size.

Distribution of intrusion according to the model 2023

- In the risk model, the intrusion is estimated as:
 - Close to 4% in 3 rivers
 - Around and below 1% in 89 rivers
 - No intrusion in 43 rivers.



Icelandic Aquaculture Regulation - Chapter XII article 57

“Producers of salmon eggs are obliged to keep in databases the genetic markers of farmed salmon so that the origin of farmed salmon escaping from cages and subsequently caught can be traced at any given time to certain cage farms. In addition, producers of eggs are obliged to keep in databases the genetic material of parental fish and keep accounts of which parents are sold to each producer so that the origin of farmed salmon caught can be traced to a certain cage site at any given time”.

All farmed fish caught in rivers can be traced to company and farming site!

Monitoring - Escapees in angling rivers 2017-2022:

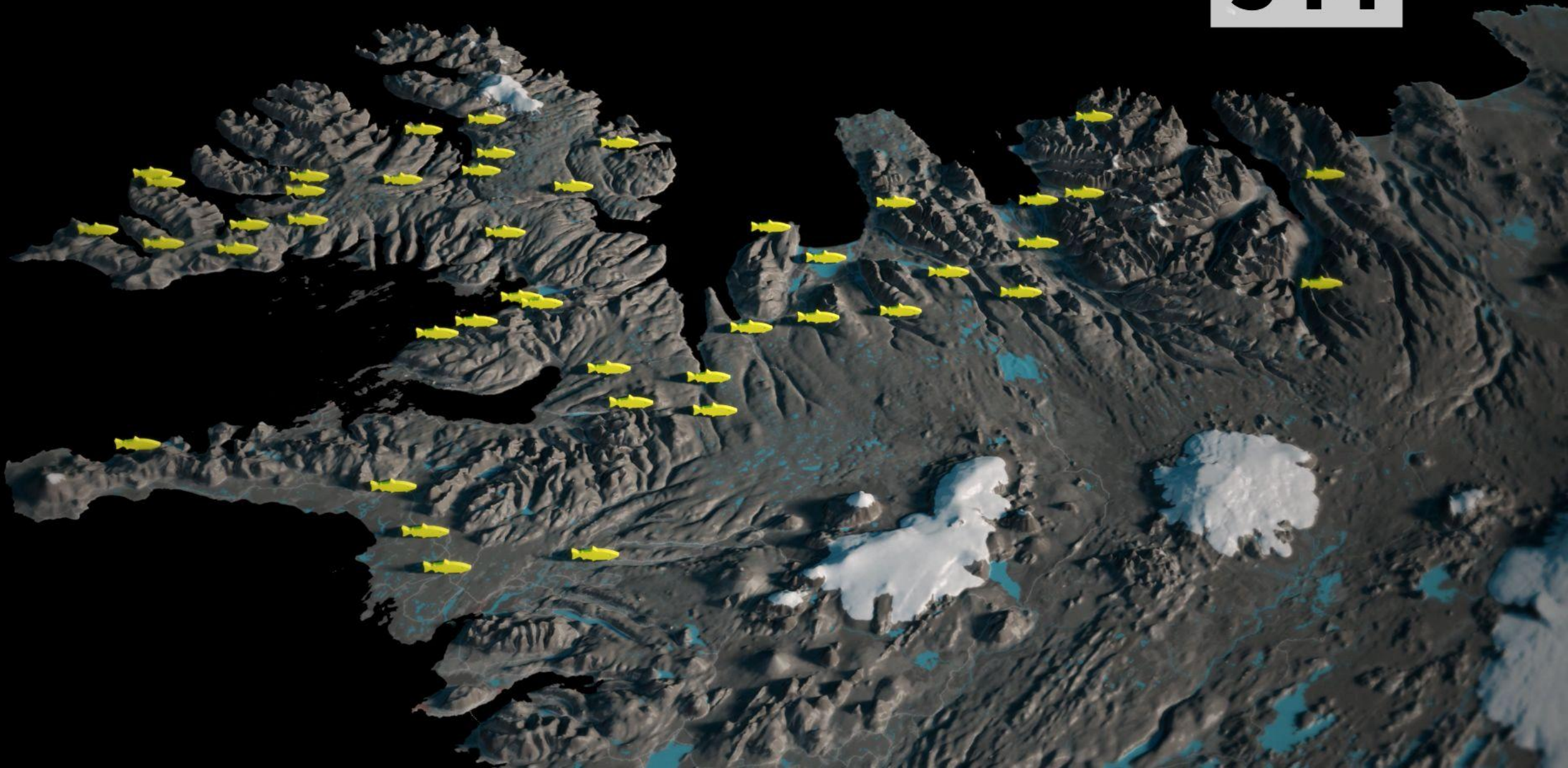
Angling river	Escapees	Fishing	Ratio
Rangárnar	1	9300	0,01%
Hvolsá og Staðarhólsá	1	106	0,94%
Fjarðarhornsa	1	170	0,59%
Laugardalsá í Ísafjarðardjúpi	1	214	0,47%
Staðará í Steingrímsfirði.	1 ; 1	84	1,19%
Víðidalsá í Steingrímsfirði	1	136	0,74%
Vatnsdalsá	1	747	0,13%
Breiðdalsá	1	231	0,43%
Total:	10		
From other countires:	2		
From farning in Icelandi:	8		

Monitoring – Escapees in rivers close to farming sites

River	Year	Number	Farming site
Fjarðarhornská	2018	1	Hringsdalur Arnarfirði
Fífustaðadalsá	2018	2	Hringsdalur Arnarfirði
Selá í Ísafirði	2018	1	Laugardalur Tálknafirði
Mjólká	2018	2	Hringsdalur Arnarfirði
Mjólká	2019	5	Hringsdalur í Arnarfirði
Mjólká	2022	22	Haganes 20, Eyrarhlið 1, unknown 1
Ósá	2022	4	Haganes 2, Tjaldanes 1, unknown 1
Sunndalsá	2022	2	Haganes



The event of August 2023



- What was different from before?

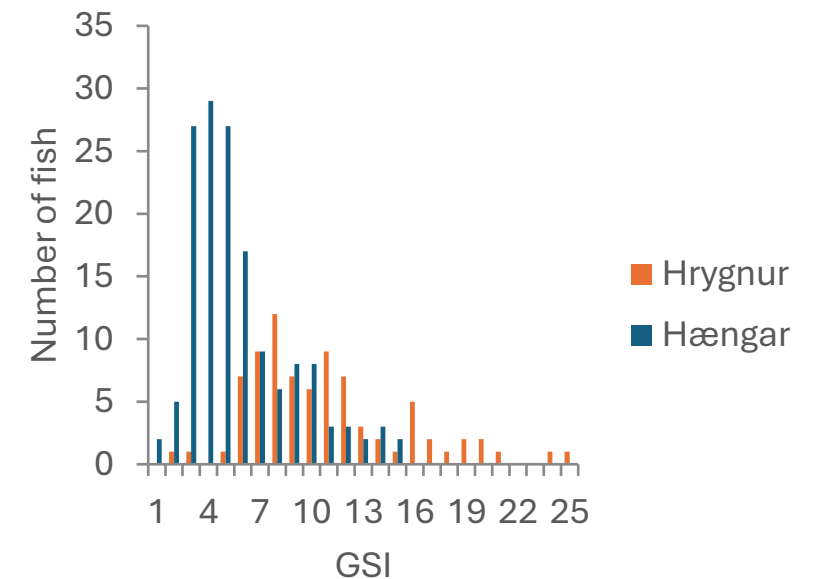


GSI measurements

- 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 Hringsdalur and Laugardalur 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.

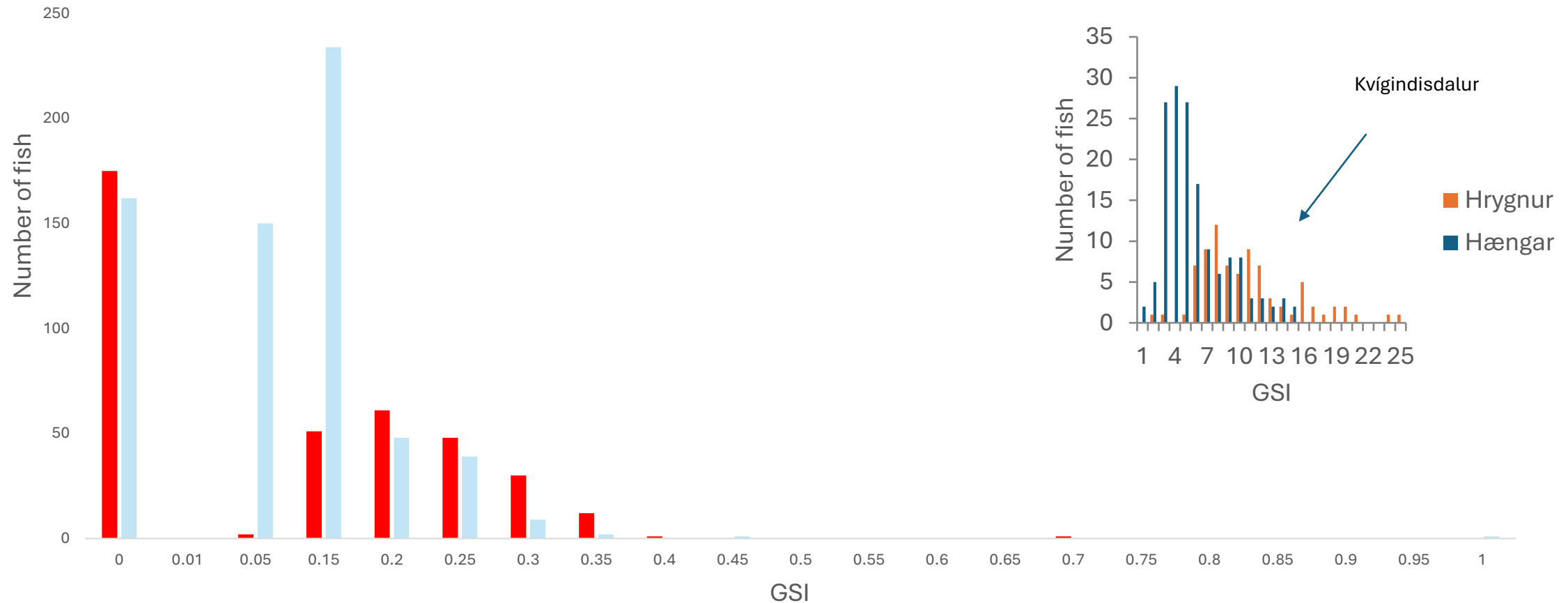
Sex	Count	Percentage (%)
Males	63	61%
Females	40	39%
Total	103	100%

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



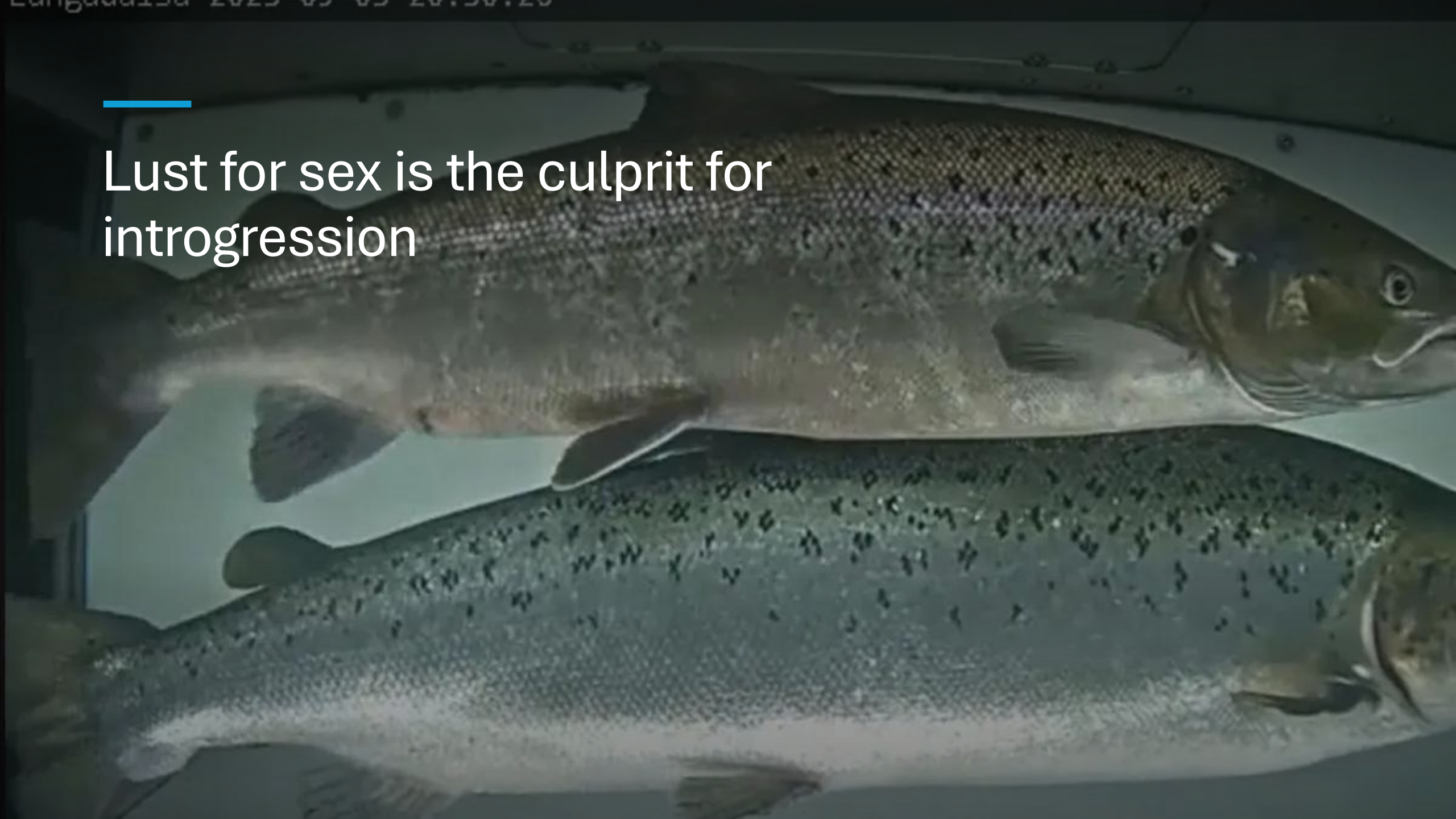
General Status of Maturation in Farmed Cages

1,128 samples from all other companies (3)



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

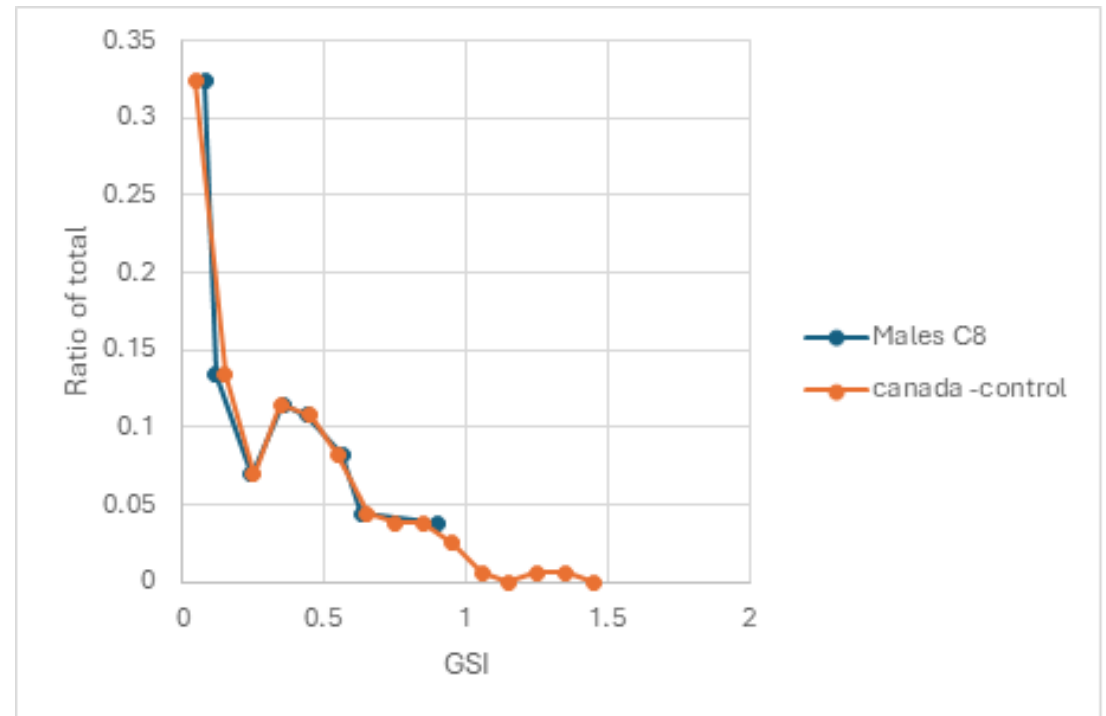
Lust for sex is the culprit for
introgression



Effect of smolting on sexual maturation in later stages.

- In accordance with regulatory changes made on May 1, 2024, the GSI index was monitored in fish in cages from late June through July.
- 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.

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.

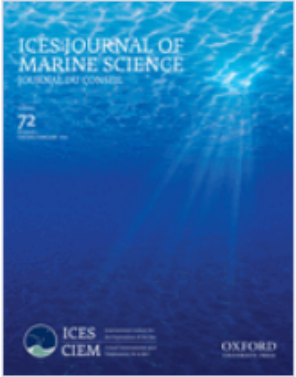


Cages with Fish from Nauteyri Station (Cages C1, C2, C3, C4):

- 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 transport to pens.
- Visible maturation: No visible signs of maturation

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 24-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.



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JOURNAL ARTICLE

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

Ove T. Skilbrei, Mikko Heino, Terje Svåsand [Author Notes](#)

ICES Journal of Marine Science, Volume 72, Issue 2, January/February 2015, Pages 670–685, <https://doi.org/10.1093/icesjms/fsu133>

- A Monte-Carlo method was developed to estimate the annual numbers of escapees from Norwegian fish farms based on reported catches of escaped farmed salmon in the sea and in rivers and the recapture probabilities reported here.
- **Importantly, our analysis suggests that the total numbers of post-smolt and adult escapees have been two- to fourfold as high as the numbers reported to the authorities by fish farmers, depending on whether the incomplete sea fishery statistics are compensated for.**



Are the populations in the release experiments and the population commercial cages in Norway identical?

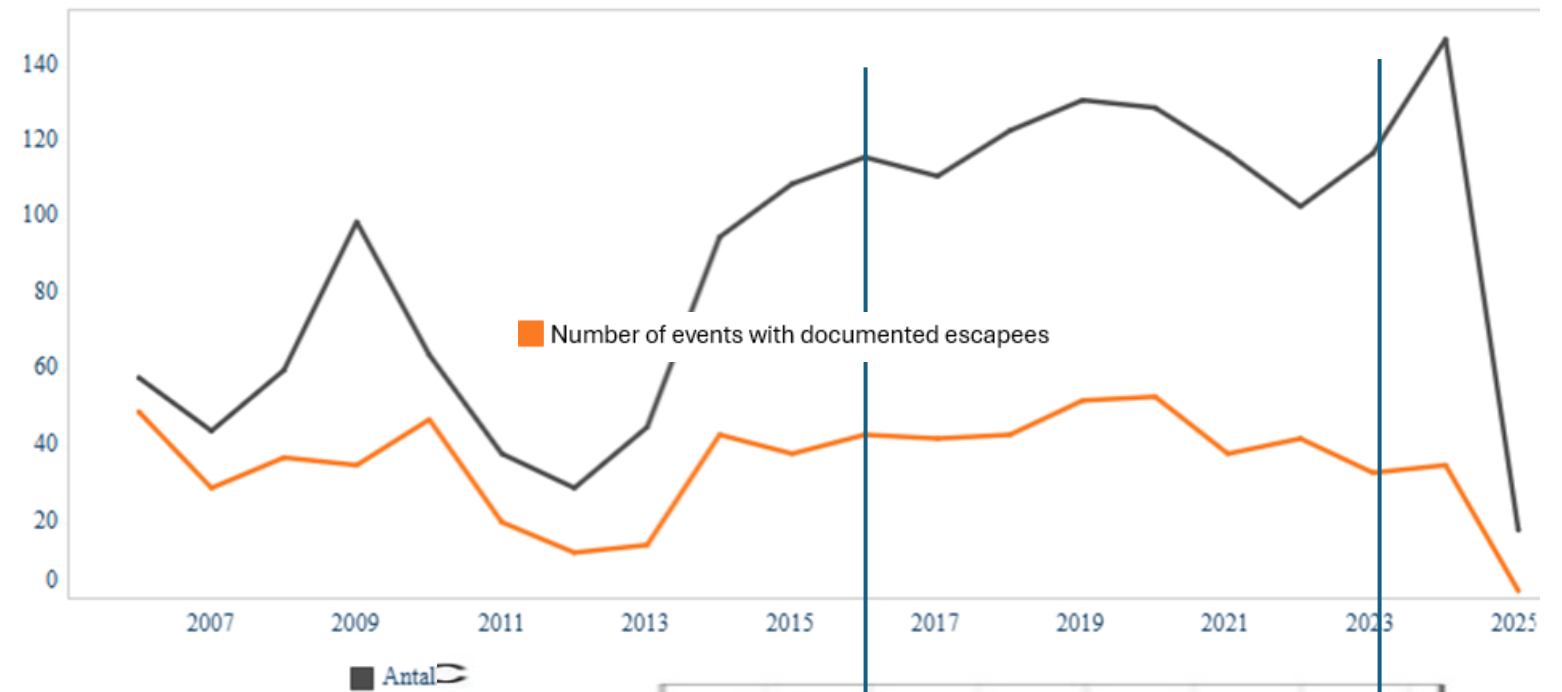
- In the Skilbrei experiment, smolts of various sizes were released, with an average weight of 250 grams.
- Among the total of 93,600 fish, 468 were adult fish potentially nearing maturity (average size: 5.45 kg). – but probably not
- This suggests that most fish would behave as smolts, seeking feeding grounds and returning after 1-3 sea winters (SW).
- The migration rate for smolts is very low, at 1-3 ‰ (parts per thousand).
- The adult fish likely had a low maturation level, which affects the migration rate.
- Fish involved in escape events are generally larger and closer to maturation.
- This results in a selection bias that may explain the difference in the number of fish in rivers compared to the expected recapture probabilities from the experiment.
- *It is therefore likely that the number of escapees given by the fish farming companies is correct.*

An aerial photograph of a salmon farming operation in the ocean. Several large, circular metal cages are visible, floating on the blue water. The cages are arranged in a somewhat scattered pattern. The water has a textured, wavy surface. The text is overlaid in the center of the image.

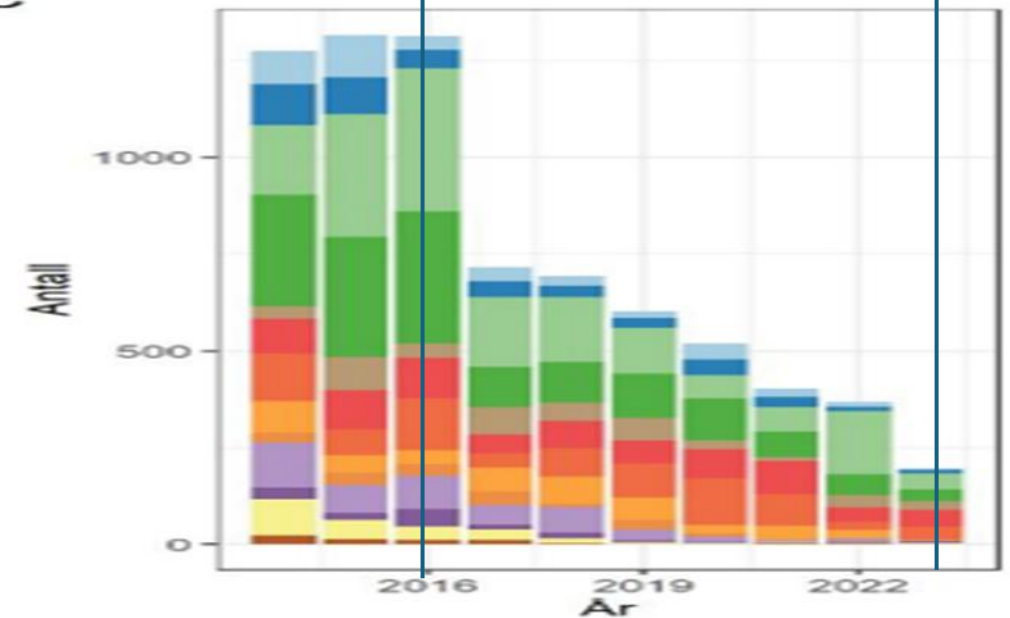
Have developments in smolting
methods had and impact on
migration into Norwegian rivers?

Reported escape events from 2006 to 2025

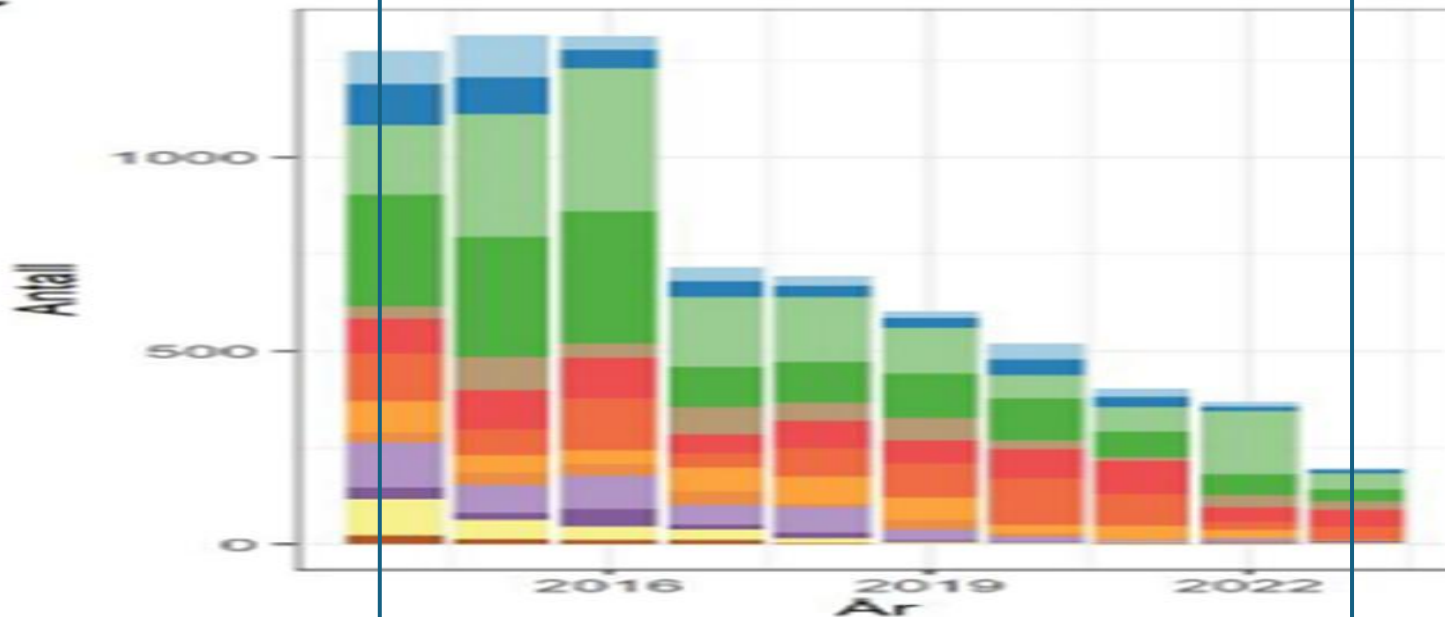
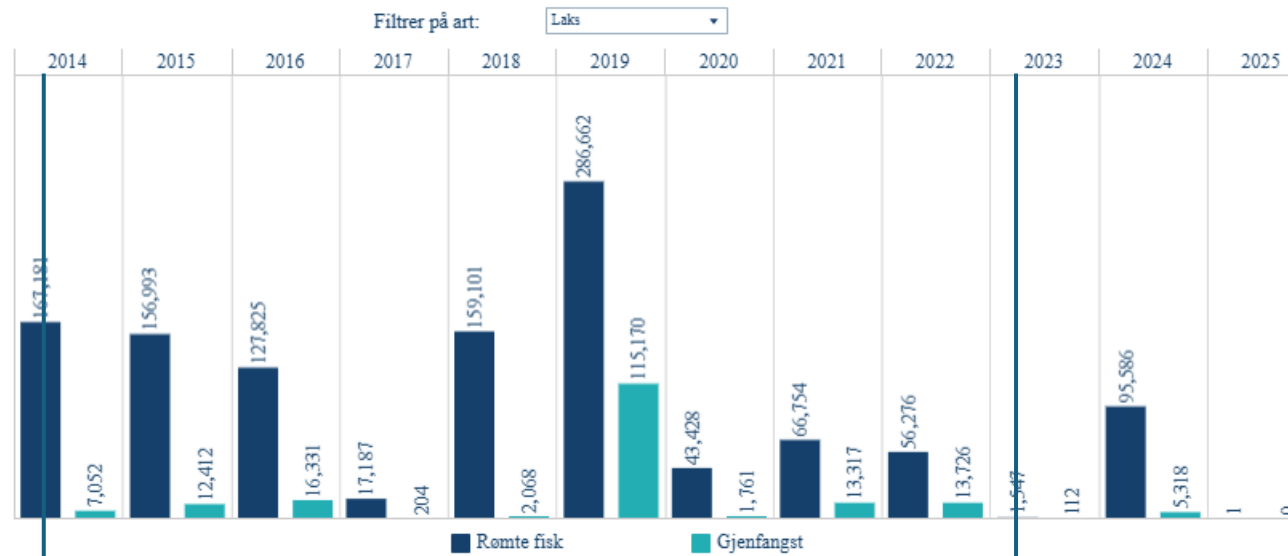
See [Fiskeridiretoriatet](#)



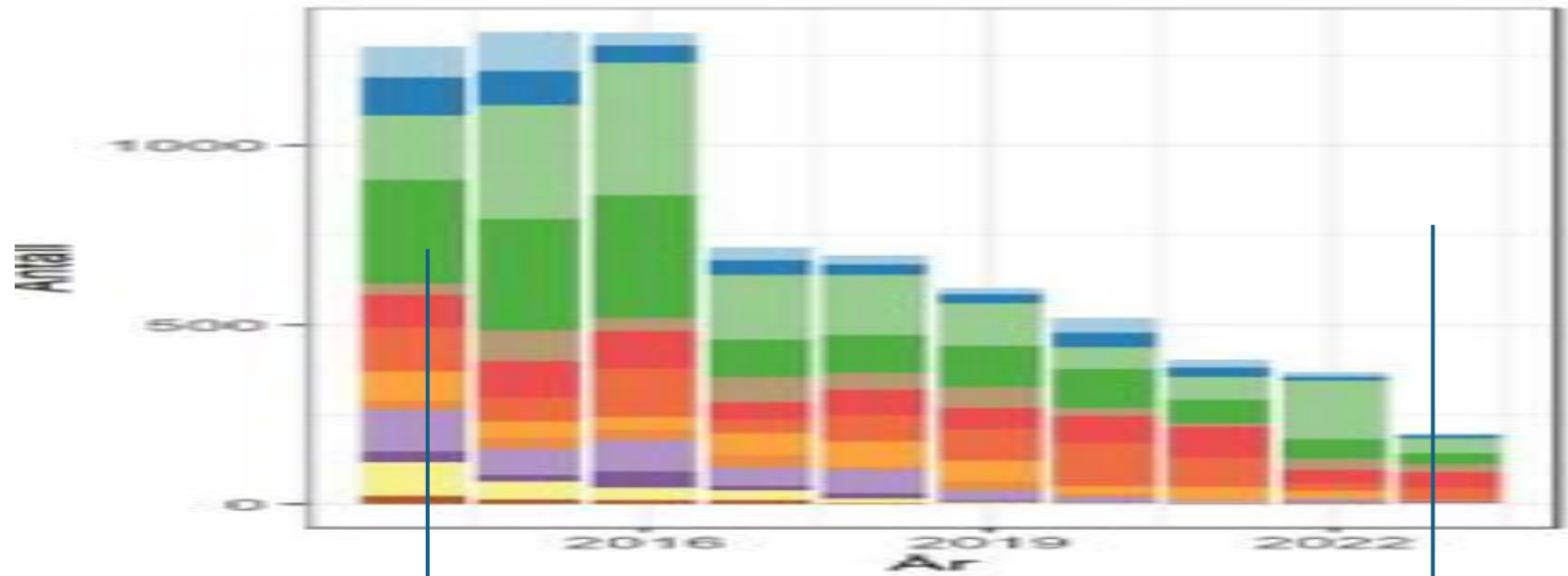
Number of escaped farmed salmon observed and registered in the database of the monitoring program.



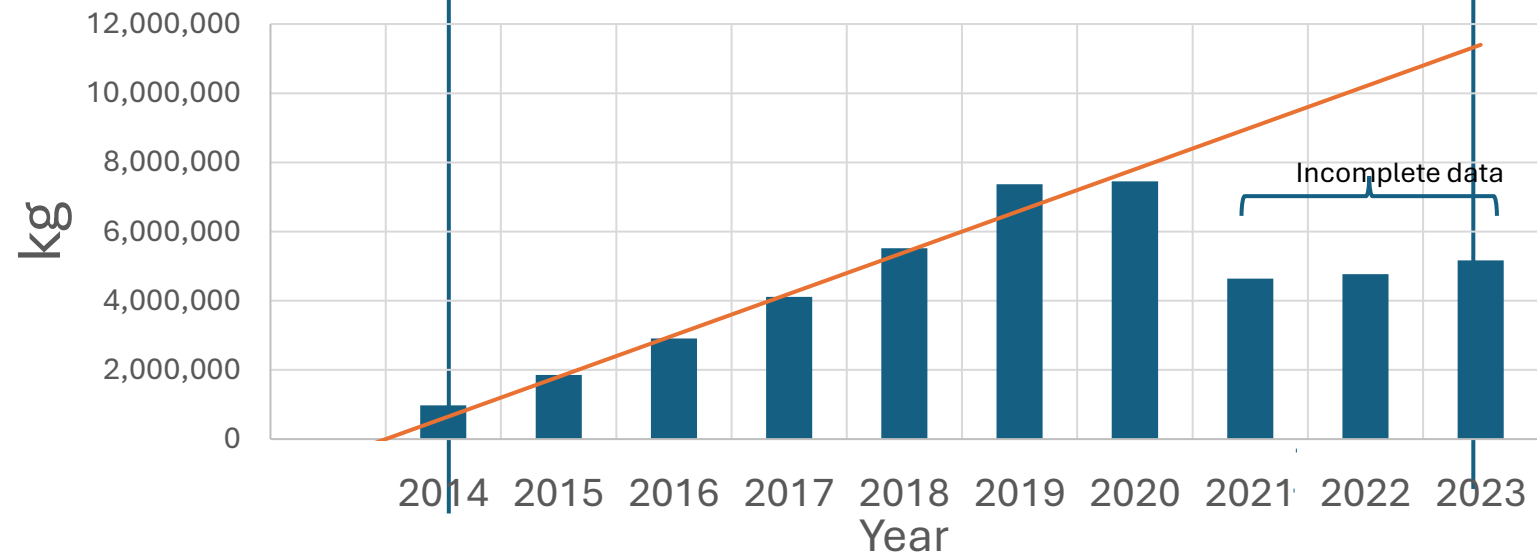
Number of escapees reported and from recapture from 2014-2025



Number of escaped farmed salmon observed and registered in the database of the monitoring program.



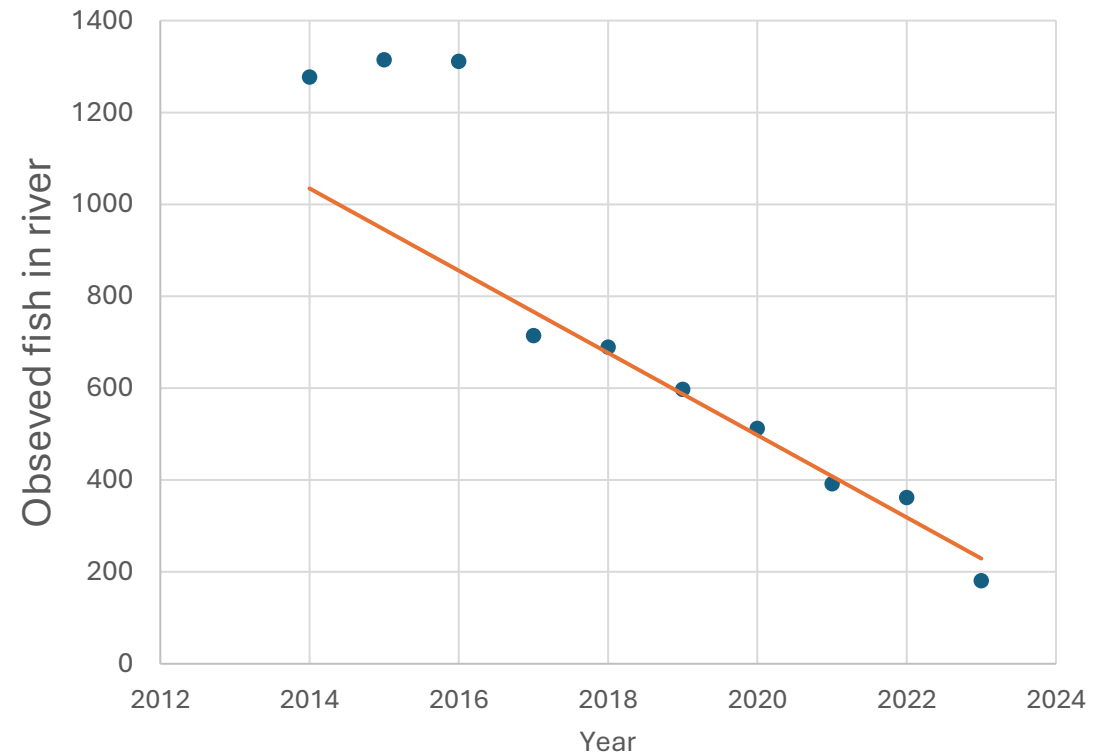
Sales of Smoltfeed in Norway



Estimated decrease of number of escapees observed in river as a function of smoltfeed use

- Assumptions:

Increase kg/year	1.110.000	kg
	300.000	kg
feed per smolt	0,062	kg
Harvest size	5	kg
Total production	1.100.000	Ton
Observed ratio	0,10%	



Number of escaped farmed salmon observed (blue dots) compared to decrease of matured fish due to the use of smoltfeed, if assumed that fish smolted with saltfeed do not run

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, or 1-3 ‰.
- Smoltification at high temperatures, combined with a six-week darkness period followed by an 18:6 light cycle, an elevated temperature could be the culprit
- If precautionary measures are implemented, this method should be avoided 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.
- *This needs to be verified with measurement under controlled conditions*

The land-based salmon revolution

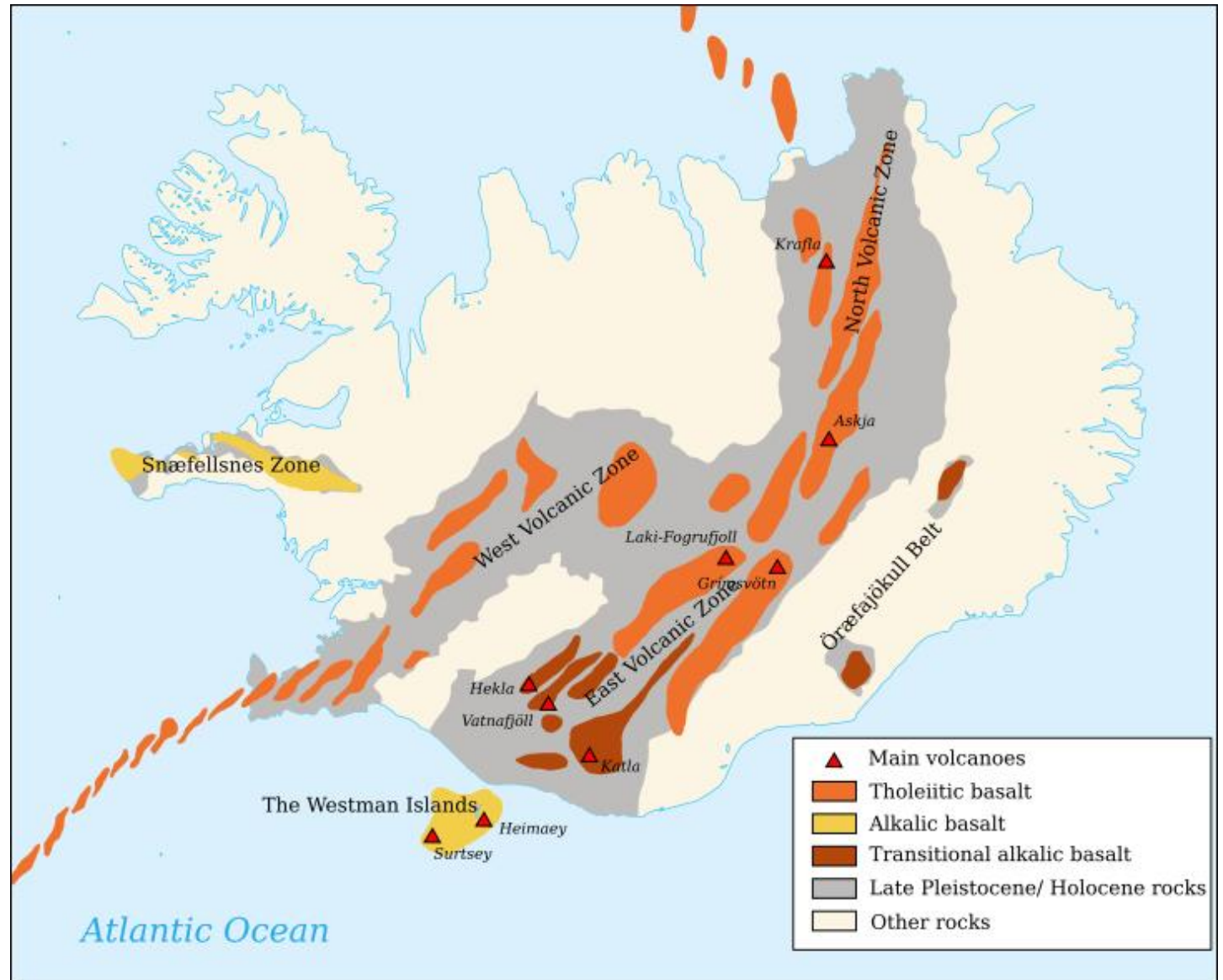
1993



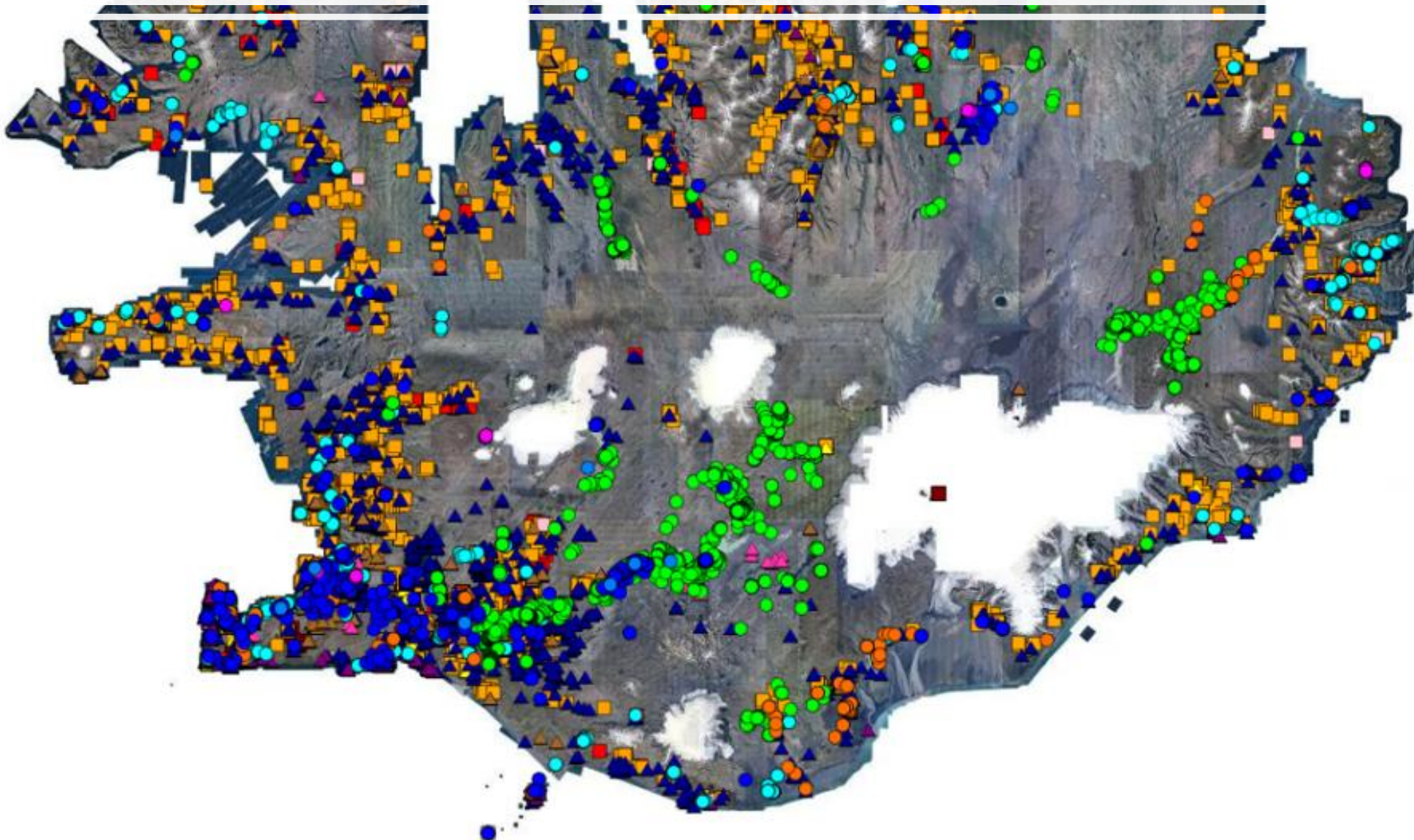
2024



Iceland is volcanic



Map of boreholes in Iceland



Map interface showing borehole locations in Iceland. The legend on the right lists various borehole types and their corresponding symbols:

- ☒ Hleðslustöðvar
- ☒ Boreholur
 - ☒ Aðrar holur
 - ☒ Annað
 - ☒ Jarðefnaleit
 - ☒ Rannsóknaholur
 - ☒ Jarðskautsholur
 - ☒ Virkjanarannsóknir
 - ☒ Mannvirkjagerð
 - ☒ Kalt vatn
 - ☒ Sjótaska
 - ☒ Eftirlitsholur
 - ☒ Leitarholur
 - ☒ Kaldavatnsholur
 - ☒ Skolvatnsholur
 - ☒ Jarðhiti
 - ☒ Varmadæla
 - ☒ Niðurdælingarholur
 - ☒ Hitastigulsholur
 - ☒ Heitavatnsöflun
 - ☒ Gufuöflun
- ☐ Kortasafn OS
- ☐ Nytjavæðing
- ☐ Virkjanir



Seawater boreholes

Up to 200 liters per second



First Water - Thorlákshöfn (www.firstwater.is)



Laxey salmon farm – Westman Islands

Eldfell



Sep 2025

Share



Sep 2025



Google Maps



Fully Executed



Fully operational by 2032

36.000 tonnes (HOG) annual production by 2032
Equal to 175 millions meals

Estimated turnover m.EUR 300.
Tax revenue to the state and local municipality.
16 EUR / HOG – Capex.

100 direct jobs created
100 additional indirect jobs

- Fully funded (incl. site groundworks & Hatchery)
- Future growth plans

Office and smolt farm of Laxey



Smolt
station
Full RAS
system
(Aquagroup)



Diameter=28 m
height = 8 m

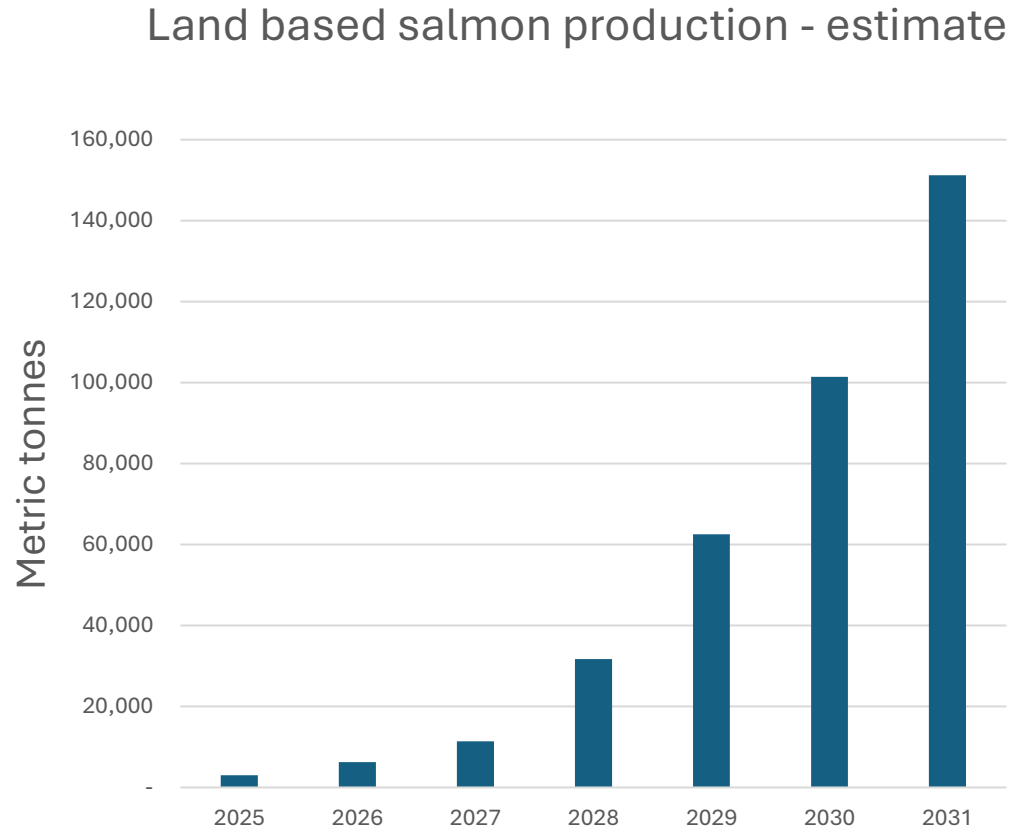
4500m^3
water volume



The aim is to build a
36,000 ton/y fish farm



-
- Land-based salmon farming growing fast in Iceland
 - 2025: 4,000 tonnes of salmon produced
 - 2031: Estimation of 150,000 tonnes



I have nothing more to say...



Thank you...

