A stochastic simulating model for escape events

General

AREV was asked by the Federation of Icelandic River Owners to assess the probability of the escapee ratio to exceed the maximum level of 4%, which is stated in the current MFRI risk assessment (Jóhannsson, 2020). The work on the model was conducted during the better part of last year. The authors of the model are: Jón Sch. Thorsteinsson mathematician, Kristján Dagur Egilsson (3rd year math student at the University of Iceland, hons.), Kalman Christer (Biologist, M. Sc.) and Særós Óskarsdóttir, M.Sc. Most of this group works for a small hedge fund advisory in Reykjavík.

Model parameters

Annual production: P in tons of farmed salmon

Escapees: S_{early}, S_{late} is the estimated number of salmon that escapes for each ton produced

Adjustment for homing: η is a ratio which indicates whether salmon returns to rivers and fishing waters, or to pens

Out-of-season ratio: $\tau_{early}, \tau_{late}$ is the ratio of months to total months where salmon is at risk to go to rivers to spawn

Under reporting ratio: $\rho_{not\ reported}, \rho_{lost\ tag}$

Documented escape events, precautionary approach and classifications of escapes

In an answer to a question asked in the parliament, the MFRI stated that reported escapees are 0.54 per ton of production on average (Alþingi, 2023). In the current risk estimate (Hafrannsóknastofnun, 2020) the number of reported escapes is multiplied by four in accordance with Skilbrei et al., (2015) and the precautionary approach.

We utilize Skilbrei's (2015) classification, where early escapes (smolt and post smolt) weigh less than 900 g and late escapes (adults) weigh more than 900 g.

The Westfjords

The maximum annual production in the Westfjords is $P = 64{,}500$ thousand tons. Based on this and in accordance with the current MFRI risk assessment (Jóhannsson, et al., 2020), the average annual escapees, once the production has reached its maximum should amount to:

$$4 \cdot 0{,}54 \cdot 64{,}500 = 139{,}320$$

In table 7 (Skilbrei et. al, 2015), it is assumed that 20% of escapes are late escapes and that 80% are early escapes.

In the current risk assessment (Jóhannsson, 2020) it is assumed that the post smolt out-of-season period is 4 months (in autumn) out of 18. The measurements of Skilbrei et al., (2015) show that 22.8% of late escapees are found in the ocean, rivers and fishing waters. It is noted that some tagged salmon that returned were not found. The following formula was proposed for early escapes:

$$(1-\rho_{lost\ tag})\,(1-\rho_{not\ reported})\ = (1-0.1)(1-0.33) = 0.60.$$

We don't expect that tags are lost for late escapees as 90% of those found are found within 2 months from escape:

$$(1-\rho_{not\ reported})\ = (1-0.33) = 0.67.$$

We assume that, on average, 75% of fish in rivers is captured. Based on this the ratio of late escapees in the Westfjords should be:

$$22.8\% \cdot \frac{4}{18} \cdot 7.5\% \cdot \frac{1}{0.67} = 0.57\%$$

Further, the number of late escapees that enter rivers and fishing waters annually, on average, should be:

$$0.57\% \cdot 20\% \cdot 139.320 \cdot \frac{1}{0.75} = 211$$

According to (Skilbrei et al., 2015) 1.3% of post smolts and L. post smolts returned from early escapes. Here it is helpful to apply a bit more precision since 70% of these smolts were L. post smolts that were captured within 60 days of escaping, mostly all of them at sea. Therefore, we only include 10% weight on these L. Post smolts. Hence, we find that 0.45% of post smolts return (instead of 1.3%).

On average, we anticipate that the out-of-season for this category is 6 months out of 12. We estimate that 75% of this group returns to the original pen (as opposed to a river or a fishing water) and that the balance to rivers and fishing waters.

Based on this the rate of return of early escapes is:

$$0.45\% \cdot \frac{6}{12} \cdot \frac{1}{0.6} \cdot 25\% = 0.093\%$$

and the average annual return of early escapees is:

$$0.093\% \cdot 80\% \cdot 139.320 \cdot \frac{1}{0.75} = 138$$

By applying this formula, the total number of early and late escapees that enter rivers and fishing waters is 349, when production has reached its maximum value.

This data is entered into the model. We anticipate that the distribution of fish around the country will be similar to the distribution from the Kvígindisdal escape in 2023 (Fjóla Rut Svavarsdóttir editor, 2024).

Eastern fjords.

Similar calculations have been performed for the Eastern Fjords.

Description of simulation model.

Data

The Westfjords (rivers/fishing waters and pens)

Contains coordinates of fjords with pens and the maximum production in each fjord

Contains the coordinates of rivers/fishing waters, a five-year average catch, standard deviation, % catch of total stock, number of escapes, clockwise from pen, salmon blocking at river mouth, and whether it should be displayed or not

Coordinates for the coastline of Western Iceland, the Westfjords and North Western Iceland (see appendix 1)

Function to estimate distances from pens to rivers in km using the Haversine formula

Gradient boosting used to assess the attractiveness of rivers to escapes based on the location of an escape (pen), the number of escapees, the locations of the rivers, number of fish, and other parameters. The Kvígindisdalur escape is used as a baseline

Function that prepares distribution for simulation

The function input is the parameters for a Poisson distribution and the number of periods. The output is a matrix with annual distributions of early and late escapes. Utilizing 1000 years gives a steady state result of the simulation.

Simulation loop

The loop iterates each river/fishing water. Each time a new distribution is produced for the simulation. Next, a pen is chosen at random, And the simulation produces escape events in accordance to probability distributions. This method utilizes the distance between the pen and the river/fishing water, as well as other attributes of the river to estimate the numbers of escapees that enter. This process is repeated for every year. Finally, the results show how often the ratio of escapees to stock goes above 4%, and how often the escapee ratio is above 2% for four successive years.

Simulation result tabulation

See appendix 2

Shared link to code

https://colab.research.google.com/drive/1bHcBh7ryd4yXIYjNKC_ldXwQlX5aLi0m?usp=sharing

Appendix 1- data

```
#@title Vestfirðir: uppflettitöflur búnar til fyrir staðsetningu og
magn í kvíum og staðsetningu og magn í ám, veiðiálag frá
(2024,Hafrannsóknastofnun)

#Staðsetning, max í kví miðað við Patriksfjörð
Vestfjarðarkvíar = {
  "Patriks" : ((65.56971,-23.96096),1),
  "Tálkna" : ((65.66,-23.98),1),
  "Arnar" : ((65.76,-23.74),1),
  "Dýra" : ((65.90,-23.61),0.5),
  "Önunda" : ((66.06,-23.62),2.5/20),
  "Ísafjardar" : ((66.09,-22.86),1.5)}

# Staðsetning, (Meðaltal fiska seinustu 5 ára, fjöldi eldislaxa),
(Standard deviation fiska, álagsstuðull), birta?, réttsælis?, tálmar?
Vestfjarðarár = {
  #ár í kringum Patreksfjörð
  "Örlygshöfn" : ((65.57953,-
24.10281),(0,4),(0,0.5),False,False,False),
  "Mikladalsá" : ((65.528186,-
23.912959),(0,3),(0,.5),False,False,False),
  "Patreksfjörður" : ((65.56971,-
23.96096),(0,6),(0,0.5),False,False,False),
  "Ósá, Patreksfirði":((65.53,-23.756),
(0,4),(0,0.5),False,False,False),
  "Botnsá" : ((65.592406,-23.780223),(0,44),(0,0.5),False,False,False),
  "Selárdalsá" : ((65.787693,-
23.985597),(0,1),(0,0.5),False,False,False),
    #Vesturland
#  "Hvítá":((64.60260,-
21.71058),(625,1),(272.7,0.5),False,False,False),
  "Álftá" :((64.58,-22.22868),(205.4,1),(62.8,0.5),False, False,False),
  "Hítará" : ((64.69161,-22.33968),(478.4,1),(184.4,0.5),True,
False,True),
  "Haffjarðará" : ((64.81242,-22.41454),(874.2,11),(300,0.5),True,
False,False),
  "Holtsá" : ((64.92277,-23.50243),(0,1),(0,0.5),False,False,False),
  "Kársstaðaá" : ((64.972406,-
22.571878),(0,5),(0,0.5),False,False,False),
  "Svínafossá" : ((65.031896,-
22.210853),(0,2),(0,0.5),False,False,False),
  "Laxá á Skógarströnd" : ((65.027192,-
22.12239),(133.8,1),(40.7,0.5),False,False,False),
  "Miðá" : ((65.028182,-21.778856),(144,1),(28.7,0.5), False,
False,False),
```

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  "Haukadalsá" : ((65.03873,-
21.77298),(386.6,5),(91.3,0.5),True,False,False),
  "Laxá_Dölum" : ((65.09784,-21.75877),(812.4,13),(150.9,0.52),True,
False,False),
  "Krossá" : ((65.27128,-22.36376),(38.5,1),(25.43,0.5),False,
False,False),
  "Búðardalsá" : ((65.31017,-22.22691),(205.5,10),(62.8,1),True,
False,False),
  "Hvolsá og Staðarhólsá" : ((65.39306,-
21.93518),(202.6,10),(79.6,0.5),False, False,False),

    #Vestfirðir

  "Fífustaðadalsá" : ((65.760145,-
23.900291),(0,25),(0,0.5),False,False,False),
  "Bakkadalsá" : ((65.735808,-
23.809717),(0,1),(0,0.5),False,False,False),
  "Þorskafjarðará":((65.60421,-22.09366),
(17,1),(5.3,0.5),False,False,False),
  "Djúpadalsá" : ((65.573533,-22.28813),(202.6,3),(79.6,0.5),False,
False,False),
  "Fjarðarhornsá" : ((65.643547,-22.54375),(111.3,2),(40.05,0.5),False,
True,False),
  "Kjálkafjarðará" : ((65.618016,-22.93989),(0,2),(0,.5),False,
True,False),
  "Vatnsdalsá Ísaf":((65.58577,-23.13299),(50,3),(20,0.5),False,
False,False),
  "Móra":((65.50186,-23.38313),(9,3),(0,0.5),False, False,False),
  "Suðurfossá":((64.465,-23.933), (34,5),(29,0.5),False,False,False),
  "Sunnudalsá":((65.62094,-23.39303),
(0,20),(0,0.5),False,False,False),
  "Norðdalsá" : ((65.632028,-
23.37420),(0,1),(0,0.5),False,False,False),
  "Dynjandisá" : ((65.73729,-
23.21110),(0,4),(0,0.5),False,False,False),
  "Mjólká" : ((65.77442,-23.17101),(0,4),(0,0.5),False,False,False),
  "Ísafjarðará" : ((65.78213,-22.58123),(19.33,21 ),(6.35,1),False,
True,False),
  "Laugardalsá_Ísafj" : ((66.01219,-22.64368),(135,2),(51.1,0.5),True,
True,False),
  "Langadalsá" : ((65.90127,-22.34840),(138.4,9),(57.3,1),True,
True,False),
  "Hvannadalsá" : ((65.90681,-
22.33974),(37.8,3),(23.6,0.5),False,False,False),
  "Selá" : ((66.04162,-22.44985),(10.5,2),(9,0.5),False,False,False),
  "Kjósará" : ((65.94076,-21.58798),(0,1),(0,0.5),False,False,False),
  "Selá Steingrímsfirði" : ((65.777571,-
21.731236),(21.9,1),(9.8,0.5),False,False,False),
```

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  "Staðará Steingr." : ((65.76681,-
21.78488),(73.6,6),(23.6,0.5),False,False,False),
  "Húsadalsá" : ((65.68239,-
21.686753),(0,11),(0,0.5),False,False,False),
  "Víðidalsá" : ((65.68437,-
21.67342),(141.6,1),(29.29,0.5),False,False,False ),
  "Hrúta_og_Síká" : ((65.15,-21.07),(317.8,50),(92.7,0.5),True,
False,False),
  "Kálfá á Snæfellsnesi":((64.04544,-
20.26508),(0,2),(0,0.5),False,False,False),
  "Laxá á Ásum":((65.61,-20.34),(712,0),(95.7,0.5),True,True,True),

    # Norðurland
  "Miðfjarðará" : ((65.349,-20.9357),(1594,26),(176.9,0.58), True,
True,False),
  "Tjarnará" : ((65.64550,-20.78126),(0,3),(0,0.5),False,False,False),
  "Hóp" : ((65.53696,-20.51423),(0,1),(0,0.5),False,False,False),
  "Víðidalsá Hún" : ((65.49210,-
20.54410),(632.2,3),(138.9,0.5),False,False,False),
  "Vatnsdalsá":((65.53865,-20.38503),(435.6,18),(29.8,0.5),False,
False,False),
  "Blanda" : ((65.66121,-20.29713),(490,55),(112.4,0.47),True,
True,False),
  "Laxá í Refasveit": ((65.72462,-
20.26118),(315.8,14),(103.1,0.5),True, True,False),
  "Hallá":((65.785776,-20.27705),(70.6,1),(18.7,0.5),False,
True,False),
  "Héraðsvötn" : ((65.74251,-19.54761),(17.4,1),(12.1,.5),False,
True,False),
  "Húseyjarkvísl":((65.59422,-19.44651),(193.2,6),(39.9,0.5),False,
True,False),
  "Norðurá":((65.433612,-19.18388),(1088.2,1),(342.8,0.5),False,
False,False),
  "Hjaltadalsá/Kolka" : ((65.53696,-
20.51423),(5.25,1),(4.56,0.5),False,False,False),
  "Fljótaá" : ((66.047645,-19.027557),(338,1),(56.15,.5),False,
True,False),
  "Eyjafjarðará" : ((65.65002,-18.06502),(13,1),(2.25,.5),False,
True,False),
  "Fnjóská" : ((65.89088,-18.09438),(259.8,2),(65.4,0.5),False,
True,False),
 }
```

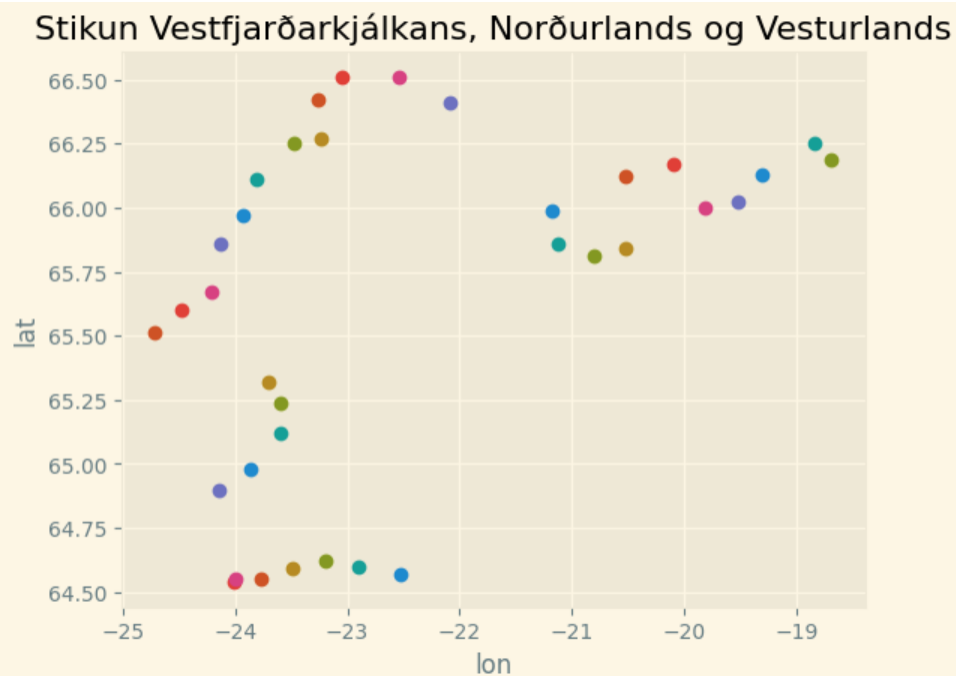
```
#@title Austfirðir: uppflettitöflur búnar til fyrir staðsetningu og
magn í kvíum og staðsetningu og magn í ám, veiðiálag
Austfjarðarkvíar = {
    "Berufjörður":((65.21,-13.63),75/160),
    "Fáskrúðsfjörður":((64.89617199,-13.79035234),3/4),
```

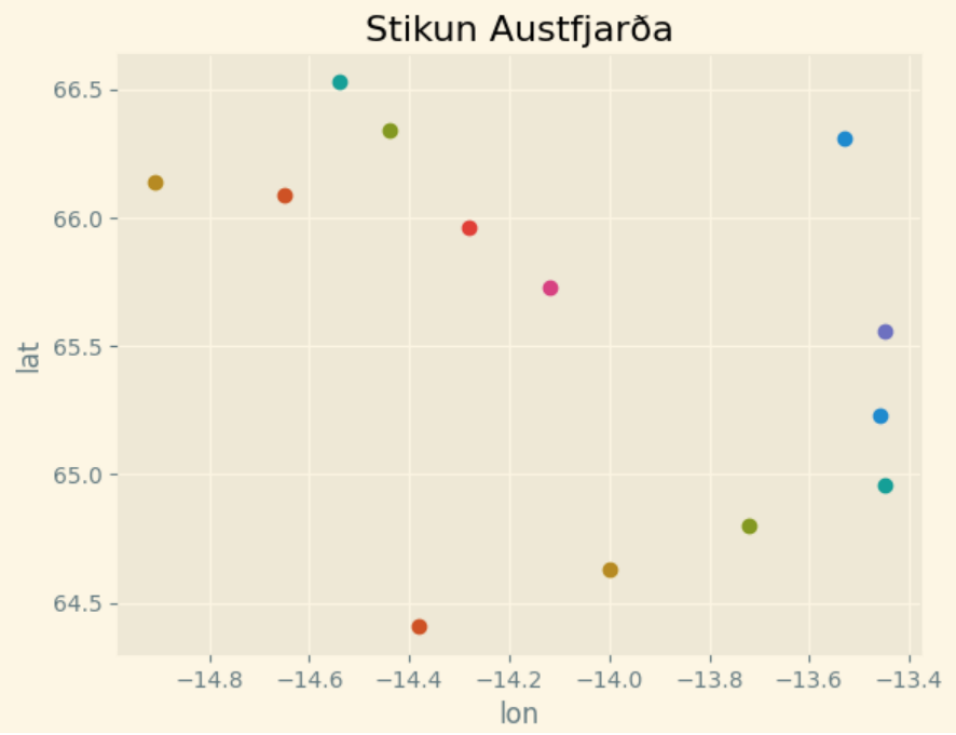
```
    "Reyðarfjörður":((64.98,-13.82),1),
    "Seyðisfjörður":((65.30,-13.74),65/160)

}
Austfjarðarár = {
"Selá í Vopnafirði":((65.72,-
14.81),(1180.4,0),(261.5,0.7),True,False,False),
"Hofsá og Sunnudalsá":((65.72,-
14.81),(936,0),(278.1,0.5),True,False,False),
"Miðfjarðará í Bakkafirði":((66.0422430792035,-
15.0974429503912),(187.8,0),(47,0.5),True,False,False),
"Hafralónsá":((66.141665550671,-
15.3838915888037),(325,0),(86,0.5),True,False,False),
"Ormarsá":((66.24,-15.55),(284,0),(90,.5),True,False,False),
"Hölkná":((66.1961967683568,-
15.5084639708459),(101.2,0),(26,0.5),True,False,False),
"Sandá":((66.2165074578297, -
15.5721037809815),(351,0),(105,0.5),True,False,False),
"Breiðdalsá":((64.785,-14.0881),(85.8,0),(28.1,0.5),True,True,False),
"Jökulsá á Dal":((65.66,-14.31),(621,0),(203,0.5),True,False,False)

}
```

Appendix 2: Coastline coordinates





Appendix 3: Figures-

Case 1 (Conservative)

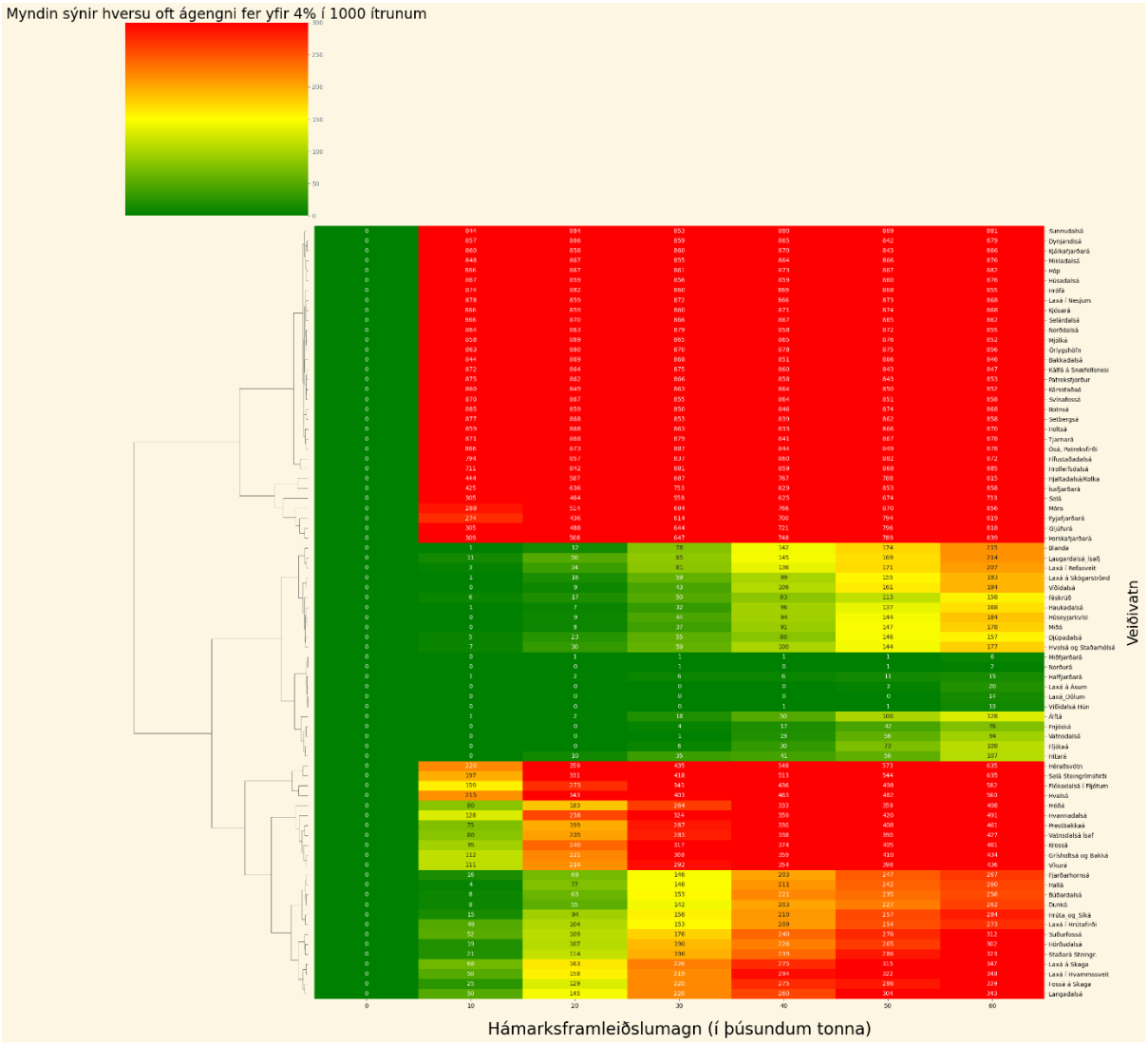


Figure 1 shows he shows how often (out of thousand simulations) the escapee ratio is above 4% of the total stock in particular river. Each column shows the escapee ratio based on different maximum production in thousand tons

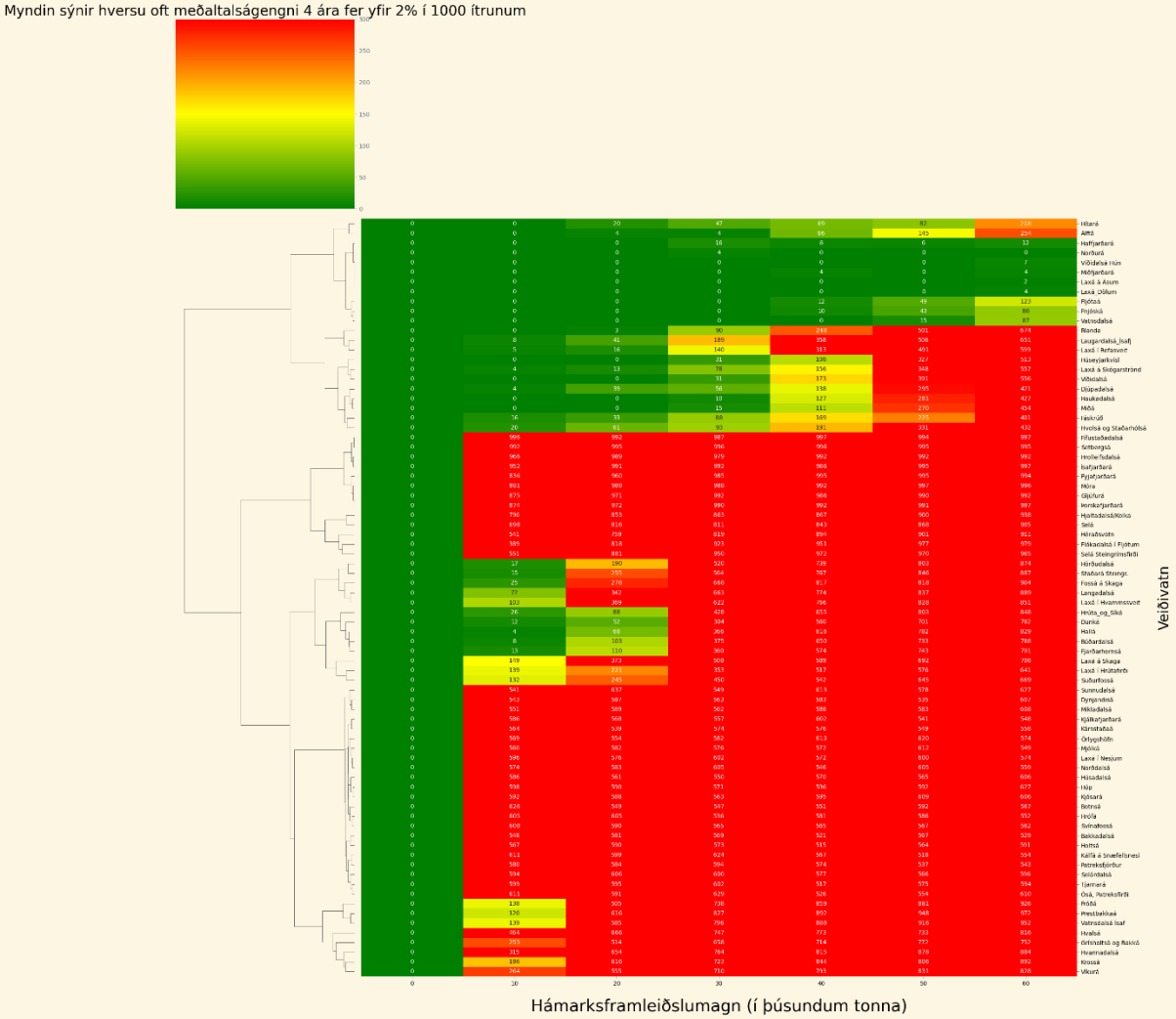


Figure 2 shows how often the escapee ratio is above 2% for four successive years. Each column shows the escapee ratio based on different maximum production in thousand tons

Case 2

The case shows how sensitive the intrusion is to increase number of escapees

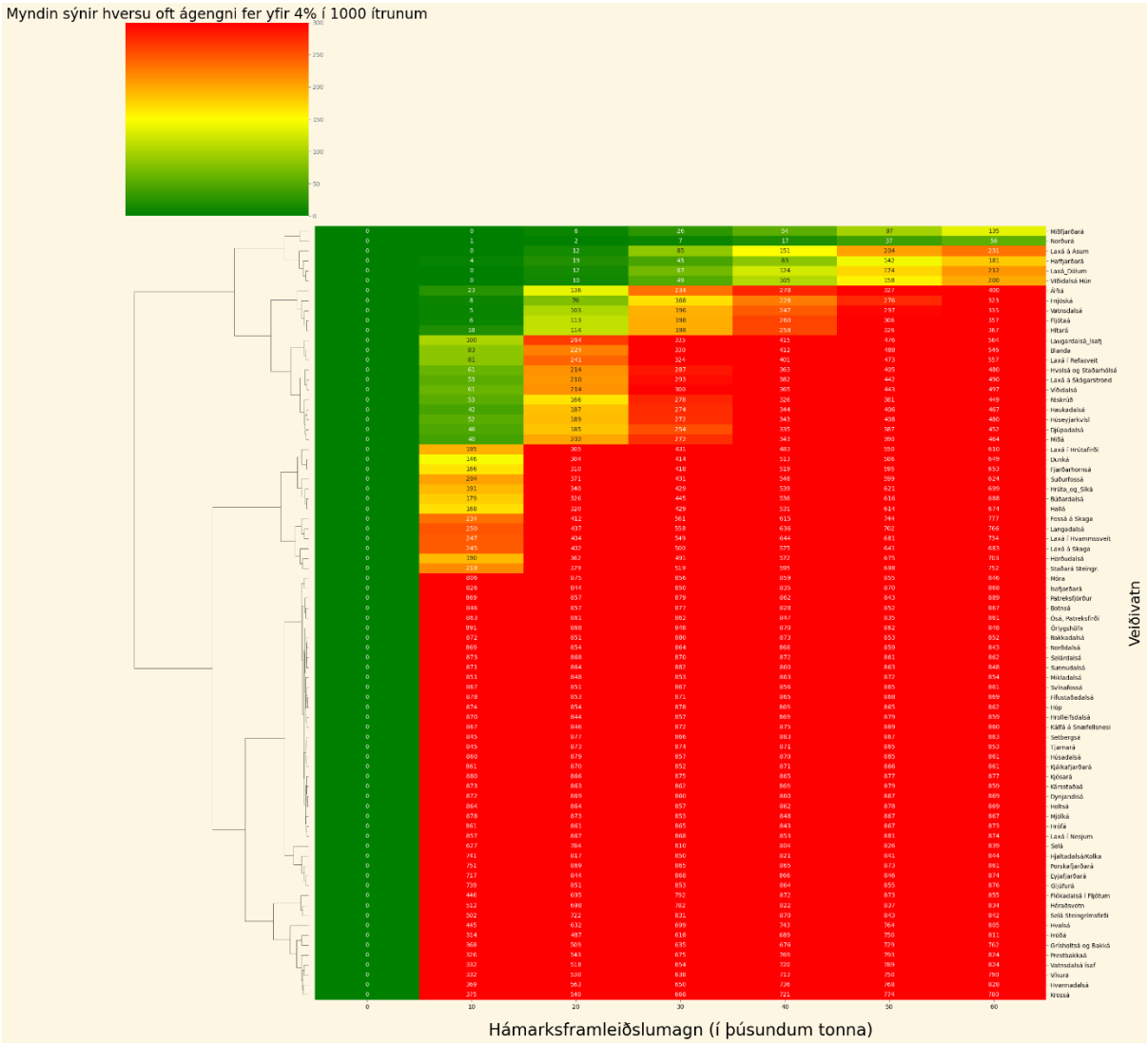


Figure 3 shows he shows how often (out of thousand simulations) the escapee ratio is above 4% of the total stock in particular river. Each column shows the escapee ratio based on different maximum production in thousand tons

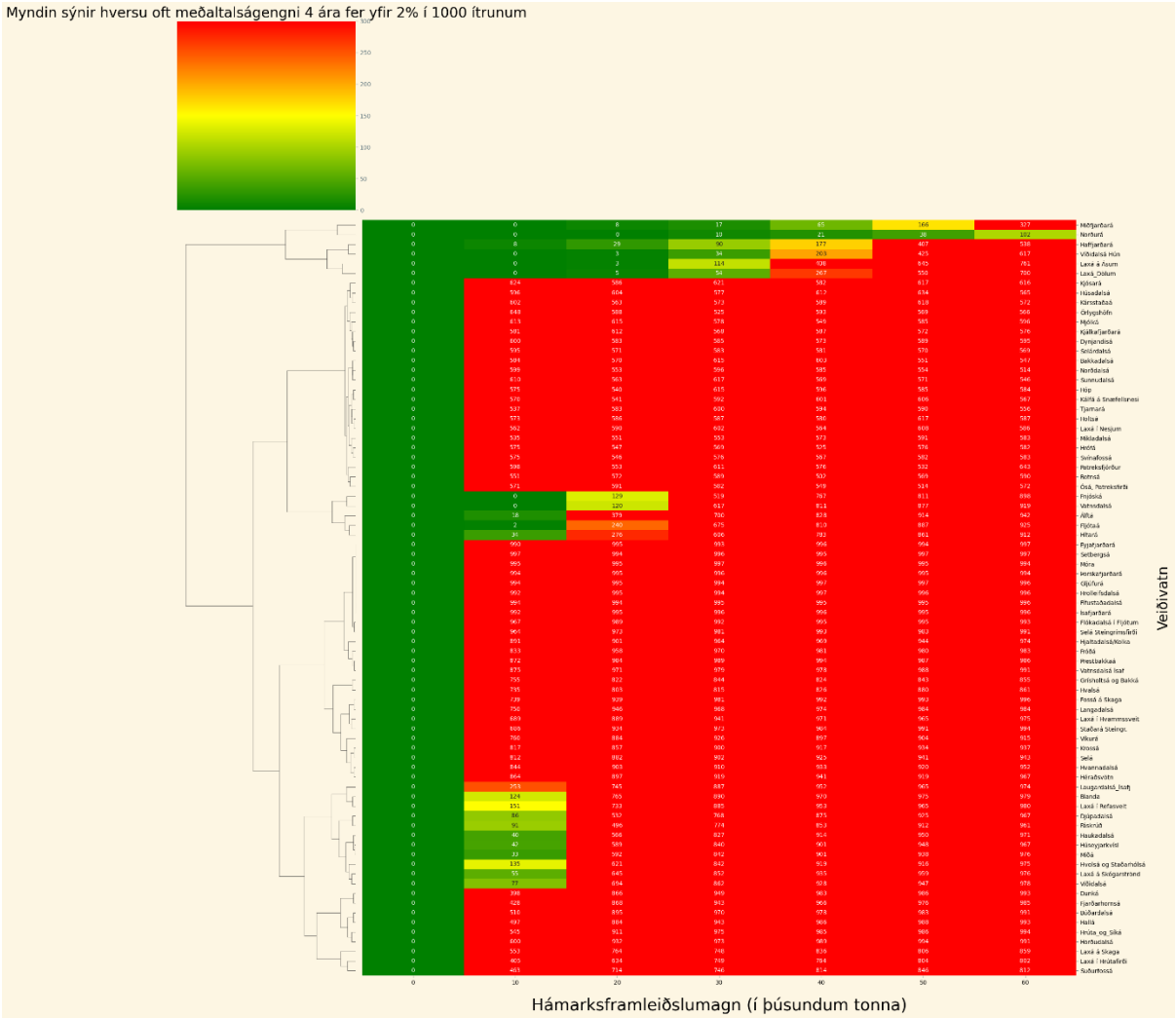


Figure 4 shows how often the escapee ratio is above 2% for four successive years. Each column shows the escapee ratio based on different maximum production in thousand tons for case 2.

References

Alþingi. 2023. Svar matvælaráðherra við fyrirspurn frá Gísla Rafni Ólafssyni um eldislaxa sem sleppa. Sótt 21.12.2023 frá: https://www.althingi.is/altext/154/s/0420.html

Fjóla Rut Svavarsdóttir (ritstj.), Guðni Guðbergsson, Hlynur Bárðason, Ingi Rúnar Jónsson, Leó Alexander Guðmundsson, Sigurður Már Einarsson og Sigurður Óskar Helgason.(2024) Haf og Vatn. Sótt frá: https://www.hafogvatn.is/static/research/files/voktun-vegna-ahrifa-sjokviaeldis-2023_hv-2024-29-1.pdf

Jóhannsson, R., Guðjónsson, S., Steinarsson, A., Friðriksson, J. (2020). Haf og Vatn. Áhættumat vegna mögulegrar erfðablöndunar milli eldislaxa og náttúrulegra laxastofna á Íslandi. Sótt frá: {1404ce38-ac35-ec11-9baa-005056bcce7e} (island.is)

Skilbrei, O. T., Heino, M., and Svåsand, T. (2015). Using simulated escape events to assess the annual numbers and destinies of escaped farmed Atlantic salmon of different life stagesfrom farm sites in Norway. ICES Journal of Marine Science,72:670–685.