

Iceland request on aspects of the Genetic Intrusion Risk Assessment Framework for salmon aquaculture (GIRAF)

Advice summary

ICES reviewed available information on the latest version of the Genetic Intrusion Risk Assessment Framework (GIRAF). The framework is applied to evaluate the risk of genetic intrusion of aquaculture salmon into wild salmon populations in Iceland.

In general, the types of data collected to support GIRAF are appropriate, although the current focus on sampling effort following escape events is unlikely to detect the presence of all escaped farmed salmon (escapees) in rivers. ICES advises on the establishment of a systematic, in-river monitoring programme independent of escape events to improve data collection. Systematic monitoring will ensure representative sampling that accounts for river habitat, time of year, life-history stages, and the potential large dispersal and uneven distribution of farmed salmon throughout river networks.

The estimated stock size of wild Atlantic salmon currently used in GIRAF appears to include sea-ranched salmon and to be overestimated in comparison with available information on recent returns of wild Atlantic salmon to Icelandic rivers. Since an overestimation of stock size will result in an underestimation of genetic intrusion, ICES advises that assumptions and analytical procedures involved in stock-size estimation be reviewed to ensure that GIRAF is appropriately risk averse. ICES cautions against including sea-ranched salmon in the wild stock-size estimate.

ICES notes that prediction uncertainty and potential bias arising from some parameter estimates or missing information are currently not accounted for in GIRAF. Uncertainties in the estimated numbers of escapees are a cause of concern, and data on dispersal and survival of farmed salmon are currently based on a limited number of escape events in Iceland. ICES advises that sensitivity analyses are needed to determine how missing information, or changes in various parameters, impact the outcomes of the risk assessment in the Icelandic context.

Several small rivers and wild salmon populations that do not have a stock-size estimate are currently not included in GIRAF. Not including all wild salmon populations can introduce bias in the risk assessment and underestimate the genetic intrusion risk to small populations. ICES advises that alternative methods to obtain population size estimates for small rivers be explored to ensure that all wild salmon populations are ultimately included in GIRAF.

ICES advises that the genetic intrusion threshold implemented in GIRAF (4% escapees relative to the wild population size) aligns with the precautionary approach. However, until various sources of uncertainty are explicitly incorporated in GIRAF, ICES considers the estimation of the amount of salmon predicted to be safely reared in pens does not yet align with the precautionary approach.

Request

ICES is requested to review and provide advice on the following aspects of the Genetic Intrusion Risk Assessment Framework for salmon aquaculture (GIRAF), including :

- a. How data are collected to estimate genetic intrusion and introgression*
- b. How the data are processed*
- c. The adequacy of current monitoring programmes*
- d. Are the data fit for purpose as used in GIRAF?*
- e. Are mitigation measures adequately accounted for in the model?*
- f. In the absence of data, how does the model account for uncertainty?*
- g. Are the assumptions and the parameterization of GIRAF scientifically robust?*
- h. Does the framework align with the precautionary approach in relation to: i) its estimation of genetic intrusion risk; and ii) its estimation of the amount salmon predicted to be safely reared in pens?*

Elaboration on the advice

Genetic interactions between escaped farm salmon (escapees) and wild Atlantic salmon populations have been documented across the North Atlantic and can result in demographic decline and significant genetic change in wild

populations. The Genetic Intrusion Risk Assessment Framework (GIRAF) is used to advise on the level of aquaculture production of salmon in net pens that can be sustained without undue impact on these wild populations.

In this advice, the term “wild populations” refers to harvestable salmon populations, and the term “average stock size” corresponds to the sum of river-specific stock size estimates prior to the fishing season. The term “genetic intrusion” refers to the proportion of escapees in the recipient populations in wild Atlantic salmon rivers. The “genetic intrusion risk” is the risk of population-level consequences occurring as a result of intrusion and the potential for interbreeding between farmed and wild salmon. “Hybridization” and “genetic introgression” refer to the incorporation of genetic material from escapees into wild populations. Introgression results in a change in the genetic character of wild populations at the genomic level.

How data are collected to estimate genetic intrusion and introgression

The data necessary to estimate genetic intrusion and introgression are collected using different methodologies. These include methodologies for estimating the number of escapees, the distribution and size of wild populations, the presence of mature farmed salmon in rivers, and the subsequent levels of hybridization and introgression.

Numbers of escapees are estimated based on vaccination numbers, mortality in the net pens, stocking rates in the net pens, changes in feeding rates, counts of fish at slaughter, and numbers extrapolated from recaptures from other escape events. There is uncertainty and inherent error in each of these approaches, with corresponding uncertainty in the estimated numbers of fish in net pens and size of escape events. ICES advises that such uncertainties should be explicitly acknowledged and incorporated in GIRAF.

The size of wild salmon populations is determined by direct count where available but mostly by run reconstruction using river-specific catches and regional exploitation rates. This approach is only applicable to rivers with counters or reported harvest, thereby excluding many small rivers and salmon populations that do not have a stock-size estimate from the risk evaluation. ICES notes that smaller populations may be at greater risk of exceeding acceptable levels of intrusion than larger ones. A complementary approach using accessible habitat area to extrapolate population size has been employed elsewhere (Bradbury *et al.*, 2020; Department of Fisheries and Oceans [DFO], 2024); this could be applied to include smaller or data-limited wild salmon rivers in GIRAF.

Data on the presence of escaped and mature farmed salmon in rivers is collected both routinely for stock assessment purposes and following escape events. Data is collected using a variety of methods such as snorkelling, traps, in-river fish counters, netting, and targeted angling. In addition to approaches directly targeting escapees, electrofishing of juveniles is also carried out to estimate the distribution of escapees and the potential number of farmed parents through the detection of their offspring. ICES notes that visual identification of farmed salmon can be uncertain when fish escape early in their lives (post-smolts) or have been at large for an extended period of time. Therefore, ICES suggests that verification of morphological classification be substantiated through the collection of scales and tissue samples for scale patterns reading and genetic screening. ICES suggests that all salmon samples be screened for farmed origin, regardless of assumed origin, to confirm their provenance for the risk assessment. It also suggests that information on maturation status and sex be collected to improve estimates of the potential for introgression as the result of the expected sex bias in reproductive success (Fleming *et al.*, 1996; Hindar *et al.*, 2006). ICES advises that the current focus on sampling effort following escape events is unlikely to detect the presence of all escapees in rivers. ICES advises that the establishment of a systematic, in-river monitoring programme independent of escape events would improve the data for GIRAF.

Levels of hybridization and genetic introgression are estimated through the screening of juveniles with genetic markers. The genetic methods employed have been shown to accurately identify recent hybrids, as well as backcrosses and overall levels of introgression in Iceland (Guðmundsson *et al.*, 2023; ICES, 2025).

How the data are processed

There are several sources of data that can be used to estimate levels of intrusion. ICES advises that all data, regardless of their origin, should be considered for use in GIRAF. Approaches for combining different data sources should be explored. Genetics data are currently processed using single nucleotide polymorphism (SNP) panels that can distinguish among Norwegian-origin farmed salmon, Icelandic wild salmon, and their hybrid offspring, which is consistent with best available evidence in terms of genetic methods.

Adequacy of current monitoring programme

The current programme for monitoring genetic intrusion and introgression is in its infancy and does not yet accommodate differences in life-history stages, times of the year, or the potential large dispersal of the escapees, particularly for smolts that may enter fresh water to spawn one to four years after the escape event. As such, the current programme is only partly adequate. The information acquired so far has been largely limited to periods following escape events. ICES advises to enhance the monitoring programme with systematic in-river sampling independent from escape events. Systematic monitoring should ensure representative sampling accounting for river habitat, time of year, and the likely uneven distribution of farmed salmon throughout river networks.

Are the data fit for purpose as used in GIRAF?

In general, the types of data collected are fit for purpose in GIRAF. However, ICES advises that the uncertainty in some of the underlying information needs to be included in the framework, including potential bias introduced in the estimation of wild salmon stock sizes, the estimation of escape rates, and the estimation of dispersal and survival of escapees.

There is uncertainty in the average stock size for Atlantic wild salmon used in GIRAF, and evidence that this number may be overestimated relative to the average number of recent returns estimated by ICES (2024). An overestimation of stock size will result in an underestimation of the risk of genetic intrusion. The average stock size for Atlantic wild salmon currently used in GIRAF also appears to include sea-ranched fish, but this does not account for the difference in the estimates. The differences in these estimates should be further investigated. ICES cautions against including sea-ranched salmon in the wild stock size estimate. ICES advises that stock size data need to take account of the observed trends in the returns of wild Atlantic salmon to Iceland. The sensitivity of GIRAF to these issues should be investigated in order that the framework be appropriately risk averse.

Precision in the estimated numbers of escapees are a cause for concern. Numbers of escapees based on recapture rates from other escape events are uncertain and sensitive to small differences in the observed recaptures. Data on feeding rates can help detect an escape event, but cannot accurately estimate the number of fish escaping. ICES advises that the number of fish within a cage should be estimated regularly and that following a large escape event, the remaining fish should be counted to enumerate the escapees. This would ensure the same methodology is applied for estimating the number of escapees across different escape events.

Available information on the frequency and magnitude of escape events is currently based on data from Norway. It should be viewed with caution when applied to GIRAF.

Data on survival and dispersal is currently based on a limited number of escape events in Iceland. Information from experiments that have been undertaken in other jurisdictions show large variations in outcomes of survival and dispersal given variation in life stage, time of the year, and location from which the escapes occur. ICES advises to mobilize data on dispersal and survival of escapees available from other jurisdictions for use in GIRAF.

Are mitigation measures adequately accounted for in the model?

Genetic impacts caused by escapees have already occurred in some Icelandic rivers in the presence of mitigation measures, indicating that additional measures are warranted. Mitigation measures that are currently in place in Iceland, such as strategies to reduce maturation rates of farmed salmon, indirectly feed into the parameterization of the model. Explicit incorporation and evaluation of the effect of existing (e.g. escapee recapture) and potential (e.g. fish sterilization) mitigation measures in the model are needed and would increase the value of the model as a tool to inform management decisions.

In the absence of data, how does the model account for uncertainty?

Prediction uncertainty and potential bias arising from some parameter estimates or missing information are not fully accounted for in the model (e.g. unreported escape events and timing of escape events). ICES advises that sensitivity

analyses are needed to determine how missing information, or changes in various parameters, impact the outcomes of the risk assessment in the Icelandic context.

Are the assumptions and the parameterization of GIRAF scientifically robust?

The framework approach is considered appropriate; however, some of the assumptions and parameterization require further support and sensitivity analysis to fully understand their potential impacts on final risk valuations. This includes assumptions relating to the accuracy of stock-size estimates of wild salmon, as the wild stock size values used by GIRAF model may be high relative to ICES estimates (ICES, 2024). The focus of GIRAF on wild populations with harvest information and population estimates > 40 individuals means a population size bias may be present in the assessment. Smaller wild salmon populations are likely at greater genetic risk from intrusions, so not including them can result in biased risk conclusions.

In its current version, GIRAF does not account for error in estimates of key parameters such as the number of fish in the cages, the number of escapees, the magnitude and frequency of escape events, or variation in the escapee dispersal distribution (e.g. seasonal differences); all of these data have been shown to be highly uncertain in other jurisdictions. The inclusion of sensitivity analyses to explore the impact of uncertainty in these parameters on the estimated risk is needed. Sensitivity analyses could also include catastrophic events, e.g. where several fish farms are impacted by the same storm.

GIRAF is parameterized from three escape events in Iceland. To improve robustness, information should be included from experiments undertaken in other jurisdictions that show large variations in outcomes of survival and dispersal given variation in life stage, time of the year, and location from which the escapes occur. The escape estimates need to take account of the possibility of leakage and trickle events and the unreporting of escape events that may give rise to biases in model predictions (Skilbrei *et al.*, 2015).

Does the framework align with the precautionary approach:

In relation to its estimation of genetic intrusion risk?

The threshold for intrusion currently applied in GIRAF (4% farmed salmon in the wild population), is below the intrusion levels of 5 to 10% demonstrated in simulations to result in only weak phenotypic and demographic changes in the recipient wild population over 50 years. Considering that Atlantic salmon farmed in Iceland is non-local Norwegian farmed salmon, ICES considers the estimation of genetic intrusion risk in GIRAF to align with the precautionary approach.

In relation to its estimation of the amount of salmon predicted to be safely reared in pen?

GIRAF estimation of safe production levels currently deviates from the precautionary approach in terms of its treatment of uncertainty. Moreover, the available evidence indicates a disparity between the amount of salmon predicted by GIRAF to be safely reared in pens and the level of genetic changes presently observed in wild salmon populations in Iceland. On this basis, ICES considers that, in relation to the estimation of the amount of salmon that is predicted to be safely reared in pens, GIRAF does not yet align with the precautionary approach.

Suggestions

ICES highlights the benefits of international scientific cooperation on the parameterization and review of aquaculture risk assessment tools, including participation of a diverse array of stakeholder groups. ICES suggests to convene an expert workshop specifically dedicated to defining and testing genetic intrusion risk assessment parameters that are informed by historical and contemporaneous data; this should include sensitivity testing of the robustness of GIRAF conclusions to various assumptions and parameter values informed by industry and management data. This process would strengthen the scientific basis for salmon aquaculture management in Iceland, Canada, Ireland, Scotland, and Norway.

ICES suggests the development and implementation of improved identification tools for farm salmon escapees. An example is AI-assisted identification protocols which could improve monitoring efficiency based on data from video cameras installed in key salmon rivers.

ICES suggests that consideration be given to sterilization of farmed salmon reared in sea pens as a means to mitigate the risk to wild populations from escapees.

Basis of the advice

Background

GIRAF estimates the amount of fertile salmon that is considered precautionary to raise in the sea at any given time in regard to the risk of genetic introgression into wild salmon populations. GIRAF is based on two main factors, the intrusion of farmed salmon, i.e. the likelihood that farmed salmon that has escaped from sea pens will enter river systems in a given year, and the risk that it will be able to mix with wild salmon so that genetic mixing/introgression takes place. The framework is part of the formal advice from the Marine and Freshwater Research Institution (MFRI) to the Ministry regarding management of cage-based salmon aquaculture in Iceland.

GIRAF was first published in 2017 and was developed in collaboration with two foreign experts in the field of population genetics. GIRAF became a legal requirement by amendments to law no. 101/2019 which amended the law on aquaculture no. 81/2008. In the initial legal draft, it is stated that one of the arguments for the legalization of the GIRAF is that the government's policy is to exercise a precautionary approach in the development of fish farming and that decisions will be based on the estimates of GIRAF.

The 2019 law amendment also introduced provisional clause no. VII, that states that the Minister shall appoint a committee of three impartial scientists in the fields of fisheries, population genetics and/or ecology to review the methodology used by the MFRI in the assessment of carrying capacity and in the preparation of risk assessments. The scientific committee submitted a report in June 2021. In the report, it was stated that the model behind GIRAF stood up to a scientific scrutiny, but on the other hand, it remained to be seen how the framework responded to data collected from Icelandic rivers. This was one of main conclusion of the report, as most of the model's assumptions were based on data from Norway.

The aim of GIRAF is to ensure that the intrusion of farmed salmon remains below 4% in wild salmon populations that are subject to harvests.

Results and conclusions

How data are collected to estimate genetic intrusion and introgression

The monitoring programme tracks and assesses the extent of escapees in rivers, determines their origins, and evaluates potential hybridization. It employs several data sources, data collection methods, and monitoring techniques, which include

- Fish counters equipped with video cameras in key salmon rivers. These counters provide real-time data on migration patterns and enable the detection of escapees based on physical traits.
- Escapee detection and reporting systems. Fishermen and officials report suspicious salmon, aiding in early identification.
- Scale and genetic samples collection and analyses from both adults and juveniles. These are used to differentiate between wild and farmed salmon and assess hybridization levels. The samples are taken both in bi-annual surveys and in selected rivers.

Catch-and-release data from logbooks, where available, are used to estimate the size of wild salmon populations. Fish counter data from index rivers are used to derive estimates of the stock sizes and exploitation rates of wild salmon through regular angling fishing with greater accuracy.

In 2023, 20 fish counters, including 13 equipped with video cameras, were operational in 17 rivers. These helped detect escapees in Icelandic rivers for the first time. Escapees were found in the Laugardalsá (six farmed salmon vs. 197 wild salmon), Langadalsá (10 farmed vs. 62 wild salmon), and Blanda rivers (53 farmed salmon were caught in the fishway, which was closed for up-migration). Following escapee detection, fish passage routes were closed, and farmed salmon were captured for analysis. Freshly escaped farmed salmon are identified by morphological traits such as damaged fins,

smaller tails, and silvery colouration. Scale samples from escapees help determine their age and growth patterns. Genetic monitoring from juvenile samples are taken to detect F1 hybrids, backcrosses, and earlier occurrences of introgression.

How the data are processed

Following an escape event, a preliminary estimate of the number of escapees is provided within days by the Icelandic Food and Veterinary Authority (MAST). This happens within days. A second estimation is done based on the specific feed rate (SFR) per individual analysis, processed with stocking number and mortality counts. A final estimation is done following harvesting and is based on vaccination number, mortality numbers and harvesting number, and the comparison of SFR ratios. The detection limit or error around the final estimate is $\pm 2\ 000$ fish.

The stock sizes of most wild salmon populations are estimated based on run reconstructions from catch data and exploitation rates. In some rivers, more accurate estimates are available from fish counters. Stock size estimations are only done for rivers that have catch data available. When escapee events occur, similar methods are applied to the numbers of confirmed escapees to estimate the total run size for each river. This approach is uncertain, since there is currently no method in place to estimate the total run when increased efforts are used to catch escapees, e.g. when multiple methods of catching such as harpooning, extension of angling season, and netting are used. Genetic analysis of juveniles and their kinship is also used in the estimation of the number of farmed adults that took part in spawning in rivers.

Adequacy of current monitoring programme

The monitoring programme is designed to monitor and assess the potential impact of farmed salmon on wild populations, but monitoring efforts are principally focused on reported escape events. The monitoring of the number of escapees in each escape event can be improved with systematic in-river sampling at an appropriate frequency to lower detection limits and account for river habitat, time of year, and the likely uneven distribution of farmed salmon throughout river networks. Improvements in the monitoring of wild populations are also needed. These include an increase in the number of rivers with video counters and regular snorkeling counts, for the latter especially in rivers where catch numbers are the only data available. Establishing dedicated catch sampling programmes in partnership with river-specific fishing associations could assist with increasing the geographic scope of scale sampling and numbers of scales sampled. Tissue samples for genetic analysis that have been collected are numerous and span a good collection of rivers, but the sampling design could be improved to cover larger parts of each river. Genetic analysis of scale samples in addition to tissue samples could serve to increase the geographical spread of the samples. The development of an eDNA detection method could assist with the identification of potential occurrences of farmed salmon in wild populations.

Are the data fit for purpose as used in GIRAF?

GIRAF aims to incorporate new data as they become available. For example, the first versions of the framework relied more on data from other countries, such as those on the ratio between events with early and late escapees in Norway and Scotland. All events that occur, and data that become available with monitoring, are analysed in relation to GIRAF and, if possible, implemented and used in GIRAF.

ICES identified uncertainties in the value of the average stock size for Atlantic salmon in Iceland currently used in GIRAF. A preliminary figure presented to ICES is more than twice the average number of returns during the last six years, even when the sea-ranched salmon returns are added to the wild salmon returns estimated by ICES (2024). It was estimated by ICES (2024) that in 2023, there were 33 900 wild Atlantic salmon that returned to the coast of Iceland and that the previous five-year average was 43 500. Data on stock-size estimates in wild salmon rivers are in most cases based on logbook catch data information; with increased monitoring and better analysis and use of data already available, this could be improved. There is uncertainty in the stock size estimate and whether ranched salmon were included to estimate the intrusion risk in all rivers in GIRAF.

The level of accuracy in the approaches and assumptions used to determine the number of escapees and the magnitude of effect that minor adjustments can have in the escape events is a source of concern. Experience from Norway demonstrates that even when counting fish there can be a large degree of uncertainty in the number reported.

Are mitigation measures adequately accounted for in the model?

Mitigation measures adopted through the regulation of aquaculture production (e.g. technical standards aiming to limit the number of escapees per production tonne, light manipulation, and salt feed to limit maturation) affect the intrusion risk of escape events in indirect ways.

The GIRAF is reviewed every three years and updated when new data become available. Any mitigation action should be accounted for in the model. For example, following the major escape event of 2023 in Kvíngindisdalur, regulations were put in place to decrease the risk of farmed salmon reaching sexual maturity. These include maturity examination (measurements of the gonado-somatic index) for fish over 4 kg in June and July, as monitored by a third party. Further evidence of the effectiveness of salt feed treatment in reducing maturation rates is needed to justify its potential inclusion as a mitigating factor in the model. The suggested control of gonadal somatic index (GSI) in June/July may not be the most reliable way of reducing the number of fish maturing in the autumn. GIRAF does not explicitly incorporate the effects of existing (e.g. escape recapture) or potential (e.g. fish sterilization) mitigation measures on the estimation of intrusion risk.

In the absence of data, how does the model account for uncertainty?

The model accounts for natural stochasticity in run-size and corresponding stock-size estimates for wild salmon. However, rivers that do not provide catch data are not included. If escapees are caught that are not linked to a reported event but can be traced back to a producer and cages, the number of escapees is estimated by back-calculation from the number of those caught in-river, catch effort estimations, maturation rate in pen (GSI from harvest), and estimated migration rate.

Are the assumptions and the parameterization of GIRAF scientifically robust?

In general, it is felt that the framework approach is appropriate; however, some of the assumptions and parameterization requires further support and sensitivity analysis to fully understand the potential impacts and final risk valuations. Gathering more data, such as those involved in estimating the size of wild salmon populations, could improve the robustness of certain assumptions. The following parameters are included in the model:

For escape events:

- The number of annual events is set at 1.75 per year. The number is based on Norwegian statistics (the average of escape events for the years 2009–2022, or 22 events) but is scaled to the Icelandic production rates, which are taken to be 12 times lower than the Norwegian ones.
- The number of escapees per 1 tonne produced is 0.55. This is calculated as the total number of escapees from Icelandic pens (113 050 individuals from four events) divided by total Icelandic production (207 407 t) in 2017–2023 (tables 2 and 3 and Annex 8 in ICES [2025]).
- The proportion of early and late escape events is set at 1/3 and 2/3, respectively. These numbers are based on statistics from Norway and Scotland. It assumes that the proportion of early escapees (fish smaller than 1 500 g) is 1/3 and late escapees (fish larger than 1 500 g) is 2/3.
- Migration rates into rivers are separated between late and early escapees and are set as 0.07% and 0.16%, respectively. For the early escapees, the migration rate is based on those calculated from the Haganes event in 2021 (Annex 8 and Table 4 in ICES [2025]). For the late escapees, the rate is based on the Hringisdal and Laugardal events in 2018 (Annex 8 and Table 5 in ICES [2025]).
- The proportion of time spent at sea for early escapees: post-smolt 0 and 1 sea winter (SW) is estimated to be 30/56, 17/56 for 2SW, and 9/56 for 3SW. This is based on the return ratio of 1SW, 2SW, and 3SW fish from release experiment by Skilbrei *et al.* (2015).

For the distribution model:

- The distribution models of early and late escapees are based on Icelandic data.
- The model assumes two exponential distribution curves for each type. The early escapee distribution is symmetrical around the release point (sea cage). The late escapee distribution is skewed according to the general ocean currents around Iceland.

For estimating and simulating the stock sizes of wild populations:

- In the simulation, the stock size is assumed to follow a lognormal distribution with a standard deviation of 0.5 for all rivers.
- The geometric mean of each river is based on the most recent ten-year stock estimates.
- Catch data are assumed to be representative (good correlation with fisheries independent counter data).
- Catch-and-release corrections 25% applied for all rivers are assumed to be the most accurate (based on tagging studies).
- Exploitation rate from index rivers applied (proposed change from previous assessments). The exploitation rate from rivers with counter data is used as a geographical index and applied to rivers with unknown exploitation rate according to their location. This uses location as a driver as has been applied elsewhere (e.g. in the run-reconstruction models used by ICES (2024) wild salmon stock assessments where salmon in Iceland are split between the Northern and Southern North-East Atlantic Commission (NEAC) area complexes.

Does the framework align with the precautionary approach in relation to: i) its estimation of genetic intrusion risk; and ii) its estimation of the amount salmon predicted to be safely reared in pens?

The alignment of genetic intrusion risk with the precautionary approach requires that the setting of the risk threshold does not result in irreversible harm to the wild populations, where harm is understood to be a negative change in the abundance or life-history characteristics of recipient wild populations.

In Iceland, the goal of the Aquaculture Act is to develop the Atlantic salmon net pen aquaculture industry in a manner that does not cause harm to the harvestable wild Atlantic salmon populations. In 2017, there was an initiative to explore the level of sustainable aquaculture in the country based on the modelled genetic impacts of escapees on wild populations. Part of this initiative was to establish a management target for the numbers of escapees that wild populations could tolerate without significant genetic impacts. In this context, a value of 4% for the proportion of escapees compared to the wild population size was established by MFRI. This was based on Taranger *et al.* (2015), set near the natural straying rate, and supported by simulations (Castellani *et al.*, 2018; Bradbury *et al.*, 2020; DFO, 2024). These simulations suggest that intrusion levels below 5 to 10% result in only weak phenotypic and demographic changes in the recipient wild population changes over 50 years. As the Icelandic Atlantic salmon aquaculture industry is currently using non-local Norwegian farmed salmon, a conservative threshold level of 4% was chosen. On this basis, ICES considers that the estimation of genetic intrusion risk threshold at 4% to align with the precautionary approach.

The alignment of the amount of salmon predicted to be safely reared in pens with the precautionary approach requires that that level of production should not cause a greater than 4% genetic intrusion risk in recipient wild populations. The disparity between the model outputs of the safe level of production and the level of genetic change presently observed in wild populations from production levels lower than those proposed by the model (intrusion, hybridization, and genetic introgression; Working Papers 06 and 07 in annexes 10 and 11 in ICES [2025]; Guðmundsson *et al.*, 2023) would suggest the estimated amount of salmon predicted by GIRAF to be safely reared in pens may not be sufficiently risk averse to protect all wild populations. Within the GIRAF estimation of this figure, there are some deviations from the precautionary approach regarding the treatment of uncertainty, lack of a sensitivity analyses, and how these are deployed in the determination of vital rate parameters. On this basis, ICES considers that the amount of salmon predicted to be safely reared in pens in the currently configured GIRAF framework does not align with the precautionary approach.

Methods

ICES reviewed the latest version of the risk assessment model applied to evaluate the risk of intrusion of farmed salmon into wild salmon rivers in Iceland, including relevant geographical factors, farming factors, and factors related to the life cycle and distribution of wild salmon populations. The review process considered available evidence and information on: i) reported escape events and escape incidence analysis; ii) stock size estimation procedures for wild rivers included in the risk assessment; iii) the distribution model used to assess the intrusion of farmed salmon from designated aquaculture areas into Icelandic fishing rivers; iv) mitigation and preventive measures currently in place to reduce the potential for genetic introgression; and v) the monitoring programme currently in place to monitor and assess the risks to wild salmon

populations genetic integrity and overall health associated with the cultivation of Atlantic salmon of Norwegian origin in open sea cages in Iceland. The information and evidence basis in support of the review is available in ICES (2025).

Additional information

Considering the current disparity between GIRAF outputs and the observed level of genetic changes in some wild populations, ICES suggests consideration be given to specifying what an acceptable level of genetic introgression from escaped farm fish is or should be. Introgression is maladaptive and potentially contributes to eroding genetic differences between wild populations. The most significant factor regarding the risk of genetic introgression of farmed salmon is the maturity level of the escaping fish.

Sources and references

- Bradbury, I. R., Duffy, S., Lehnert, S. J., Jóhannsson, R., Fridriksson, J. H., Castellani, M., Burgetz, I., *et al.* 2020. Model-based evaluation of the genetic impacts of farm-escaped Atlantic salmon on wild populations. *Aquaculture Environment Interactions*, 12: 45–59. <https://doi.org/10.3354/aei00346>
- Castellani, M., Heino, M., Gilbey, J., Araki, H., Svåsand, T., and Glover, K. A. 2018. Modeling fitness changes in wild Atlantic salmon populations faced by spawning intrusion of domesticated escapees. *Evolutionary Applications*, 11: 1010–1025. <https://doi.org/10.1111/eva.12615>
- Department of Fisheries and Oceans (DFO). 2024. Assessment of the Risk Posed to Wild Atlantic Salmon Population Abundance and Genetic Character by Direct Genetic Interaction with Escapes from East Coast Atlantic Salmon Aquaculture. *In: DFO Canadian Science Advisory Secretariat Science Advisory Report. 2023/045. ISSN 1919–5087.*
- Fleming, I. A., Jonsson, B., Gross, M.R., and Lamberg, A. 1996. An experimental study of the reproductive behaviour and success of farmed and wild Atlantic Salmon (*Salmo salar*). *Journal of Applied Ecology*; 33(4): 893–905. <http://dx.doi.org/10.2307/2404960>
- Hindar, K., Fleming, I.A., McGinnity, P., and Diserud, O. 2006. Genetic and ecological effects of salmon farming on wild salmon: modelling from experimental results. *ICES Journal of Marine Science*, 63(7): 1234–1247. <https://doi.org/10.1016/j.icesjms.2006.04.025>
- Guðmundsson, L.A., Magnúsdóttir, R.P., Karlsson, S., Bárðarson, H., Hagen, I.J., Láruson, A.J., Sveinsson, S., *et al.* 2023. Erfðablöndun villts íslensks lax (*Salmo salar*) og eldislax af norskum uppruna / Hybridization between wild Icelandic salmon (*Salmo salar*) and farmed salmon of Norwegian origin. Haf- og vatnarannsóknir, HV 2023-25. 74 bls. [In Icelandic, with an English abstract and English figure and table legends]. https://www.hafogvatn.is/static/research/files/hv2023_25_1.pdf
- ICES. 2024. Working group on North Atlantic Salmon (WGNAS). *ICES Scientific Reports*. 6:36. 415 pp. <https://doi.org/10.17895/ices.pub.25730247>
- ICES. 2025. Workshop on the Genetic Risk Assessment Framework for Salmon aquaculture (WKGIRAF). *ICES Scientific Reports*. 7:31. 183 pp. <https://doi.org/10.17895/ices.pub.28574417>
- Skilbrei, O. T., Heino, M., Svåsand, T. 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*, 72(2): 670–685. <https://doi.org/10.1093/icesjms/fsu133>
- Taranger, G. L., Karlsen, Ø., Bannister, R. J., Glover, K. A., Husa, V., Karlsbakk, E., Kvamme, B. O., *et al.* Risk assessment of the environmental impact of Norwegian Atlantic salmon farming, *ICES Journal of Marine Science*, 72(3): 997–1021, <https://doi.org/10.1093/icesjms/fsu132>

Recommended citation: ICES. 2025. Iceland request on aspects of the Genetic Intrusion Risk Assessment Framework for salmon aquaculture (GIRAF). *In Report of the ICES Advisory Committee, 2025. ICES Advice 2025, sr.2025.02, https://doi.org/10.17895/ices.advice.28574333*